Gregor C. Falk
Manfred R. Strecker
Simon Schneider
Editors

Alexander von Humboldt

Multiperspective Approaches

Springer

Alexander von Humboldt

Gregor C. Falk · Manfred R. Strecker ·
Simon Schneider
Editors

Alexander von Humboldt

Multiperspective Approaches

Springer

Editors
Gregor C. Falk
Institute of Geography
University of Education Freiburg
Freiburg im Breisgau
Baden-Württemberg, Germany

Manfred R. Strecker
Institute of Earth and Environmental Science
Universitat Potsdam
Potsdam, Brandenburg, Germany

Simon Schneider
Department of Earth and Environmental
Sciences, Geophysics/Forum der
Geowissenschaften
Ludwig-Maximilians-Universität München
Munich, Germany

ISBN 978-3-030-94007-2 ISBN 978-3-030-94008-9 (eBook)
https://doi.org/10.1007/978-3-030-94008-9

David Rumsey Map Collection, David Rumsey Map Center, Stanford Libraries

This Springer imprint is published by the registered company Springer Nature Switzerland AG
The registered company address is: Gewerbestrasse 11, 6330 Cham, Switzerland

Preface

Alexander von Humboldt, one of the most influential natural researchers of all time, has continued to fascinate generations of Earth scientists and biologists with his crossing of boundaries between disciplines and his observations of the natural world that were as far-reaching as they were prescient. Much has changed since Humboldt's early integrative studies in South America at the beginning of the nineteenth century: The pace of technological advances has increased enormously, and the disciplines of both Earth and Life sciences have been fragmented into numerous sub-disciplines between which there is less and less collaboration. However, to face today's challenges of global change—with the increasing frequency and magnitude of extreme meteorological events, the progressive depletion of natural resources, the far-reaching impacts of geophysical extreme events, the loss of biodiversity, and the continued expansion of land use—it is Humboldt's more integrative approach and cross-disciplinary understanding of the Earth system that is needed more than ever.

The end of the twentieth century saw a radical shift in how people perceive Earth and nature. Environmental degradation, climate change, frequent extreme events, and increased competition for natural resources, combined with human vulnerability to natural hazards, moved environmental issues from the fringes of public awareness to the forefront of many government policies. This change in awareness was presaged by paradigmatic shifts in the Earth Sciences themselves that led to the modern view of the Earth as a dynamic system of interactive physical, chemical, and biological processes. As such, the integrated Earth Sciences have provided an essential contribution to the discourse on the direction of environmental and social development in the twenty-first century and now stand at the vanguard of our attempt to cope, on a global scale, with the changes in our natural environment that continue to challenge us, both in our efforts to understand them and in our need to deal with them. The time has thus come to seek holistic research approaches in the different compartments of the Earth system with which to obtain a comprehensive understanding of processes on a variety of timescales. Against the backdrop of current political and social contexts, it is particularly important that this knowledge is made accessible and usable for people with diverse cultural and educational backgrounds. To achieve this, it is imperative to improve knowledge transfer and find new educational approaches to ensure a geoscientific literacy that, in the context of globalization and under the looming specter of global change, will provide societies with the geoinformation necessary to face the challenges of today and tomorrow.

It is important to note that already in the first half of the nineteenth century, Alexander von Humboldt had considered and addressed many of the topics that we are concerned with today. He did this with detailed studies in the fields of geology, geobotany, climatology, paleontology, geophysics, and hydrology, and concerned himself with "modern" issues that include geothermal resources, hydrocarbons, links between climate change, vegetation cover and erosion associated with human impact, changes in the magnetic field, and the transfer and publication of knowledge. Early on, Humboldt thus paved the way for an integrated Earth System Science approach that is desperately needed today for deciphering, characterizing, and modeling the various forcing factors and their feedback mechanisms that govern the Earth system.

On the occasion of Humboldt's 250th birthday and in keeping with his strong belief in the importance of disseminating expert knowledge to the public, the German Academy of Sciences Leopoldina held a symposium for the general public and researchers in Halle, Germany, in June 2019 to assess and highlight Humboldt's influence on the various areas of Earth System Science, including life-long learning and the education of the public. Thirteen speakers from a wide range of disciplines addressed Humboldt's approaches and his contributions to the analysis of complex problems in Earth System Science.

Inspired by the manifold aspects of Humboldt's work presented in Halle, the idea was born to publish a compilation of some of the topics discussed at the symposium in the form of a "multiperspective approach". The intention was not to provide another purely scientific collection of the latest research results by Humboldt scholars, but rather to address a wider audience, comprising not only researchers from fields beyond the Earth Sciences but the general public as well. This volume seeks to disseminate the knowledge and insights of and about Humboldt from the perspective of contemporary scientists. Sometimes, these perspectives contradict views currently hold by many scholars and thus provoke an ever new interpretation of Humboldt's life and work. While some of the contributing authors are well-established Humboldt experts, others approach Humboldt's work from their own fields of expertise, including but not limited to geology, geography, biology, and education.

In recent decades, countless scientific texts, biographies, feuilletons, illustrated books, and much more have been published about Alexander von Humboldt. Due to the rediscovery of Humboldt's scientific achievements and the rekindling of his popularity and the public's fascination with him, one might speak of a kind of "Humboldt Renaissance". So why another volume about this illustrious figure? This compilation of articles illuminating aspects of Alexander von Humboldt's broad oeuvre from many perspectives aims to add some less known fragments to the mosaic of knowledge while at the same time presenting an unvarnished view of his achievements. Thus, we will follow the tradition that may have started with Karl Bruhns' seminal work about Alexander von Humboldt, published in 1872,[1] by bringing together researchers from various disciplines to write about Humboldt's respective scientific merits in individual chapters. Furthermore, we want to highlight additional reading that merges various perspectives on Alexander von Humboldt life and work by mentioning Hanno Beck's two-volume biography of Alexander von Humboldt.[2] Finally, we want to draw your attention to the *Humboldt im Netz* project HiN that publishes current research on Alexander von Humboldt in English, German, Spanish, and French. Here, you can find the most recent discourse and findings as well as quite critical voices, too.

The chapters in this volume have been grouped thematically into five parts. In the first, *Humboldt's Integrative Scientific Approach* is discussed by Stefan Brönnimann and Mathias Glaubrecht. Both authors critically reflect on the idea of regarding Humboldt as a pioneer of modern Earth System Science. As Brönnimann states in his paper, "claiming Humboldt to be the first Earth System scientist is also a projection of our current view back onto Humboldt". Brönnimann deconstructs our biased view of the relevance of Humboldt's work in the context of the development of the Earth Sciences. In his critical demystification of Humboldt's life and work, Glaubrecht takes a particularly detached look at the "hagiographic fashion" in which Humboldt is discussed. His contribution invites the reader to "revisit the Humboldt Renaissance".

The following chapter draws attention to *Humboldt's Influence on Biogeography*. In their paper "Humboldt, biogeography, and the dimension of time", Carina Hoorn, Jana Ebersbach, and Alexandra Muellner-Riehl discuss the impact of early biogeographers, in particular Alexander von Humboldt and Alfred Russel Wallace, on contemporary biogeography research. In her contribution, Naia Morueta-Holme invites the reader to revisit Humboldt's analysis of the vegetation cover on the Chimborazo volcano as the "cradle of plant geography".

The third chapter highlights a very special aspect of *Humboldt as an Earth Scientist*. The paper by Victor A. Ramos focuses on just one particular fragment of Humboldt's contributions, namely his meticulous exploration of the Andes, which established him as the first Andean volcanologist.

Humboldt's Relevance for Contemporary Education Strategies and Political Discourse is discussed in the fourth chapter in papers by Thomas Hoffmann and Gregor C. Falk. While Hoffmann answers the question of whether Alexander von Humboldt should be part of contemporary geography education, Falk's essay develops ideas on why Humboldt can be considered a "liberal ecologist".

The group of papers that follows in the fifth chapter highlights *Humboldt: Empathic Patron, Consultant and Communicator of Science*. In his contribution "The Humboldt Paradox: Science Communication and Mythology", Oliver Lubrich discusses the great disparity between Humboldt's fame and the visibility of his

[1]Bruhns, Karl (Hrsg.) (1872): Alexander von Humboldt. Eine wissenschaftliche Biographie, Bd. 1. Leipzig: F. A. Brockhaus—sometimes also referred to as Carl Bruhns.

[2]Hanno Beck (1959–1961). Alexander von Humboldt. Wiesbaden. Franz Steiner Verlag.

written work, and how he became a victim of his own communication. Focusing on "Humboldt's Idea of Intercultural Understanding", Simon Schneider examines how Humboldt's perception and appreciation of indigenous knowledge may be relevant for contemporary concepts of geoethics. Finally, Jörg Stadelbauer illustrates Humboldt's "Dual Role as Consultant and Explorer" with reference to his journey to Russia and Siberia in 1829.

As an *Epilogue*, the contribution of A. M. Celâl Şengör analyzes the question whether Humboldt is a "Dilettante of Natural History or an Oracle of Modern Science?" As a starting point, Şengör states that the fame of Alexander von Humboldt has declined due to the fact that observational sciences "have lost prestige" compared to theoretical sciences.

All chapters in this book are supplemented by their own, chapter-specific bibliographies. Since in modern publishing it is possible to read individual chapters, it is important for us that the sources for each chapter are cited separately. Therefore, there are of course also multiple citations of individual sources.

Reading and editing the manuscripts of the individual contributions was an inspiring task for the editorial board, and we often found ourselves captivated by the depths of Humboldt's multifarious concepts and ideas. Quoting Humboldt's contemporary Friedrich von Hardenberg, one of the team members remarked during the opening speech of the Humboldt symposium at the Leopoldina that dealing with Humboldt's work is like looking into a prism that generates many reflections. In this sense, we present this volume in the hope that readers may encounter some new "Humboldt perspectives" and enjoy the inspiring conceptional ideas discussed by the authors.

Freiburg im Breisgau, Germany Gregor C. Falk
Potsdam, Germany Manfred R. Strecker
Munich, Germany Simon Schneider

Acknowledgements

The editors would like to thank the authors of this book for submitting their work to this volume and for sharing their insights on Alexander von Humboldt's work and his influence on modern Earth System Sciences from a wide variety of perspectives. Several of the contributions were presented as oral presentations at the Alexander von Humboldt Symposium of the German Academy of Sciences, Leopoldina in Halle, Germany in June 2019. The symposium "From von Humboldt into the Anthropocene" was jointly coordinated by the Leopoldina—German Academy of Sciences, the GeoUnion Alfred Wegener Foundation, and the Earth and Environmental Sciences Research Center at the University of Potsdam.

The symposium was made possible in part by generous funds provided by the International Science Conferences Program of the German Research Foundation (DFG; Project-ID 42 19 21 187). Christian Anton and the friendly staff of the Leopoldina in Halle, Christof Ellger from the GeoUnion, and Dagmar Fritz and Veronica Torres of Potsdam University were instrumental in helping with the organization of the meeting; we also would like to thank Johannes Vogel and Ferdinand Damaschun of the Museum of Natural History of Berlin for their support.

All contributions were peer-reviewed. We therefore would like to thank Tony Abbott (Stetson University), Boris Braun (University of Cologne), Carsten Butsch (University of Cologne), Wilfried Endlicher (Humboldt University of Berlin), Alexander Follmann (University of Cologne), Tim Freytag (University of Freiburg), Klaus-Dieter Hupke (University of Education Heidelberg), Stephen Jackson (University of Wyoming & USGS), and Ursula Klein (Max Planck Institute for the History of Science) as well as both anonymous reviewers for their reviews. Edward Manning, Janan Barksdale, and Daniel Prince are thanked for their dedicated and diligent editorial assistance. We furthermore thank Corinna Kallich and Heiko Pingel of Potsdam University for helping with the artwork.

Contents

Editors and Contributors

About the Editors

Prof. Dr. Gregor C. Falk's research interests focus on the intermingled social, political, and ecological dimensions of land use, climate, and landcover change. As a teacher trainer and professor of Physical Geography at Freiburg University of Education, he is involved in research activities related to education, learning, and digitalization.

Prof. Manfred R. Strecker, Ph.D. teaches Geology at the University of Potsdam. His research focus is on the interaction between tectonics, topography, and climate in the Central Andes, East Africa, and Central Asia. He is a member of the Argentine and German Academies of Sciences; he received the Gottfried Wilhelm Leibniz-Award of the German Science Foundation (DFG) in 2004 and is a Fellow of the Geological Society of America.

Dr. Simon Schneider has made the move from geophysics to communication science and back to the geosciences. His main research interest is deciphering and understanding the challenges and mechanisms that drive intercultural science communication. He is currently a member of the Department for Earth and Environmental Sciences at Ludwig-Maximilians Universität München.

Contributors

Stefan Brönnimann Institute of Geography and Oeschger Centre for Climate Change Research, University of Bern, Bern, Switzerland

Jana Ebersbach Department of Molecular Evolution and Plant Systematics and Herbarium (LZ), Institute of Biology, Leipzig University, Leipzig, Germany

Gregor C. Falk Institute for Geography and Geography Education, University of Education Freiburg, Freiburg, Germany

Matthias Glaubrecht Center of Natural History, Universität Hamburg, Hamburg, Germany

Thomas Hoffmann Leuphana Universität Lüneburg, Karlsruhe, Germany

Carina Hoorn Institute for Biodiversity and Ecosystem Dynamics, University of Amsterdam, Amsterdam, The Netherlands

Oliver Lubrich Institute of German Studies, Comparative Literature, University of Bern, Bern, Switzerland

Naia Morueta-Holme Center for Macroecology, Evolution and Climate, GLOBE Institute, University of Copenhagen, Copenhagen, Denmark

Alexandra Muellner-Riehl Department of Molecular Evolution and Plant Systematics and Herbarium (LZ), Institute of Biology, Leipzig University, Leipzig, Germany; German Centre for Integrative Biodiversity Research (iDiv) Halle-Jena-Leipzig, Leipzig, Germany

Victor A. Ramos Instituto de Estudios Andinos don Pablo Groeber, Universidad de Buenos Aires-CONICET, Buenos Aires, Argentina

Simon Schneider Department of Earth and Environmental Sciences, Ludwig-Maximilians-University Munich, Munich, Germany

A. M. Celâl Şengör ITU Eurasia Institute of Earth Sciences and Geology Department, Faculty of Mines, Istanbul, Turkey

Jörg Stadelbauer Institute of Environmental Social Sciences and Geography, Albert-Ludwigs-Universität Freiburg, Freiburg, Germany

Humboldt's Integrative Scientific Approach: Pioneering Modern Earth System Sciences

Fig. 1 View: Esquisse des Principales Hauters des Deux Continens. Geographie Mathematique, Physique et Politique de Toutes les Parties du Monde, Publiee par Edme Mentille, de l'Institute national, Malte Brun, Geographe Danois. Atlas. Compose de 45 Cartes, gravees par J.-B.-P. Tardieu aine, sur les dessins de J.-B. Poirson, ingenieur-geographe, revues et corrigees d'apres les meilliurs autorite, par Edme Mentelle … Paris, Chez Henry Tardieum Imprimeur-Libraire ... (Chez) Laporte. An XIII. 1804. (Courtesy of David Rumsey Collection)

"Through a Country We Never Intended to See". Revisiting the Humboldt Renaissance

Matthias Glaubrecht

Abstract Not only has an entire scientific era and new scientific endeavour been named after the German explorer-naturalist Alexander von Humboldt: even in the twenty-first century, his scientific legacy continues to flourish. At the 250th anniversary of his birth, it became evident that Humboldt is revered in almost hagiographic fashion and has undergone a renaissance to be considered a scientific hero beyond comparison. However, Humboldt hardly stands as a useful icon for the challenges of science and society in the new century, as has been erroneously proposed by the activists and adherents of this Humboldt renaissance. This essay looks into the legacy of Humboldt's long-ignored scientific predecessors and the ancient roots and persistence of his thinking in a pre-Darwinian world. It argues that, as a naturalist, Humboldt's perception of nature is retrograde in the theoretical concepts and regressive in perspective. Consequently, contrary to claims that he had allegedly helped to create the intellectual world Darwin inhabited, Humboldt failed to solve any of Darwin's so-called mysteries of mysteries, such as the dimension of biodiversity (number of species) or its origin and evolution (nature of species and speciation).

Keywords Humboldtian science · Plant geography · Zoogeography · Ecology · Biodiversity · Origin of species · Charles-Marie de La Condamine · Horace-Bénédict de Saussure · Jean-Louis Giraud-Soulavie · Eberhard August Wilhelm von Zimmermann · Charles Darwin

Introduction

The deeds of the German geographer and explorer-naturalist Alexander von Humboldt have entered into legend, and his name has been stamped on a variety of phenomena. As only one of the many indications for his cross-disciplinary legacy,

M. Glaubrecht (✉)
Center of Natural History, Universität Hamburg, Hamburg, Germany
e-mail: matthias.glaubrecht@uni-hamburg.de

G. C. Falk et al. (eds.), *Alexander von Humboldt*,
https://doi.org/10.1007/978-3-030-94008-9_1

we can start with the observation that an entire marine region and phenomenon on earth, viz. the Humboldt Current, has been named after him, not to mention several mountains and cities, as well as a county on earth and a crater on the moon. In addition to this, numerous botanical and zoological species and other taxa bear his name. What is more: His contributions to various fields—not only plant geography, but also *avant la lettre* to ecology and even evolutionary biology—fundamentally altered the way we view the natural world. This, at least, has repeatedly been put forward recently, in what will be called here a "Humboldt renaissance". This is often done in the wake of and with reference to most popular sources, such as a highly successful, albeit largely misleading and incomprehensive biography, which makes exaggerated and often unsubstantiated claims (Wulf 2015), or other influential accounts (e.g. Ette 2009a, 2018a, b; Jackson 2009a, b). To give only one example, Wulf (2015: 5) claims that: "Here was a man who viewed nature as a global force with corresponding climate zones across continents: a radical concept at the time, and one that still colours our understanding of ecosystems"; see for more, e.g. Glaubrecht (2016a, b). Astonishingly, her otherwise readable biography on Humboldt, while long lacking, was largely uncritically endorsed (e.g. Morrison 2016; Kabat 2017). However, neither was Humboldt in any respect a "hero of science", as Wulf (2015) supposes, nor was he "lost" to historians of science or other informed scholars at any time (although he might have been less well-remembered to the Anglo-American scientific community than in Latin America or Germany). Nevertheless, on the occasion of Humboldt's last anniversary in the year 2019 this view was largely rehashed in a plethora of popular accounts and the media. This uncritical perception—one that completely ignored the scientific context of the time and the links with Humboldt's predecessors—was then repeatedly adopted even in some highly regarded scientific journals, including but not limited to "Nature Ecology and Evolution" (Anonymous 2019) or "Journal of Biogeography" (Fattorini et al. 2019; Norder 2019; Schrodt et al. 2019).

Much of Humboldt's legendary status can be attributed to his certainly highly adventurous travels in the American colonies of Spain from 1799 to 1804. Albeit often overlooked, he received permission by King Carlos IV of Spain mainly as a mining geologist, ostensibly to discover new mineral deposits but with some room to also indulge in his passion for botany. And much of Humboldt's reputation still centres on Mount Chimborazo, a massive snow-covered volcano rising just 1° south of the equator, which last erupted 1500 years ago and receives its moisture from the Amazon Basis to the east. With his ascent of Chimborazo on 23 June 1802—at that time thought to be the world's highest mountain—Humboldt together with Bonpland and Charlos Montufar set an alpine record for many years to come. Only three quarters of a century later, in 1880, did Edward Whymper (who in 1865 had also first ascended the 4478-m-high Matterhorn in the Alps) actually summit the peak of Chimborazo at 6310 m (today determined more precisely at 6263 m). Humboldt and his companions, plagued by altitude sickness and with bloody, gloveless hands and sodden boots, could not climb higher when faced with an "unübersteigliche Grenze", a final obstacle in their quest, a chasm barring their way. Although they had to turn back, at an elevation of 3036 French Toises (i.e. about

5915 m), thus only some 400 vertical metres short of their goal, Humboldt was proud to have climbed "a place higher than all others that men had reached on the backs of the mountains" (Humboldt 2006).

Despite the initial failure to reach its peak, Chimborazo came to be Humboldt's "Schicksals-Berg" and served him well; indeed, he managed to paint his defeat on the peak as a triumph. Not long after his descent from the mountain, he sketched a spectacular diagram that used the slopes of this equatorial volcano, from lush tropical rainforest at sea level all of the way up to the hardy alpine lichens clinging to barren rocks bordering permanent glaciers, to depict a concept that had, if we follow the legend, crystallized during his climb: namely that the climate is the organizing principle of life, shaping the distinct communities of plants and animals found at different altitudes and latitudes. In his spectacular and iconic "Tableau physique des Andes et des pays voisins", or "Naturgemälde" (which translates roughly as "painting of nature"), he mapped different vegetation zones onto a fanciful version of the Chimborazo, accompanied by fairly precise indications of altitude for individual plant species noted in tiny writing and, with a second volcano, the Cotopaxi (5897 m), in the background. The "Tableau" links geophysics with biology, framed by parallel columns that mark other relevant information next to the altitude and thus not only synthesizes general insights on plant distribution, tree lines and snowlines, but also summarizes lessons on the interconnectedness of terrestrial phenomena. This costly water-coloured foldout was beyond doubt highly influential; and it is certainly still one of the most famous visualizations of science in the nineteenth century. Contained in this microcosm of Andean volcanos were the seeds of what would become Humboldt's magnum opus, "Cosmos".

When Humboldt first described this view in his *Essai des géographie des plantes* that accompanied in 1807 the publication of his "Naturgemälde", he almost single-handedly founded plant geography, as it is often at least implicitly suggested. His famous graphic of Chimborazo, almost exclusively heralded as the first depiction of the idea of an interconnected web of life, has also become an iconic milestone, almost a foundation myth, in the history of the discipline of biogeography and ecology, with the central issue of explaining the distribution and abundance of species. Humboldt's illustration of the distribution of plants on the slopes of Chimborazo is considered the first work documenting how species composition varies along an elevational gradient, serving as a conceptual model for the study of this gradient but also in a wider approach of ecology. Until today, one of the most repeated claims is that it was Humboldt who first recognized the importance of alpine vegetational belts with the different plant communities found in specific regions defined by abiotic factors; and, moreover, that it was Humboldt who placed these belts into a general model that can be used to generate hypotheses (e.g. Egerton 1970; Jackson 2009a, b; Wulf 2015; Ette 2018a; Päßler 2018a; Norder 2019; Schrodt et al. 2019). Since then, recognizing and using elevational subdivisions has been at the heart of ecological and biogeographical studies in mountain ecosystems (e.g. Hawkins 2001; Fattorini et al. 2019).

Humboldt's ascent of Chimborazo becomes emblematic in many respects. Although he used Chimborazo to play to the gallery for many years, his own detailed report on the event was only published posthumously (Humboldt 2006). Often forgotten, this volcanic mountain was not the first that he had climbed during his American travel, either elsewhere before or in Ecuador. And as we come to understand only recently, it was by no means Chimborazo but instead Antisana, another volcano to the north, where Humboldt and his botanical companion Aimé Bonpland actually collected those alpine plants later depicted on Chimborazo and described for the vegetation in relation to their altitude, as will be detailed below. As a consequence, Humboldt's Andean Mountain episode can be viewed in a different light with respect to how we perceive his facts and theory, his induction and empiricism, rendering anew his scientific understanding on the interplay of analysis and synthesis.

In essence, this essay deals with the fact that even an entire scientific era and new scientific endeavour has even been named after Alexander von Humboldt, with many today following the proposal of the historian of science Cannon (1978: 95–96) in considering a particular "Humboldtian science". Weighing this up, it is argued here that Humboldt, although contributing enormously through his books and lectures for a wider audience to help view the natural world as an interconnected whole, held a perspective on the relationships between biota and geography that was neither his nor radically new at his time. Others before him had collected data on the climate that was most influential and put similar ideas into print, while many of his contemporaries shared a holistic view of nature. It will also be shown that it was actually not Humboldt in the Andes who laid the foundation of biogeography and ecology by contributing the idea on the vertical distribution of plants; instead, this contribution had already been made in the Alps and the Pyrenees decades before. Finally, I will detail why Humboldt did not substantially contribute to the development of Darwin's and Wallace's evolutionary theory by natural selection; at least not in any other way than that his poetical travel account was read by other successors, inspiring them to follow in his footsteps as not one of the first but one of the most famous explorers.

The Renaissance: Re-enacting Humboldt

It is not only his reputation as the era's superstar scientist and explorer that was voiced too often at his 250th anniversary, uncritically repeated at least by those who suddenly had to give lectures and addresses without having ever read an original line written by Humboldt, but also by many scientists no longer used to looking into historical sources in order to evaluate them in their contemporary context. For example, it was claimed that Humboldt was "arguably the most influential scientist of his day", and that his approach to science "was instrumental in furthering other scientific disciplines, such as evolution" (cited from Schrodt et al. 2019; see also Wulf 2015).

These and other unsubstantiated propositions often start with Humboldt's expedition to South and North America. Although he is no longer considered South America's "second discoverer" (which was obviously never true), his journey is often viewed as "one of the most famous and most important travels of the modern era" (e.g. cited here from Ette 2009b: 9). What is often overlooked, however, is that his expedition was more of a fortunate coincidence, with the route and focus repeatedly changed, than a well-planned and purposeful endeavour. Only few have remarked that Humboldt did not have a clear-cut research programme and did not go to unknown regions with unexplored natural history (see, e.g., Lack 2003; Glaubrecht 2019a, b, 2020, 2021). However, reporting in letters back home to friends and colleagues on his adventures and inquiries, he started to mould himself as an indefatigable traveller-explorer and ever-moving field surveyor early on—an attitude that is also evident, for example, in paintings depicting him with the Chimborazo and other Andean scenery in the background, or in the dense jungle of the Orinoco; in these paintings, Humboldt is always shown with equipment and diverse measuring devices of various kinds, making notes already in the field. Until the end of his long life, Humboldt was nearly always portrayed in theatrical style, as a naturalist on the move. Even in old age and at home in his library he is depicted writing notes instead on a table on his crossed legs, as if still travelling and in the field. There remains no doubt that Humboldt, right from the time of his expedition, actively channelled and conducted the reception of his public picture with the help of all available media of his time, creating the image of an explorer and promoting himself as the permanent traveller. This, in particular, has led to one of Humboldt's most eloquent, prolific, and influential proponents in Germany to portrait him today as permanently agile with his science being dynamic, or "Wissenschaft aus der Bewegung" (e.g. Ette 2018a, b, 2019). This anachronistic perception, however, fails to situate Humboldt correctly within his time and distorts reality, but it has helped to create the modern mythos of "the surveyor of the world" and laid the groundwork of the narrative that Humboldt is the "hero of science".

In contrast to this hagiography of an Humboldtian renaissance, Humboldt was largely forgotten soon after his death in that fateful year 1859; and with him his monumental, five-volume "Cosmos" fell into oblivion. Here, Humboldt (1845–1863) attempted to draw his many areas of enquiry into a single account of the known universe—"the assemblage of all things in heaven and earth, the universality of created things constituting the perceptible world". As much as it was a grandiose goal, it was an impossible task. Of little value to science at that time, Humboldt and his science was no longer discussed, with others moving to the forefront already during his later decades. In the early three-volume biography by Bruhns (1872), who wished to present an account wholly removed from the fabulous ("eine von allem Sagenhaften entkleidete Darstellung"), a sober if not sobering tone is struck throughout. In the individual chapters presented there, with the exception of his geographical and botanical works, Humboldt was considered neither up to date nor at the vanguard of the scientific advances of his time (on this point see, e.g., Carus on zoology).

No doubt, however, that Humboldt's engagement with nature moved considerably from speculation influenced by classical scholarship to a more rigorous science. He sought to observe and study natural close up and directly—more so, at least, than contemporaries of the Goethe's time of "Naturphilosophie". Following Cannon's (1978) interpretation, Humboldt's approach to science, i.e. combining an aesthetic and artistic perception of nature with empirical research, increasingly gained interest, leading to a first renaissance, as described, e.g., by Daum (2000). However, often the "tensions between objectivity and subjectivity, macro-scale survey and micro-scale theatre, scientific explanation and artistic representation" were ignored, as Buttimer (2001) has pointed out. After a period of dialectic appropriation, one which increased in the course of the second half of the twentieth century, and is fittingly summarized by Rupke (2008), the years particularly before Humboldt's 250th anniversary (e.g. Ette 2009a, 2018a, 2019; Wulf 2015) have led to the current hagiographic renaissance of industrial scale, transforming him as reincarnation of a scientific hero beyond comparison; see, e.g., Anonymous (2019), Schrodt et al. (2019), Norder (2019). However, the most recent and most often consulted invention of Humboldt in Wulf's (2015) "Invention of Nature" is neither a fully comprehensive account of Humboldt's impressive life nor in fact an in-depth analysis of his ideas. Most importantly, however, it is largely misleading with respect to the scientific origin of his ideas in what we today call the discipline of biogeography and ecology.

It is essential to consider the contemporary state of knowledge about the natural world and the way of doing science during Humboldt's time to better contextualize his real contribution, the role he played, and the influence he actually had. In contrast to hagiographic hyperbole and self-reflective reception of Humboldt, even though sophisticatedly worked out and eloquently presented, this essay attempts to sketch the following theses. First, Humboldt had important, now largely forgotten predecessors who antedated the core of methods and insights that are now largely attributed to him alone; in this regard, they not only evinced a similar standpoint towards plant geography, but also Humboldt's holistic approach, mostly clearly expressed in his "Naturgemälde", and included aspects of his visual language. In particular, I will show that what became known as "Humboldt formula", i.e. his credo that everything is interdependence ("Alles ist Wechselwirkung"), was not his original thought but much more of contemporary perception of his time. This essay aims to caution against tracing everything back to Humboldt, just because he was already set up as a towering figure by others.

Second, we will ask to what extent Humboldt actually approached nature in a novel way, as is often proposed today. It is argued here that, in contrast to earlier suggestions, Humboldt's perception of nature as being in harmony and in a state of equilibrium is less modern and suitable for a vision of the future than mostly implied today. Instead, Humboldt referred to a classical understanding originally conveyed since antiquity and reflected much more of the romantic ideas of the late eighteenth rather than mirroring the state of empirical science in the early nineteenth century. Therefore, we have to realize that Humboldt's oeuvre—despite "its enormity" being for the large part unfinished—was the last mega-fragment of the European “Sattelzeit” (Osterhammel 1999: 108) and is thus with hindsight deeply embedded in the romantic era of Goethe and Schiller.

In the first few decades after 1800, Humboldt’s attempt to establish a kind of “aesthetic science” was considered fruitful only in a handful of cases. Certainly, his influence was more related to his engaging writing and oratory skills that had helped to stoke his popularity, rather than to the specific advances in science that he actually made. This is evident from the lack of any theory developed by him, despite the extraordinary quantity of measurements and wealth of detailed observations accumulated and analysed in many fields of expertise, albeit without real integration and substantial synthesis. Given this, it can be doubted whether Humboldt’s way of research, albeit often praised as “transdisciplinary” and “intercultural”, but in fact lacking theory and the real power of synthesis, is actually as modern as often held and sustainable in the sense of being able to act as a guide to the future. Better then to refrain from taking Humboldt uncritically into the twenty-first century, as was done so often in particular during the year of his 250th anniversary. Humboldt certainly deserves better.

Humboldt’s American Expedition and Collecting: The Facts

Having received news of the launch of the French maritime expedition under Nicolas Baudin (whom they had originally planned to accompany to Australia), Humboldt and Bonpland left Cuba hoping to meet his ships in Lima in Peru. They arrived in Cartagena at the north coast of today’s Columbia in March 1801 with the prospect of travelling about 3600 km “through a country we had never intended to see” (“In Folge einer falschen Zeitungsnachricht haben Bonpland und ich über 800 Meilen [i.e. French Lieues] in einem Lande gemacht, das wir gar nicht hatten bereisen wollen”), as Humboldt (1814) later noted in his travelogue.

One of the most significant result of this—primarily unintended—Andean expedition was the roughly 6000 plants that Aimé Bonpland and Humboldt collected. Most of these were new to science and 3600 species would later for the large part be described either by themselves, or with the help in particular of the Prussian botanist Karl Sigismund Kunth (see Lack 2003, 2009). Remarkably, this was the largest increase in the history of modern systematic research in botany between the years 1810 and 1840 (Barthlott 2011: 36). More an accident than a plan, Humboldt and Bonpland travelled through two of the global centres of biological mega-diversity on our planet: viz. the Chocó region, extending from Columbia to Costa Rica, and the East Andes region; and they would also go on to explore a third in Mexico (see map, e.g. in Barthlott 2011: 39). Only recently has it been realized that with a total of 118,308 species and in terms of overall biodiversity among plants, but also some selected animal taxa, tropical Latin America is by far the most species-rich region on Earth, relative to the size of the region and compared to the Afrotropical or Southeast Asian region (Raven et al. 2020).

In the midst of this most diverse treasure trove, however, Humboldt missed most of this biological wealth, as his prime interest was understanding biogeographical patterns rather than documenting and accurately describing constituent parts of biodiversity. Developing his perspective on nature as a web of life in which plants and animals are interconnected, he focused more on the physical parameters as abiotic factors than on the primary biotic parts, i.e. species in botany and zoology. Since his beginnings as a student of nature, Humboldt explicitly and repeatedly declared that he had no interest—neither as a zoologist nor even as a botanist—in the systematic collection and taxonomic description of new species, lacking as he did any detailed research programme and, thus not able to live up to his own aspiration regarding empiricism. However, we should note that as an exception to the rule, Humboldt did start out with such a systematic survey of plants in his "Flora Fribergensis" (Glaubrecht 2019a, b, 2020, 2021).

For example, in the "Journal botanique", the systematic notebook essentially kept (as we know today) by Bonpland instead of Humboldt during the American journey, and later meticulously analysed by Willdenow und Kunth in Paris for their descriptions of species (e.g. Lack 2003), a total of 4528 numerical entries are supplemented by only 33 numerical animal objects. Given the lack of factual objects, no longer to be found in natural history collections, we are forced to turn to their pictural representation in Humboldt's complete oeuvre, which includes about 1500 available graphics (see Lubrich 2014), as paper substitutes, or "papierenen Ersatz", as Bayerl (2017: 319) has called it. Among 1334 plates, a total of 1274 (95.5%) are dedicated to the flora, in contrast to the only 60 plates (4.5%) depicting zoological objects, with 259 drawings of animals supplemented by 21 plates with anatomical details. For more on Humboldt as a zoologist and systematist, see Glaubrecht (2019a, b, c, 2020, 2021).

Nor was Humboldt a classical botanist either regarding examining and describing botanical collections, and his engagement and authorship is still contentious. In particular, the "Nova Genera et Species Plantarum", published between 1816 and 1825, is the work of others, viz. Aimé Bonpland, Sigismund Kunth and partially Willdenow (Lack 2003, 2009; Götz 2019; Müller-Wille and Böhme 2020). In the same way, while Humboldt published some detailed anatomical articles, e.g. on the condor, sea cow or crocodiles, in his later two-volume compilation of his "Recueil d'observations des zoologie et d'anatomie compare", published between 1811 and 1833, he left the classification and systematic description of all his collected fish, insects, as well as land and freshwater molluscs to experts in Paris (Glaubrecht 2019b, 2020, 2021).

Humboldt's approach, which was later often described as a holistic view of the natural world as a set of interlinked and overlapping factors, was not only at odds with the practice of most other naturalists of that time, whose intension was primarily to classify and, admittedly, compartmentalize nature. It also neglected an essential feature of conducting any truly empirical and inductive science. As constituent parts of nature, species represent the factual basis of biology that is accessible exactly through the same kind of empiricism that Humboldt demanded in his more physically oriented approach to science.

Early Empiricism: "Condaminean Science"

Focusing on the physical aspects of nature (or, as we today call it, the abiotic factors), Alexander von Humboldt is often considered responsible for having brought accurate measurements and a mathematical approach to biological science, a shift vividly narrated in Kehlmann's (2005) famous bestselling novel "Measuring the world". This might hold true for his careful early chemical experiments on the composition of gases, when he fully adopted the quantitative approach of French chemistry (Klein 2012). However, another myth in need of dispelling is that Humboldt was the first to measure nature.

Around 1800 saw a general new organization of knowledge on nature and a subdivision of several of its constituent disciplines, among which was also biogeography (e.g. Jardine et al. 1996; for biogeography, e.g. Larson 1986; Glaubrecht 2000; Ebach 2015). In contrast, Humboldt's particular rise to the top and self-aggrandizing led to erroneous suggestions that the entire era be called "Humboldtian Science" (Cannon 1978). It is important to note that this comprised a dual approach: on the one hand an empirical method with precisely measured and physically quantifiable variables or parameters; and on the other hand, it reflected romantic ideas, such as of harmony and equilibrium, as part of an aesthetical perception of nature and all of what is there in general, including the cosmos. Particularly during his later years, Humboldt was prompted by an approach to nature today known as "Naturphilosophie", or natural philosophy, a romantic appreciation of nature, but then attempted to integrate art and aesthetics with exact measurements and empirical science (Nicolson 1987, 1996; Dettelbach 1996, 1999; Hey'l 2007; for the young Humboldt, see, e.g., Klein 2012, 2015). Thus, Humboldt not merely followed an empiricist's concept, but instead "paid attention to the formulation of knowledge as well as the effects and the esthetic impact of that knowledge" (Daum 2000).

Both these constituent parts and perspectives of "Humboldtian science", however, had existed long before him and were practiced alongside each other, starting at the latest about half a century earlier. Humboldt was only one prominent figure of many who were convinced that descriptions of nature could be simultaneously scientifically accurate and inspiring. Contrary to her own delimitation of this epoch, Cannon (1978) stated that the earliest accurate astronomical measurements of the earth had already started during the eighteenth century. In context of an "European knowledge-building project", Pratt (1992: 38) also relegated earlier attempts to systemize nature to the century before Humboldt. However, it is only recently that these early founders of a scientific era have reconsidered what was later only named after but not founded by Humboldt (e.g. Glaubrecht 2019a, 2020, 2021).

One of the most neglected figures of this early scientific era—therefore more properly to be called "Condaminean science"—is the French astronomer, mathematician and naturalist Charles-Marie de La Condamine. Among many other achievements he was, during his ten-year travel from 1735 to 1745, the first to systematically take barometric measurements in the equatorial Andes while climbing (also as first known European) the heights of volcanic mountains, as well as to take readings along the river Amazon (see, e.g., Gretenkord 2003; Glaubrecht 2014, 2019a, 2020, 2021). As much focused on astronomical and barometrical measurements as Humboldt, in 1744 Condamine mapped the exact geographical position of the Amazon river's course for the first time, including many tributaries. In this "Journal du Voyage á l'équateur", Condamine (1751) described the connection between the major river systems of the Orinoco and Amazon via the natural canal of Rio Casiquiare.

Condamine's travelogue later served as template to Humboldt (1814) when writing the first parts of his own travel account in the "Relation historique". Although Humboldt mentioned Condamine several times (usually when Humboldt was able to go one step further or had a better idea), he did not adequately pay homage to his predecessor who had made many observations and measurements in the Andean highlands long before. Consequently, Condamine not only figured marginally in Humboldt's writings, but was largely forgotten soon after. Noteworthy here is that Humboldt essentially followed in the footsteps of Condamine while in the Andes of Ecuador. Seven decades before Humboldt, the French naturalist had climbed to the crater of the 4700-m-high and active volcano, Pichincha, near Quito, as well as to some heights on Chimborazo. Even more relevant in our context here, in his "Journal du Voyage" Condamine was also the first to reflect on the elevational change of the Andean vegetation. As early as mid-eighteenth century, this idea which became so important for ecology *avant la lettre*, had its origin apparently not in the Alpine but the Andean mountains and with Condamine, who in 1751 also published the topographic profile of altitude as the first graphic representation of a truly new research programme (see more in Wolter 1972).

On the Origin of a "Physical Geography"

Alexander von Humboldt, together with Aimé Bonpland, was the first to formally describe many species of the flora, and to a much lesser extent also the fauna of Latin America. However, it should not be forgotten that his basic ideas of relating plants with the physical parameters of their habitat rests firmly within the European scientific framework of his time. See, e.g., Ebach (2015) and Juárez-Barrera et al. (2018) on recognizing spatial pattern of biodiversity in the nineteenth century and the roots of contemporary biogeography. As such, these ideas have many roots and have taken various avenues, of which only two are followed here in more detail—the early Alpine mountain exploration in Europa and the origin of zoogeographical methodology transferred by Humboldt to plant geography.

Humboldt's most famous notations of the "physical geography" of plants did not only have a decade-long genesis but also most illustrious predecessors. Both these important aspects, however, have largely been ignored. Early plant geography has been attributed to Humboldt almost routinely; allegedly, it was Humboldt alone who first recognized the importance of such patterns and placed them into a general model that was used to generate hypotheses (e.g. Nicolson 1987, 1996; Jackson 2009a, b; Wulf 2015; Ette 2018a; Norder 2019). Humboldt's study of the Andean vegetation, in particular the illustration of plant and animal distribution on the slopes of Chimborazo, is considered the first work to document how the composition of plant species varies according to altitude and temperature and served as a conceptual model for the study of elevational gradients and climate (see, e.g., Hawkins 2001; Fattorini et al. 2019).

Humboldt was born into a wealthy Prussian aristocratic family living near Berlin, and his privileged upbringing also enabled him to explore one growing obsession, namely linking the distribution of organisms to local environmental conditions—an interest crucially influenced by his early friendship with Willdenow (see Klein 2015). Not only during his studies of geology at the *Bergakademie* in Freiberg, but also during travelling in Switzerland, France and Italy, Humboldt spent a considerable amount of his earlier years exploring the mountains of Europe. Although first observed by La Condamine in the equatorial Andes, the idea of vertically varying vegetation and the concept that the physical environment shaped the grand patterns of life were in fact not born on Chimborazo but in the French and Swiss Alps.

When, in context of "Humboldtian science", it is stressed how novel the empirical approach was, we should remember the active role of the two geologists and botanists, viz. Horace-Bénédict de Saussure and Louis-Francois Ramond de Carbonnières, who each took barometric and thermometric measurements on European mountains at the end of the 1780s. They both recognized and described how the vertical zones of vegetation depended on the altitude and temperature (Ramakers 1976; Bourguet 2002). In his own work, Humboldt owed crucial methodological insights and inspiration in particular to the geologist and meteorologist Saussure. Born in 1740 in Geneva, Saussure is considered the founder of Alpine research. He invented and improved various instruments, such as the cyanometer (to measure the intensity of the colour of the blue sky) or the hygrometer (to measure air moisture), and both were intensively applied by Humboldt during his travel in America. The first scientist to do so, Saussure climbed the Montblanc in 1787 (one year after the first ascent, marking the advent of alpinism), fixing its height using the barometer at 2450 Toises (converted to 4753 m, which comes close to the accepted height of 4810 m today). In his four-volume book "Voyages dans les Alpes", published between 1779 and 1796, and called by Humboldt an immortal work ("ein unsterbliches Werk"), Saussure explicitly pointed to the occurrence of plants depending on altitude, rendering him certainly one of the most influential forerunners and founding-fathers of plant geography. This finding was later almost exclusively but erroneously attributed to Humboldt alone. Interestingly, although Humboldt mentioned Saussure in no less than 40 of his less well-known articles, in his later much-read travelogue he only mentioned him once, and then only as role model for his own travel account (for more details, see Glaubrecht 2019a, 2020, 2021).

In 1789, the French geologist and botanist, Louis-Francois Ramond de Carbonnières, recognized the relation of montane vegetation and height in the Pyrenees. He also contributed valuable mathematical approaches in converting measurements taken by barometer and thermometer into altitude, something later utilized extensively and referred to by Humboldt, and thus also laying the foundation to his later comparisons of the zonation of Andean vegetation to that on Tenerife in the Canary Island. Nevertheless, Ramond is also only marginally cited in Humboldt's later accounts on plant geography or the American journey. Accordingly, Humboldt's role is continuously overestimated (e.g. Päßler 2018a), while the role of Saussure and Ramond des Carbonnièéres is left in the shadows.

Jean-Louis Giraud-Soulavie and the Origin of Plant Geography

Certainly, the most important contribution as to the vertical geography of plants came from the French Alpine researcher, Jean-Louis Giraud-Soulavie, who was read and also cited by Humboldt, albeit only in his earliest works; see for more details Ramakers (1976), Bourguet (2002) and Glaubrecht (2019a, 2020, 2021). Giraud-Soulavie had made the accurate measuring of nature his programme, elaborated and exemplified in his still-unfinished, eight-volume work, "Histoire naturelle de la France méridionale" (1780–1784), and showcased with the montane vegetation of the Ardèche in southern France. Giraud-Soulavie's 1783 illustration "Coupe verticale des Montagnes Vivaroises" depicts the zonation of plants related to altitude, given as "hauteur barometrique" in two flanking columns in his three-dimensional profile of a mountain slope, and clearly resembles Humboldt's Chimborazo profile in its visual language and content. As much as Humboldt's "Tableau", Giraud-Soulavie's "Coupe verticale" is also the same kind of a thematic map of biogeography with all its relevant features that are later attributed to Humboldt alone (see, e.g., Päßler 2018a). While as young student Humboldt praised Giraud-Soulavie several times as "founding father of plant geography", after his return from America he declared himself as the originator (Glaubrecht 2019a, 2020, 2021).

This context was essentially ignored and/or forgotten by Humboldt researchers for decades, even after Ramakers (1976) published his detailed appraisal of Giraud-Soulavie's contribution to plant geography, a work which is not to be found in many accounts on the evolution of this discipline (e.g. König 1895; Nicolson 1987, 1996). In his accurate measuring as well as his innovative graphic depiction, Giraud-Soulavie antedated essential features later found in Humboldt's writings, who admitted (in a private letter, though) that Giraud-Soulavie "mérite de justes éloges" (see Bourguet 2015: 123).

More importantly, it is mostly overlooked, or at least only rarely if at all mentioned, that Humboldt's general perception of nature, with the key idea of the interconnectedness of abiotic and biotic factors, was evidently at the core of Giraud-Soulavie’s published work. Not only does modern Alpine research owe much to Swiss naturalists before Humboldt; in addition, his main credo, that everything is interdepending, or “Alles ist Wechselwirkung”, was essentially general thinking of many of his contemporaries. Humboldt’s credo was only afterwards forgotten again and then, even later, attributed to him alone during the Humboldtian renaissance (see above).

“Alles ist Wechselwirkung”: The Roots of the Idea of Interconnectness in Nature

Although Humboldt started his career in 1793 with a systematic survey of the cryptogamic flora of mining galleries at Freiberg, his main goal during the American journey was not systematics and the description of new species, but instead the study of the geographical relation of plants with their environment. Accordingly, Humboldt aimed to understand the harmonic concurrence of external physical factors with the organisms (Glaubrecht 2019a, 2020). However, the idea of an interplay between abiotic and biotic factors originally goes back to the same French naturalist, Jean-Louis Giraud-Soulavie, whose works on altitudinal variation of vegetation Humboldt had studied and praised in earlier years.

In his “Histoire naturelle de la France méridionale”, Giraud-Soulavie described how everything in the universe is interconnected and how nature is an integrated and complex unity, comprising of physical and biological facets. Nothing in nature is to be regarded as isolated, with everything cooccurring and interacting; or “rien n’est isolé dans la nature, le néant seule est isolé”, as Giraud-Soulavie (1780–1784; vol 2, 1783: 228) wrote in the first part of the second volume of his major work. Today often considered virtually as “Humboldt’s formula”, i.e. that the big picture should be taken into account and with the credo that “Alles ist Wechselwirkung” (as Humboldt wrote 1803 in a letter), this perception can in fact clearly be found in Giraud-Soulavie’s writings. Indeed, Giraud-Soulavie’s avowed aim was to find the most general laws governing the universe: “suivre la Nature dans ses opérations les plus générales and les plus etendue” (Giraud-Soulavie 1780–1784: vol. 1, p. 150), and to strive for those “principes universels, qui s’étendent dans tout l’orbe des êtres organisés” (Giraud-Soulavie 1780: vol. 1, p. 50). He called these universal principles “vérités fondamentales”, or “loix les plus universelles de la nature” and “loix fondamentales”. Given the interdependence of all things being (“alles Seienden”), it was Giraud-Soulavie’s ultimate aim to correlate from all isolated observations a single whole, connected in all its parts (see Ramakers 1976: 12). Finally, it should give pause for thought that Giraud-Soulavie’s credo reflects the contemporary perception of nature and natural history studies at the end of the eighteenth and early nineteenth centuries.

While Humboldt did not explicitly mention the actual role Giraud-Soulavie played in the genesis of plant geography, we also look in vain for adequate references to its founding father after Humboldt claimed this role for himself. For example, Giraud-Soulavie is not mentioned in Humboldt's famous and influential "Cosmos lectures" (while Ramond at least got a passing mention). Thus, contrary to the claim that it was Humboldt who first had a comprehensive cosmological approach (see, e.g., Päßler 2018a), we can assert that this perception of reciprocal concatenation had already solidified in Giraud-Soulavie's works. This view of nature also included viewing man as an ecologica in his own right, as a part of nature rather than something removed from it.

Consequently, if there is anything like a "Humboldtian Science" with the dual aspects of empiricism and aesthetics, it all began with barometric measurements and temperature readings by Condamine in the Andes, with Saussure in the Alps and Ramond de Carbonnières in the Pyrenees. But, in particular, it was the far-reaching cosmological holistic approach of Giraud-Soulavie that had profound implications and influenced Humboldt's "Essai sur la géographie des plantes" several decades later. The later dominant and monopolistic positioning in Humboldt's name are only caused by both his self-attribution and the ignorance of essential precursors in combination with neglect of the scientific context of his time. Consequently, even without Humboldt, a geography of plants had already long existed, one which described and depicted the local association of vegetation in distinct climatic conditions.

How the "Tableau Physique des Andes et des Pays Voisins" Originated

Humboldt's "Naturgemälde", or "Tableau", is of central importance in his entire oeuvre, as the universal is seen within the particular. It deserves praise for various reasons, for example, as it accurately summarized the advanced scientific knowledge of his time. In the "Tableau", his work as a whole is epitomized, aesthetics joins analytics, observation links with experience, scientific knowledge with human understanding through in-depth study of the earth's biosphere (Buttimer 2001: 119). Most recently, for example, Ette (2019) has repeated earlier acclamations of this graphic that depicts "die ganze Welt in einem Bild", complimenting it as "ein wahres Wunderwerk der Wissenschaft", and proposing that "etwas gänzlich Neues wurde geschaffen". However, the two major and often uttered claims, viz. that the "Tableau" is genuine and as much scientific as it is artful and aesthetic, are both disproportioned and unfounded.

Decades earlier Condamine had drafted a topographic vertical profile of Andean mountains during his time in Quito, published in his 1751 "Journal du voyage". Half a century later, it was followed by Humboldt's similar vertical profile, designed during the ascent through the valley of the Rio Magdalena in today's Columbia, en route from Cartagena to Bogotá. Known as "Nivelación barométrica hecha por el

Báron de Humboldt en 1801 desde Cartagena de Indias hast Santa Fe de Bogota" from an unauthorized copy by the Columbian naturalist Francisco José de Caldas (see, e.g., Wolter 1972; Päßler 2018a), it should not be forgotten as instrumental in representing Humboldt's thinking and graphic expression. His famous "Tableau", depicting the Andean vegetation plotted on the profile of the conic volcano of Chimborazo, was then developed from sketches and textual drafts that originated about half a year after ascending this mountain, in January and February 1803, in Guayaquil in today's Ecuador. A first elaborate draft version, the aquarelle "Geographie der Pflanzen in der Nähe des Äquators", is preserved today in the Museo Nacional de Columbia in Bogota (see Lack 2009: 45 ff; Knobloch 2011).

Remarkably, at the time of his Andean expedition a decade had already gone that Humboldt first conceived the idea to devise a "geography of plants" in an account on its own. His plan and vision were long in the making. Climbing the Andean volcanos and, in particular Chimborazo, helped him to visualize his idea, even without having the systematic-botanical and ecological details as an empirical foundation. Emphasizing that Humboldt's extraordinary synthetic achievement antedated his empirical analysis, Lack (2009: 46) rightly points out that Humboldt had developed his graphical language long before the plants that were collected climbing Mount Chimborazo were determined and systematically described. As we have discovered only most recently, Humboldt not only lacked the empirical basis for a considerable time, he also did not pay too much attention to it, as will be detailed below in connection with his notes and plants of the "Tableau" that came from the Antisana instead of the Chimborazo volcano. In this particular context, we should perhaps reread Humboldt's own statement that his "Naturgemälde" was a risk ("Wagnis"); certainly, it throws new light on Humboldt being empiricist as well as "philosopher of nature" (see Knobloch 2011: 297, 300).

Humboldt's first original drawing, the Bogota aquarelle, is a schematic cross-section of the Chimborazo, visualizing the idea of altitudinal occurrences of individual plants and, thus, essentially represents a vertical map of an Andean mountain. In the accompanying "Essai sur la géographie des plantes", which was published in March 1807 as his first work after his return from America, in French in Paris and in German in Tübingen, Humboldt established that tropical mountains compress many climates into a small space: "On this steep surface climbing from the ocean level to the perpetual snows, various climates follow one another and are superimposed". This essay was first given as a lecture on January 7, 1805, when Humboldt reported to a board on mathematical and physical sciences at the Institut National in Paris (that had elected him during his expedition in South America as "membre correspondant étranger"). Although the finale manuscript of the essay is apparently lost, the manuscript of this earliest lecture is extant in the Bibliothequé centrale du Muséum national d'histore naturelle (Bourguet 2015: 115). We should not forget to place this publication in context with the competition between Humboldt and the French botanist Augustin-Pyramus de Candolle. In the same year 1805, the latter published a floristic inventory of plants in France, also accompanied by a map of geographical distribution, albeit depicting the horizontal extension of plants and less the topographical aspects as in Humboldt's vertical sketch.

Nevertheless, he also described those factors as contributing to the distribution in relation to geography, which is also why the start of plant geography can be seen to have been founded with these two texts in Paris 1805. Candolle, who gave a chronology of milestones in the history of the discipline, including the legacy of Giraud-Soulavie, did not accept Humboldt indisputably as founding father of botanical geography. Bourguet (2015) has detailed this competitive relationship with Candolle, pointing out that Humboldt placed more emphasis on the influence and importance of physical factors and measurements in the development of this discipline, while Candolle focussed on the geological and geographical dependencies, with this difference laying the foundation for the later distinction of ecological versus historical biogeography (see, e.g., also Glaubrecht 2000). Thus, the competition and argument between Humboldt and Candolle not only concerned priority, predecessors and methods, but also theory and the direction of the discipline, such as it was.

The "Poetics of Landscape Visualization"

Humboldt visualized the vertical zonation related to altitude on the cross section of the Andean mountain, with meticulously noted occurrences of plants in their Latin generic and specific names, themselves inscribed in tiny writing. Via annotations on the left- and right-hand sides, he gave a total of 16 flanking columns plus four scales (for altitude in French Toises and metres given on both sides), comprising physical measurements, such as air pressure, humidity, boiling point and temperature, as well as additional environmental factors. Here, Humboldt is describing plants in their natural history dimension, that is to say not primarily classifying them systematically but emphasizing the perspective of spatial occurrence and vertical distribution, itself dependent on abiotic factors and in correlation with other biotic aspects. After adding a pictural flank of Chimborazo to the pure cross section of the original aquarelle, Humboldt chose the French word "tableau", which means both table and painting.

This distilled depiction—"the most important result of my journey" ("das wichtigste Resultat meiner Reise"), as Humboldt noted—is equally complex and descriptive (see Lack 2009: 45). It represents his version of the invention of an info graphic that later became one of the most important "Denkbilder" of natural history in the early nineteenth century, as often used as Darwin's cryptic drawing of an evolutionary tree. As much as the latter picture illustrates the beginning of evolutionary thinking (see below), Humboldt's "Tableau" was used to symbolize the beginning of the scientific disciplines of both plant geography (albeit being older) and ecology (which was only later called such; see Haeckel 1866).

Later students of "Humboldtian science" err, however, in assuming that his depiction of plants on Chimborazo was "a pioneering piece of data visualization". As we have seen above, Giraud-Soulavie already illustrated distribution zones of mountainous vegetation in exactly the same way and visual language in relation to conditions such as altitude and temperature, including a vertical scale of barometric readings on both sides. Therefore, it was Giraud-Soulavie who first broadened the purely taxonomic approach of botany by adding functional relations in order to encompass interdependences of all forces in nature. Crucially, it was only later that Humboldt compared the zonal distributions across other mountain ranges of the world, implying a global connection between the biotic and abiotic realms. In this, he was guided much more by a desire for the aesthetic depiction than, for example Giraud-Soulavie; but, as this essay has repeatedly stressed, Humboldt was neither the first nor, if we consider his milieu, as pioneering as some scholars have him be.

Humboldt's language was much more a visual one, a "poetics of landscape visualization", as Buttimer (2001: 117) has described. As his rendering of landscapes was so central to all his work, Humboldt "touched on aesthetic and ethical dimensions of humanity's relationship to the natural world". In fact, the "Tableau" was ultimately perhaps quite as important for its evocative appeal, as it was for succinct communication of scientific results. It appeals simultaneously to many audiences and made nature an engaging focus for artists and literary scholars, as well as a legitimate focus for scientific enquiry. The "Tableau" marks Humboldt as both an empirical naturalist and lyrical romanticist. Aesthetics in his science, we should not forget, was a crucial part and foundation of his thinking, not only something additional or marginal, not only adornment, decoration or ornament, as Ette (2019) would have it. In this respect, Humboldt's graphic language of the "Essai" in combination with his "Naturgemälde" in fact not only opens the door to his travel account but evokes aspects of insight and of intuitive perception. At the same time, most recent research—in particular on the empirical foundation of his depiction of plant geography in the "Tableau"—has revealed an astonishing lack of factual evidence, rendering Humboldt's most famous achievement a product as much of fiction as of fact.

Plants from Antisana Rather than Chimborazo

Humboldt is currently mostly described and envisioned as an empiricist whose contribution to science lies in his plethora of extensive geophysical measurements and the precise recording of geographical location of thousands of specimens. "Humboldt's obsession with geographically referenced measurements and collections was central to his vision" (Jackson 2009a). However, in effect, there was less rigour in his factual evidence and measurements than is generally admitted, as he placed less emphasis on and careful attunement to his own observational process and the inevitable subjectivity of his perception. Accordingly, his "Naturgemälde" of Andean vegetational zonation illustrated for Chimborazo is not so much a synthesis of available facts based on data but, with its aesthetical appeal, more of an overall vision of his comprehensive "general physics of the Earth".

Although Humboldt later considered this condensed depiction as "the most important result of his journey", his diary of the ascent in June 1802 was only published posthumously (see above). The data compiled in his "Tableau", nevertheless, have recently been used in an attempt to reconstruct a long history of how plants have migrated, being mined as a record of mountain biogeography from the beginning of the industrial revolution and providing a unique baseline for gauging the changes since. In fact, mountains are, next to polar seas, among the fastest-warming regions of the planet, with the same feedback loops familiar from the Arctic in terms of the extent to which solar radiation is absorbed on reflective ice surfaces. Humboldt's own account as well as the associated notes and illustrations were recently taken as being precise and accurate enough to help reconstruct the altitudinal change in context of global warming over the past two hundred years, with the reconstructions finding a strong upslope shift in Chimborazo's vegetation.

Humboldt not only took elevation readings with a fragile glass barometer, but together with his botanist companion, Aimé Bonpland, recorded and collected plants during their ascent of the volcano. Ecologist Morueta-Holme et al. (2015) and her team tapped these data from the "Tableau" and other records Humboldt compiled. First, they reported on his historical information regarding the altitude ranges of some 50 alpine plants from Chimborazo. Second, the team climbed much of the way Humboldt did in order to compare where those plants grow now. While Humboldt and Bonpland found an upper limit for seed plants at 4600 m, Morueta-Holme et al. (2015) reported pioneers of the same plants now as high as 5185 m, thus documenting an upslope vegetational shift by an average of more than 500 m since 1802. With rising global air temperatures, the ice of glaciers had seemingly retreated, resulting in not only plants but also farmers moving upward also on Andean mountains. While agriculture reached its limit at around 3600 m in Humboldt's time, it has now pushed hundreds of metres upslope, with potatoes growing where frost has become rarer in the former "pajonal" grassland, a habitat that once reached over and above 4600 m, but now extends to 5070 m (see Morueta-Holme et al. 2015). Having come in for criticism, the team now admits that the report was "erroneous" with the "inconsistencies and uncertainties in Humboldt's accounts", and "messy historical data, open to interpretation", and posing "difficulties for inferring precise range shifts" (Morueta-Holme et al. 2019). Nevertheless, they still assume that the "diary-based accounts of the Chimborazo ascent provide evidence of botanizing at high elevations, with plant collections and frequent elevation recordings up to at least ∼4380 m and, beyond the last vascular plants, cryptogams up to ∼5500 m".

By way of contrast, in May of Humboldt's 250th anniversary the ecologist Moret et al. (2019a) headed a second team and went on to claim that the "Tableau" is not at all a faithful record of what grew on Chimborazo two hundred years ago. After scrutinizing available diaries and collections, they concluded that not only are Humboldt's data not reliable enough to support the above conclusions, but they discovered that Humboldt did not collect plants above 3625 m on Chimborazo, simply due to heavy snowfall at that time. Moreover, he barely used factual evidence from this particular volcano in his zonation work. Thus, it is not merely about "probably lost specimens" or "locality information missed in later descriptions”, as Morueta-Holme et al. (2019) still argue. Nor is it about the fact that Humboldt altered the altitudinal position of many plants in subsequent publications as the taxonomic treatment of the collections proceeded, rendering the “Tableau”, as we know it, as “a work in progress, an attempt to illustrate general plant distribution patterns on the equatorial peaks of South America” (Hestmark 2019).

Appearance and Exactitude in Conflict

More importantly, whether Humboldt depicted plants on altitudes that were never collected by him or Bonpland, and indeed plants that actually do not occur on Chimborazo, has been thrown into doubt by Moret et al. (2019a, b). In fact, much of the data and plants in the “Tableau” that so prominently depicts the volcanos Chimborazo and Cotopaxi instead came from the smaller volcano Antisana, with its height of 5704 m located about 130 km to the north-east. Evidently, as it now turns out, many of the alpine plants Humboldt (1807) named and placed unambiguously on the slopes of Chimborazo were actually never collected there. In fact, in March 1802 Humboldt and Bonpland had spent four days collecting and recoding a total of 63 plant species on Antisana, of which 46 were found above 3700 m; by contrast, in June of the same year they recorded only 20 species from the base of Chimborazo, having spent just a few hours on its highest slopes. Humboldt later only pretended to have observed the data on this volcano, presumably because this “most majestic of all mountains” was more famous. Accordingly, he and Bonpland on Chimborazo not only sampled less systematically than assumed, but at least the top section of the “Tableau”, above the tree line, is more of an intuitive or imagined construct based on unverified and, therefore, partly false field data that Humboldt constantly tried to revise in subsequent publications.

As Moret et al. (2019a, b) have pointed out, this also has wider implications for documenting climate change effects in the tropical Andes. Having established Antisana as the key locality from Humboldt’s and Bonpland’s historical data, Moret et al. (2019a) followed their ascent and in their 2017 survey systematically mapped the current ranges of 31 species there, comparing data for specific alpine plant species with those obtained at Antisana. From this, they suggested that a number of species have moved up by some 215–266 m over the last two hundred years. Although they found several imprecise data in the “Tableau” that made it hard to calculate just how far upslope individual plants have moved, the exemplar case of the silvery leafed shrub *Senecio nivalis* is instructive in this context. While Bonpland recorded it at a maximum altitude of 4860 m, where Antisana’s permanent snow began, it now grows above 5100 m, thus having climbed more than 200 vertical metres in step with the rising snow line—a move also corroborated by other studies. Thus, although the vegetation marched upward only half of the 500 m Morueta-Holme et al. (2015) originally calculated, it is still a dramatic shift upslope. However, it is now one that is in line with what one would expect if the average air temperature has increased by ~1 °C over the past 200 years, thus adding to the growing evidence for changes in plant communities and the shrinking of the area of true mountain habitats (see, e.g., Hestmark 2019).

Humboldt's French title of the "Tableau", as pointed out above, reflects the dual character of his famous and influential graphic much better than the German "Naturgemälde", combining as it does tabulation with painting. As we have to accept now, his drawing also combined fiction and fact and should thus be regarded as much a work of art as of science. As an "intuitive construct" it renews our understanding of Humboldt's scientific thinking, methods, and modern relevance, as Moret et al. (2019a) has rightly concluded. Humboldt used considerable artistic licence in presenting and took quite some liberty in documenting his results, not only because the taxonomic study had barely begun when sketching out his "Tableau". We should not forget that he himself warned against expecting high precision, as "in a work of this kind, one must consider two conflicting interests, appearance and exactitude".

There is no doubt that Humboldt also made extensive observations of plant elevation ranges on Chimborazo. While the "Tableau" actually includes a considerable amount information from the surrounding equatorial Andes, in particular from Antisana, it still lacks consistency and is marked by "several inaccuracies", as earlier naturalists in fact have pointed out. Moret et al. (2019a) detailed analysis of Humboldt's documents, revealing that part of the documentation published in his "Tableau" was based on incorrectly recorded field data, hardly modified from the sketch drawn at Guayaquil in early 1803, and contradicted in later publications. While his aesthetically appealing painting of Chimborazo dominated later perception, his own statement that the information assembled there covered the whole equatorial Andes area, from 10° N to 10° S, was largely forgotten, as well as that the system of high-altitude floristic belts proposed in the "Tableau" was preliminary and "perfectible", in essence "a schematic construction that contradicted part of the observations made in the field" (Moret et al. 2019a).

Humboldt's and Bonpland's expedition should still be considered outstanding and unique in the history of biological sciences, but less so for actually novel theoretical concepts it gave rise to, as too often been assumed. Their journey is still heralded for the quality of the locality data recorded for so many organisms, including plants, that can be retrieved from a cross-analysis of now available diaries, herbaria, and botanical publications (Moret et al. 2019a, b). However, the putative key role of Chimborazo in defining vegetational zonation and of this particular mountain in Humboldt's oeuvre must be re-addressed in this context.

In addition, his famous depiction of Chimborazo exemplified that in general Humboldt's empiricist or inductive approach to science should be reconsidered, as the new findings reveal a generalized misinterpretation of Humboldt's most iconic work. As powerful as Humboldt's "Tableau" still is in representing the conceptual framework, it is an idealistic schematization and its production is embedded in the historical and philosophical contexts in general, and the practice of biogeography in particular, of Humboldt's time. As Juárez-Barrera et al. (2018) have shown, quite in contrast to the claims of other historiographers, the work of some early naturalists and biogeographers including Humboldt were not distinctively descriptive, nor did they strictly adhere to the inductivist model. As is now evident, Humboldt's work and the postulated explanations as to the influence of climate based on physical causes, for example, is less supported by empirical evidence and more conjecture than has been hitherto assumed. Also, it reveals less caution when putting forward hypothesis that were not always based on actual empirical evidence.

As we have seen, Humboldt as well as contemporaries (with whom he competed, such as Augustine de Candolle) passed between an empirical factual basis and speculation, and were thus rather closer to deductive thought than to the orthodox inductivist model, as has been rightly detailed by Juárez-Barrera et al. (2018). Humboldt not only collected data and described patterns, but also carried out exhaustive empirical studies of the physical world to the extreme, as he has been depicted in popular accounts. He was less systematic in his research in case of zoology, as has recently been shown in Glaubrecht (2019a, b). But even in plant geography, when lacking the taxonomic rigour and all the necessary evidence, Humboldt developed his work under a holistic approach allowing deduction, including speculative narration and postulation, more space in promoting his hypotheses than should be done under strictly inductivist reasoning and an empiricist's principles.

In addition, some of his a priori ideas were based on hypotheses developed and exemplified earlier by other European naturalists in the Alps and Pyrenees (see above), with Humboldt's observations in the equatorial tropics sometimes even lacking the exact empirical basis, as has now been exemplified for his "Essai" and "Tableau". And his ideas had other often-overlooked sources, something Humboldt was later astonishingly quiet about.

From Zimmermann's Zoogeography to Humboldt's Plant Geography

Evidently, biogeography as the study of the distribution of organisms over the Earth's surface, with its obvious pattern of unevenness in species abundance and richness, is very much older than biogeography as an academic discipline (see, e.g., Glaubrecht 2000; Ebach 2015; and literature therein). As much as Humboldt's concept of vegetation belt was less revolutionary than later researchers claimed, there are several repeated misinterpretations of the origin of plant geography in general. Humboldt's "genius of a geographical vision" (Jackson 2009a), in viewing Earth's land surface and oceans and its inhabitants as forming an integrated whole, was neither the first nor the only work to envisage the climate as a major driver behind the expansion of altitudinal or latitudinal vegetation. Lack (2003, 2009) and Knobloch (2011), for example, as well as others (see Ebach 2015), have detailed the role of the Berlin botanist, systematist and dendrologist Carl Ludwig Willdenow and his highly influential “Grundriss der Kräuterkunde”, published in 1792. Humboldt found the strong claim for the geographical correlation of local occurrences of plants in dependence of the influence of climate in Willdenow’s works; he then used this idea first for his “Florae Fribergensis” published a year later, and later took it to the tropics when climbing the equatorial Andean volcanos.

In his account on the origin and earlier beginnings of biogeography, Ebach (2015) has rightly pointed out the influence and importance of earlier founders on the development of a general geography of organisms. However, the leading role of the naturalist and anthropologist Eberhard August Wilhelm von Zimmermann in developing a historical biogeography has only rarely found sufficient consideration; see, e.g., Bodenheimer (1955) and in particular Feuerstein-Herz (2006). In any case, Zimmermann’s influence in particular on Alexander von Humboldt should not be underestimated, as has been detailed more recently in Wallaschek (2016) and Glaubrecht (2019a, b, c, 2020, 2021). Zimmermann’s (1778–1783) “Geographische Geschichte des Menschen und der allgemein verbreiteten vierfüßigen Thiere” is not just important as the foundation of a historical biogeography, in contrast to an ecological biogeography (see details in Glaubrecht 2000): In his three-volume account, preceded by a shorter Latin edition in 1777, published in the years 1778, 1780 und 1783, and supplemented by a “Zoologische Weltcharte”, or “Tabula mundi geographico zoologica”, Zimmermann explicitly discusses questions of centres of origin, as well as his theories on migration and dispersal in particular of mammals which depend not only on climate but also on the history of the Earth.

While most proponents of the Humboldt renaissance do not fail to name him as one (if not the only) of the founding-fathers of plant geography, it remains largely forgotten that Zimmermann’s most important work on animal geography long preceded Humboldt’s plant geography, and evidently influenced it. Humboldt explicitly mentioned and paid homage to Zimmermann’s zoogeography in his earlier days as young student and naturalist. Later, however, after the return from his American expedition and when struggling to establish himself as plant geographer in his own right, he evidently increasingly marginalized Zimmermann’s contribution (Wallaschek 2016; Glaubrecht 2019a, b, 2020, 2021). Compared to the picture painted by other historiographers (summarized, e.g., in Päßler 2018a), it is important here to again stress the fact that Zimmermann’s (1778–1783) animal zoogeography, with the emphasis on historical components, clearly antedates Humboldt’s much respected plant geography, with the emphasis on ecology. In this regard, Zimmermann was not only interested in the “Vertheilung … der animalischen Produkte unserer Erde”, i.e. the distribution of animals, but in finding “Gesetze”, or laws, which govern the order found in nature, he also had a clear and strong view on not only the current patterns but also the geographical history of the organisms to explain their extant occurrence and distribution. Zimmermann proposed, for example, that this kind of history of the Earth is the reason that not only climate and other environmental factors influenced faunas but geological events reaching long into the past. Therefore, suggesting that both historical and environmental phenomena should be considered, he concluded on the reciprocal illumination of history and ecology; as next to physical and ecological factors geological and geographical factors also account for the distribution of animals and plants.

In this comprehensive and fairly modern approach to biogeography, one that combined spatial with temporal aspects, Zimmermann predated Humboldt by decades, and went well beyond the latter's comparatively restricted approach, which focused only on contemporary abiotic and biotic factors and interactions, but refrained from providing a truly historical perspective. While for Humboldt, geography remained essentially static and descriptive, with the climate as most important causative factor, Zimmermann's approach was novel in focusing on the historical dynamics and geological-geographical causation. This latter focus might have been one of the reasons for Humboldt's refusal to integrate, accept or even acknowledge Zimmermann's biogeography; see for more details Glaubrecht (2019a, 2020, 2021).

With Zimmermann's delving the depths of mammalian zoogeography at the end of the eighteenth century, naturalists realized much of the complexities of biogeography. His "Tabula mundi geographico zoologica"—"a markstone of zoogeographical mapping" (Bodenheimer 1955: 357)—represents the first systematic attempt to visualize the relation between species richness and geography in cartographic form, depicting typical faunal elements and clearly delineating defined climate regions. "Die Übersicht auf seiner Weltkarte und die Einteilung der Erde in tiergeographische Zonen stellen das sinnfällige Resümee der systematischen Aufarbeitung zahlreicher inkohärenter Einzelbeobachtungen über das Vorkommen der Säugetierarten auf der Erde dar", as Feuerstein-Herz (2006: 205, 234) summarized her research. In his "Tabula", Zimmermann detailed the geographical occurrence of mammals, giving their specific Latin names in the horizontal plan of the world map. Two decades later in his "Tableau", Humboldt transferred this idea of Latin denomination of the individual occurrence of species and genera from the horizontal perspective of a world map to the vertical perspective of his cross section of the slopes of Andean mountains, thus projecting the visual language of Zimmermann from animals to plants.

In summary, the suggestion is put forward here that Zimmermann did not only contribute important results for animal geography; even more important perhaps, he also influenced plant geography, an influence later largely and erroneously attributed to Humboldt alone. Accordingly, the science of geography studied in animals is nearly four decades older, irrespective of Humboldt's own perception or later historiographic misconception of this context. Zimmermann's dynamic-historical approach comprised vertical, i.e. temporal components, while Humboldt restricted his own static approach to horizontal pattern dependent on ecological-climatic aspects only. A "temporalization" of nature, as it was termed by Lepenies (1976), was literally unthinkable to him, as it will now be detailed below.

Humboldt's "Cosmic Vision" and Darwin's "De-Humboldtizing"

Not only during his American journey but also in the subsequent decades, Humboldt was frantically busy collecting available data and empirical evidence of natural phenomena, ranging from a cosmic perspective of the universe down to minute details of the organic world. However, paradoxically, the more isolated facts he tried to accumulate and attempted explicitly to concatenate, the more he failed to develop a general theory of nature.

Humboldt collected many new plants on the banks of the Orinoco and the heights of the Andes, discovered some animals, and made a plethora of observations, but he never found the long sought-after "law of nature". His "cosmic" vision of a well-ordered universe and nature was firmly rooted in and derived from the ancient world's view of occidental antiquity, with its emphasis on harmony, beauty and equilibrium, and revived in the romanticism of the end of the eighteenth century; see, e.g., Hard (1969: 133–177), Ramakers (1976: 11–13) and Weigl (2004: 22–49); for more on Humboldt as romanticist, see, e.g., Cunningham and Jardine (1990), Dettelbach (2001) and Köchy (2002). Although Humboldt was dedicated to empirical research, indefatigably measuring physical parameters in particular during his American journey, he uncritically presumed that there is a tendency in nature towards harmony and equilibrium. While noting that "das Gleichgewicht geht aus dem freien Spiel dynamischer Kräfte hervor", he left the existence and nature of these "dynamic forces" open to interpretation (Humboldt 1807; see also Weigl 2004; Päßler 2018a).

Ultimately, due to the ancient perception of cosmic harmony and equilibrium, Humboldt was much less modern than is currently proposed by the hagiography of a Humboldtian renaissance, as indicated in the introduction. It is in this context that we also have to reconsider Humboldt's influence on Charles Darwin, as their relationship has been subject to oft-repeated claims, in particular that the former's work had a profound effect on Darwin thinking and his development of evolutionary theory. However, we should make it clear from the start that Humboldt did not continue to influence the scientific discourse in the decades after Darwin's return from his voyage to South America with the "Beagle".

For example, it has been said that Humboldt anticipated Darwin's famous idea of an "entangled bank" of connections in the web of life, and also recognized organisms have a reciprocal effect on their environment, leading him to realize that humans were intricately entangled within this web too (Anonymous 2019). As much as it is noteworthy and correct to note that Humboldt, as one of the earliest naturalists, recognized for instance that wetland draining and forest clearance for agricultural production left indelible scars on the landscape, the underlying holistic idea of the web and that "Alles ist Wechselwirkung" has its roots elsewhere, as we have seen above.

There is no doubt that Darwin was inspired less by Humboldt's earlier "Essai" on plant geography than by his later "Personal Narrative" (as is the title of the

English translation of the “Relation historique”). Evidently, the young Darwin repeatedly read this travel account in 1831, which encouraged him to plan an expedition to the island of Tenerife in the Canary Islands. Accordingly, Humboldt’s travel-writing ignited a longing to travel in Darwin. When, on 18 May 1832, Darwin arrived in Rio de Janeiro, he wrote in a letter to Henslow: “I formerly admired Humboldt, I now almost adore him; he alone gives any notion of the feelings which are raised in the mind on first entering the tropics” (see, e.g., Buttimer 2001: 116; Glaubrecht 2009). However, we have to realize that Darwin’s subsequent travels in South America were less informed by Humboldt’s travelogue, but instead by Charles Lyell’s “Principle of Geology”, which Darwin read on board the “Beagle”. Thus, during his own journey he found and later reported extensively on the geological evidence for orogenesis, a sphere of thinking that Humboldt had never dared to know. In effect Humboldt’s influence on Darwin’s science remained comparatively marginal at best. The dragon tree of Tenerife might have lured Darwin to the tropics, but his thinking and theory developed along other paths than those Humboldt tread (Glaubrecht 2009). The same holds true for the parallel but independent development of the evolutionary thinking of Alfred Russel Wallace (Glaubrecht 2013).

Later in life Humboldt and Darwin met and exchanged letters. However, neither their correspondence nor their brief and singular personal meeting on 29 January 1842, in London, should be interpreted as evidence for any substantial reciprocal exchange of ideas. For example, Lubrich (2009: 870–871) assumed a dialog spanning decades (“einen jahrzehntelangen Dialog”) and described the relationship of Darwin to Humboldt even as one between student and successor (“Schüler und Nachfolger”), with Humboldt having thought about theories of evolution before Darwin had even published them (“Überlegungen im Sinne der Evolutionstheorie, die Darwin noch gar nicht veröffentlicht hatte”). Moreover, others have remarked on the “overlapping ideas on the transformation of species” (Anonymous 2019), as another example illustrating the ill-informed narrative that explicitly followed the misleading account of Wulf (2015).

In this context, the correspondence between Darwin and Humboldt in particular has caused much ink to be spilt, even though it comprises a total of one letter each (see Leask 2003; Päßler and Werner 2009; Werner 2009, 2010; Schmuck 2014; Päßler 2018b). In fact, we know of only one letter by Humboldt to Darwin and his answer from September and November 1839. While Humboldt thanked Darwin, in an unusually long letter, for his “*Narrative*” of the “Beagle” journey, the latter then informed Humboldt about the details of the surface temperature of the Pacific Ocean; both points are completely irrelevant to the formulation of Darwin’s idea on the transmutation of species.

While there is no doubt that Darwin was impressed by Humboldt’s literary style and legacy in his earlier years, we should not forget how important “de-Humboldtizing” later was for Darwin’s writing. As Leask (2003: 13–36) has detailed, only when Darwin freed his narrative in the new 1845 edition of his “Journal” from Humboldt’s style of writing, did his travelogue become a bestseller then as it is now. Therefore, Humboldt admittedly influenced Darwin in his desire to travel to exotic places, such as Tenerife, and he was his literary “role model” in the beginning. However, Darwin was explicitly disappointed by Humboldt and his “Cosmos” when published in 1845. To his mind, it lacked any insight into the transformation of species or the process later to be called evolution. Humboldt’s book, with his “semi-metaphysico-poetico-descriptions”, as Darwin explicitly wrote in a letter, was virtually unreadable to him (see Päßler 2018b: 248). The “Cosmos” is rightly considered the last monument of a static world view, one which has Humboldt arriving around the mid-nineteenth century on a cul-de-sac road of science.

Humboldt, Darwin and the Transformation of Species

There is good reason to meet with scepticism any alleged “predecessors” who ingeniously anticipated the views of later times, in particular when “predarwinistic” quotations are cited, as is often the case, out of the context in which they were written. Jespersen (1946), when writing on another contemporary of Humboldt as an “evolutionist”, already warned against simply lifting supposedly original and prophetic quotes from contemporaneous literature without considering the wider historical setting. Contrary to claims that Humboldt had allegedly “helped create the intellectual world Darwin inhabited” (Jackson 2009a), the former might have helped to establish the foundation for plant geography and ecology, but he was certainly not involved in founding evolutionary biology, nor was he instrumental in any respect in laying the groundwork for continental drift, as was both erroneously claimed by Wulf (2015) and others in the wake of her biography. These and similar claims of any anticipation move the focus away from the more important realization that it was Darwin’s 1859 work that resulted in a shift towards the evolutionary paradigm, establishing a new conceptual framework to explain nature and much of the underlying causation of the organic world. The “temporalization” of nature mentioned above added the essential vertical component, supplementing the more obvious spatial patterns, with the former being beyond Humboldt’s gaze. Therefore, his perspective on nature remained largely horizontal and a-historical. The theory of evolution by natural selection implied a dramatic conceptual twist and replaced a static versus the dynamic perception of nature.

For example, while he did use the term, Humboldt missed the significance of fossils as factual evidence for the transmutation of species and the genealogy of ancestor–descendant relationships, a fact that Darwin and other contemporaries did recognize. Instead of looking for influence that Humboldt’s writing never had, we should turn our attention to the major impact of British geologists and palaeontologists, such as in particular Charles Lyell with his “Principles of Geology”, but also Adam Sedgewick and Richard Owens, as well as early French “evolutionists’”, such as George Cuvier and Jean-Baptiste de Lamarck (see, e.g., Glaubrecht 2009). When Humboldt repeatedly argued against Buffon’s degeneration theory and Cuvier’s catastrophic theory, he did this without hinting at alternative hypotheses as to the temporal and spatial relation of species. Whereas Humboldt only presented analogies, Darwin suggested genealogies.

Humboldt, however, was never a Darwinist, not even a pre-Darwinist in the sense of having conceived any of the essential components of the evolutionary theory, neither regarding the genealogical ancestor–descendant connection nor the mechanisms of natural selection and the multiplication of species. The obviously erroneous perception was first uttered by the physician and physiologist du Bois-Reymond (1912), and among others also repeated by the zoologist-historian May (1904, 1911). However, neither did Humboldt have any concrete idea of the vertical dynamic of the geology of the Earth, i.e. orogeny or eustatic sea-level fluctuations, he also did not realize the dimension of "deep-time", or the historical component of life and the long-lasting genesis of living organisms. Therefore, any attempt to construe Humboldt as a pre-Darwinian naturalist or biogeographer, or even to impute that he was an early proponent of Wegener's continental drift, similar to what can be found in Wulf's (2015) biography and other accounts, is highly misleading, ill-informed and without consideration of the factual historical evidence, a point which has been repeatedly made (Glaubrecht 2019b, c, 2021).

Evidently, Darwin did read Humboldt, but we need to realize that the latter influenced his writing not his science, as Leask (2003) has convincingly shown. Darwin was disappointed in particular by Humboldt's (1845) "Cosmos", a work that he thought lacked any relevant insights into the interesting and pressing question on the nature and origin of species. Therefore, in no respect should "Cosmos" be seen as forerunner of Darwin's work and thinking, which had completely different roots and took other paths. In fact, the question of the origin, i.e. on descent and development of species, remained a problem that Humboldt did not and could not solve; indeed, he considered any attempt towards a solution mere speculation, as was also the case regarding continental drift. Although he used the phrase "struggle for existence" (as did many contemporaries) in his "Ansichten der Natur", Humboldt (1808: 321) remained highly sceptical towards the underlying question of the origin of life. Consequently, he failed to solve any of Darwin's so-called mysteries of mysteries, such as dimension of biodiversity (number of species) or its origin and evolution (nature of species and speciation).

In summary, Humboldt compiled a "cosmos" of data without developing a major theory; only later were some of his observations, such as those on latitudinal biodiversity gradients, used to develop biogeographical theory. In contrast, Darwin developed a powerful theory, based by comparison on a limited amount of data, from which he synthesized his core ideas. Alfred Russel Wallace, a true "Darwinian", embraced this in a hand-written marginal annotation in his copy of "The Life of Alexander von Humboldt" (see Bruhns 1872): the "Cosmos", it reads, is "valuable as a history of science in nineteenth century" only, not as a book that would have enduring scientific influence (Beharrell 2019). Due to its great explanatory power, Darwin's (1859) theory of evolution was rapidly adopted, even when often perceived in a too simplistic and convenient version. Thus, the year of Humboldt's death (in May) and Darwin's publication of the "Origin of species" (in November) truly marks the end of any Humboldtian approach to nature and the turn towards a new era and epoch in both the history of natural history and of science (Glaubrecht 2019b, c, 2021).

Coda and Conclusion—What Remains of Humboldt?

Beyond doubt, the persuasiveness of Humboldt's work and writing remains compelling. Humboldt was taught the enlightenment values of reason and truth as a building block, and these intellectual tools were paired with an enquiring mind and considerable ambition, which laid the foundation for his polymath interest in the natural world. However, Humboldt's idea of a holistic web of connections is nowadays almost always presented as an allegedly dramatically different vision to the dominant scientific ideas of the time. As has been repeatedly stressed, Humboldt had important (albeit long-ignored) scientific predecessors and contemporary advocates. While admittedly many naturalists focused on the systematical classification of organisms at the level of individual species, largely influenced by Carl von Linneaus, there were others—from Condamine to Giraud-Soulavie—who had developed a similar holistic approach before Humboldt's time, and who considered empirical methodology along with physical parameters and ways of aesthetic visualization.

In contrast, any emphasis as to the "allumfassende Dynamik alles Seins und Gewordenseins" in Humboldt's thinking (see, e.g., Ette 2019) is misleading, as his world view remained static instead of dynamic, resting on the perception of antiquity and romanticism, firmly rooted in pre-Darwinian thinking. Nowadays, we understand nature as much more dynamic in space and time, and stress its historical dimensions, something long-ignored in the static world view of Humboldt. Confusingly, Ette (2019) labelled Humboldt's "Tableau" as having everything in motion ("befindet sich alles in Bewegung"), declaring that "Humboldts Wissenschaft entstand aus der Bewegung". This oft-repeated notion and vision remains vague as to why all of Humboldtian thinking should "appear in motion", when quite the contrary is the case. In contrast to these unsubstantiated claims on "dynamics", and given the fact of systematically collected evidence and accurately measured data detailed above, we would do better to reconsider the prevalent cliché of Humboldt as pure inductivist and empiricist with his graphic a work of pure scientific rigour. Instead, we should consider in particular his famous "Naturgemälde" being, rather than merely a combination of empiricism and aesthetics, as much a product of phantasy and fiction, as of fact and evidence.

It is not only in this latter respect that we should be careful declaring that science today is following in Humboldt's footsteps, as it was often suggested in the year of his anniversary. On this point, one can certainly agree when it comes to leaving our homes or offices and laboratories and going out into the field in order to collect and accumulate more data directly from nature, more so than reductionist biology does today. However, we should be more hesitant when Humboldt's antique world view and romantic approach to nature are in focus, as his perceptions and ideas are often rooted more in convictions and conventions of thinking than they are based on systematic and empirical findings. Also, we should strive for a more theoretical foundation of collecting our data than Humboldt was able to achieve.

No doubt that at the end of his life Humboldt was one of the most famous men in Europe, féted by learned societies and governments around the world. Humboldt has also continued to enjoy more of posthumous fame than most other naturalists, his science today often being heralded as “transdisciplinary” and “intercultural”. His travels and ideas figured prominently in nearly every celebratory text in the year of his anniversary and his name was repeatedly associated with ecological thinking and a global view of nature. However, the extent of his fame has helped to exaggerate his achievements. Humboldt’s scientific contributions were less formidable than recently supposed, based on later erroneous attribution by those epigones who have focused largely on his literary work and looked less into the contemporary scientific context of his days. Neither did his early travels in South and Central America constitute the first scientific survey of the region by a Western observer (given what, e.g., Condamine had accomplished in the Andes and along the Amazon); nor did he contribute anything substantial to the theory of evolution or continental drift, as was put forward without reason, e.g., by Wulf (2015), and then subsequently repeated often without critical questioning.

Even claims of Humboldt having allegedly spurred on the development of biogeography and ecology are now again in need of being reconsidered, given the long-overlooked and ignored impact of earlier fundamental contributions by other naturalists of his time, for instance Auguste de Candolle and Jean-Louis de Giraud-Soulavie in plant geography, as well as Eberhard August Wilhelm von Zimmermann in animal geography. Humboldt’s contributions rest mainly on producing many very-detailed descriptive reports, with too little integration within or among the component entities to found a theory. As much as Humboldt has certainly inspired many scientists and others after him, he did not make the substantial contributions to the two emerging disciplines of biology of his time, viz. evolution and ecology, that have been claimed since. Finally, as a naturalist, Humboldt’s perception of nature and thinking of science is retrograded and, thus, he hardly stands as a useful icon or the challenges of science and society in the twenty-first century, as has erroneously been suggested by the activists and epigones of the Humboldt renaissance.

Nevertheless, modern research has often adopted Humboldt’s holistic approach, called multidisciplinary today, and repurposed it for an era of climate change and interplay of people and environment, which now affects the planet (see Glaubrecht 2019d). However, many interpretations of Humboldt’s achievements reveal, as Buttimer (2001) suggested rightly, “as much about the interpreters’ own world and concurrent agenda as they do about the scholar and his works”. Which is, certainly, also true for the present essay.

References

Anonymous (2019) Editorial. Humboldt's legacy. Nature Ecology and Evolution 3:1265–1266

Barthlott W (2011) Alexander von Humboldt und die Entdeckung des Kosmos der Biodiversität. In: Albach H, Neher E (eds) Alexander von Humboldt und Charles Darwin. Zwei Revolutionäre wider Willen. Wallstein, Göttingen, p. 35–42

Bayerl J (2017) Tierzeichnungen Alexander von Humboldts und deren Verwendung im amerikanischen Reisewerk sowie in den zoologischen Schriften von Franz Julius Ferdinand Meyen und Johann Jakob von Tschudi. In: Drews J, Ette O, Kraft T, Schneider-Kempf B, Weber J (eds) Forster – Humboldt – Chamisso. Weltreisende im Spannungsfeld der Kulturen. V & R unipress, Göttingen, p. 315–334

Beharrell W (2019) 14th September 2019: 250th anniversary of the birth of Alexander von Humboldt. The Linnean Society News (online: https://www.linnean.org/news/2019/09/14/alexander-von-humboldt)

Bodenheimer FS (1955) Zimmermann's *Specimen Zoologiae Geographiae Quadrupedum*, a remarkable zoogeographical publication of the end of the 18th century. Archives Internationale d'Histoire des Science 8:351–357

Bois-Reymond E (1912) Die Humboldt-Denkmäler vor der Berliner Universität. In der Aula der Berliner Universität am 3. August 1883 gehaltene Rektoratsrede. In: Bois-Reymond Estelle (ed), Reden von Emil du Bois-Reymond in zwei Bänden, vol. 2. Veit und Comp., Leipzig, p. 249–284

Bourguet MN (2002) Landscape with numbers: Natural history, travel and instruments in the Late Eighteenth and Early Nineteenth Century. In: Bourguet MN, Licoppe C, Sibum HO (eds.) Instruments, travel and science: itineraries of precision from the seventeenth to the twentieth century, 96–125. Routledge, London, New York

Bourguet MN (2015) „Enfin M. H…" – Ein botanisches Duell mit stumpfen Degen in Paris nach 1800. In: Blankenstein D, Leitner U, Päßler U, Savoy B (eds), „Mein zweites Vaterland". Alexander von Humboldt und Frankreich. Walter de Gruyter, Berlin, Boston, p. 113–130

Bruhns K (ed) (1872) Alexander von Humboldt. Eine wissenschaftliche Biographie. 3 vols. Veit und Comp., Leipzig (English: Life of Alexander Humboldt, transl. Lassell J and Lassell C, London 1873)

Buttimer A (2001) Beyond Humboldtian science and Goethe's way of science: Challenges of Alexander von Humboldt's geography. Erdkunde 55(2): 05–120

Cannon SF (1978) Science in culture. The early Victorian period. Dawson and Science History Publications, New York, p. 73–110

Cunningham A, Jardine N (eds) (1990) Romanticism and the sciences. Cambridge University Press, Cambridge

Darwin, C. 1859. On the origin of species. London: Macmillan.

Daum A (2000) Alexander von Humboldt, die Natur als 'Kosmos' und die Suche nach Einheit. Zur Geschichte von Wissen und seiner Wirkung als Raumgeschichte. Berichte zur Wissenschaftsgeschichte 23:243–268

Dettelbach M (1996) Humboldtian Science. In: Jardine N, Secord JA, Spary EC (eds), Cultures of natural history. Cambridge University Press, Cambridge, p. 287–304

Dettelbach M (1999) The face of nature: Precise measurement, mapping, and sensibility in the work of Alexander von Humboldt. Studies in History and Philosophy of Biological and Biomedical Science 30(4):473–504

Dettelbach M (2001) Alexander von Humboldt zwischen Aufklärung und Romantik. In: Ette O (ed) Alexander von Humboldt. Aufbruch in die Moderne. de Gruyter, Berlin, p. 137–152

Ebach MC (2015) Origins of Biogeography: The Role of Biological Classification in Early Plant and Animal Geography. Springer, Dordrecht

Egerton F N (1970) Humboldt, Darwin, and population. Journal of the History of Biology 3:325–360

Ette O (2009a) Alexander von Humboldt und die Globalisierung. Das Mobile des Wissens. Insel Verlag, Frankfurt a.M.
Ette O (2009b) Die Insel als Welt. Alexander von Humboldt auf Tenerife. In: Gebauer A Alexander von Humboldt. Seine Woche auf Teneriffa 1799. Zech, Santa Ursula
Ette O (ed) (2018a) Alexander von Humboldt-Handbuch. Leben – Werk – Wirkung. Metzler, Stuttgart
Ette O (2018b) Leben in Bewegung. In: Ette O (ed) Alexander von Humboldt-Handbuch. Leben – Werk – Wirkung. Metzler, Stuttgart, p. 10–19
Ette O (2019) Alexander, Wilhelm und die Wissenschaft(en) der Humboldts. In: Blankenstein D, Savoy, B, Gross R, Scriba A (eds) Wilhelm und Alexander von Humboldt. Deutsches Historisches Museum, Berlin (Wissenschaftliche Buchgesellschaft, Darmstadt), p. 223–229
Fattorini S, Di Biase L, Chiarucci A (2019) Recognizing and interpreting vegetational belts: New wine in the old bottles of a von Humboldt’s legacy. Journal of Biogeography 46:1643–1651
Feuerstein-Herz P (2006) Der Elefant der Neuen Welt. Eberhard August Wilhelm von Zimmermann (1743–1815) und die Anfänge der Tiergeographie. Braunschweiger Veröffentlichungen zur Pharmazie- und Wissenschaftsgeschichte, 45. Deutscher Apotheker Verlag, Stuttgart
Giraud-Soulavie JL (1780–1784) Histoire naturelle de la France méridionale, ou recherches sur la Minéralogie. t. 1–8. J.-F. Quillau, Paris (C. Belle, Nimes)
Glaubrecht M (2000). A look back in time: Toward an historical biogeography as synthesis of systematic and geologic patterns outlined with limnic gastropods. Zoology: Analysis of Complex Systems 102:127–147
Glaubrecht M (2009) Es ist als ob man einen Mord gesteht. Ein Tag im Leben von Charles Darwin. Herder, Freiburg im Breisgau
Glaubrecht M (2013) Am Ende des Archipels. Alfred Russel Wallace. Galiani, Berlin
Glaubrecht M (2014) Die naturkundliche Entdeckung Brasiliens und des „Flusses der Amazonen“. Teil 2. Naturwissenschaftliche Rundschau 67 (7):342–356
Glaubrecht M (2016a) Alexander von Humboldt wird zum Ökobaron. Die Welt, Literarische Welt 11 December 2016
Glaubrecht M (2016b) Überschätzter Universalgelehrter. Eine neue Biographie verklärt den Naturforscher“. Der Tagesspiegel 28 December 2016
Glaubrecht M (2019a) „Un peu de géographie des animaux“. Die Anfänge der Biogeographie als „Humboldtian science“. In: Ette O (ed) edition humboldt digital. Berlin-Brandenburgische Akademie der Wissenschaften, Berlin. https://edition-humboldt.de/v5/H0017686 [In print published in: Päßler U (ed) (2020) Alexander von Humboldt: Geographie der Pflanzen. Unveröffentlichte Schriften aus dem Nachlass, J. B. Metzler, Stuttgart, p. 155–194]
Glaubrecht M (2019b) Alexander von Humboldts Tierleben. Vom Fettschwalm, Manati und Zitteraal. In: Lubrich O, Nehrlich T (eds) Alexander von Humboldt: Sämtliche Schriften (Aufsätze, Artikel, Essays), Berner Ausgabe. Deutscher Taschenbuch Verlag, München, p. 343–382
Glaubrecht M (2019c) Wer erklärt uns die Natur? Alexander von Humboldt oder Charles Darwin. Geo 11/2019:30–51
Glaubrecht M (2019d) Das Ende der Evolution. Der Mensch und die Vernichtung der Arten. C. Bertelsmann, München
Glaubrecht M (2020) „Un peu de géographie des animaux“. Die Anfänge der Biogeographie als „Humboldtian Science“. In: Päßler U (ed) Alexander von Humboldt: Geographie der Pflanzen. Unveröffentlichte Schriften aus dem Nachlass. Metzler, Stuttgart, p. 155–194
Glaubrecht M (2021) Humboldts Wissenschaft. Oder: Die Systematisierung und Dynamisierung der Natur. In: Lubrich O (ed) Alexander von Humboldt: Wissenschaften zusammendenken. Berner Universitätsschriften. Haupt Verlag, Bern, p. 207–243
Götz C (2019) Linnés Normen, Willdenows Lehren und Bonplands Feldtagebuch. Die Pflanzenbeschreibungen in Alexander von Humboldts erstem Amerikanischen Reisetagebuch. In: edition humboldt digital, Ette O (ed). Berlin-Brandenburgische Akademie der

Wissenschaften, Berlin, version 5, 11.09.2019. URL: https://edition-humboldt.de/v5/H0016429, Abs. 48–61
Gretenkord B (ed) (2003) Reise zur Mitte der Welt. Die Geschichte von der Suche nach der wahren Gestalt der Erde. Thorbecke, Stuttgart
Haeckel E (1866) Generelle Morphologie der Organismen. Reimer, Berlin
Hard, G. 1969. 'Kosmos' und, Landschaft'. Kosmologische und landschaftsphysiognomische Denkmotive bei Alexander von Humboldt und in der geographischen Humboldt-Auslegung des 20. Jahrhunderts. - In: Pfeiffer, H. (ed), Alexander von Humboldt. Werk und Weltgeltung, München: Piper 1969, p. 133–177
Hawkins B A (2001) Ecology's oldest pattern? Trends in Ecology and Evolution 16(8):470
Hestmark G. (2019) On the altitudes of von Humboldt. Proceedings of the National Academy of Sciences 116(26):12599–12600
Hey'l (2007). Das Ganze der Natur und die Differenzierung des Wissens. Alexander von Humboldt als Schriftsteller. de Gruyter, Berlin, New York
Humboldt A (1807) Essai sur la géographie des plantes. Paris. [German: Ideen zu einer Geographie der Pflanzen nebst einem Naturgemälde der Tropenländer. Cotta, Tübingen; Reprint in: Beck H (ed) (2008) Alexander von Humboldt. Darmstädter Ausgabe. vol 1, 72–161. Second, revised edition. Wissenschaftliche Buchgesellschaft, Darmstadt]
Humboldt (1808) Ansichten der Natur. Cotta, Tübingen
Humboldt A (1814–1825) Relation historique du voyage aux régions équinoxiales du nouveau continent. F. Schoell, Paris [German: Reise in die Äquinoktial-Gegenden des Neuen Kontinents. Reprint in: Ette O (ed) (1991). 2 vols. Insel Verlag, Frankfurt am Main, Leipzig]
Humboldt (1845–1862) Kosmos. Entwurf einer physischen Weltbeschreibung. 5 vols. Cotta, Stuttgart, Tübingen. (Reprint edited by Ette O and Lubrich O, Frankfurt a.M. 2004)
Humboldt A (2006) Ueber einen Versuch den Gipfel des Chimborazo zu ersteigen. Mit dem vollständigen Text des Tagebuches „Reise zum Chimborazo". Mit einem Esay versehen von Oliver Lubrich, Ottmar Ette (eds). Eichborn, Frankfurt am Main
Jackson S T (2009a) Alexander von Humboldt and the general physics of the Earth. Science 324:596–597
Jackson S T (2009b) Alexander von Humboldt and Aimé Bonpland. Essay on the geography of plants. Edited with an introduction. Translated by Sylvie Romanowski. University of Chicago Press, Chicago
Jardine N, Secord JA, Spary EC (eds) (1996) Cultures of natural history. Cambridge University Press, Cambridge, Mass.
Jespersen PH (1946) J.C. Fabricius as an evolutionist. Svenska Linné-Sällskapets Arsskrift 29:35–56
Juárez-Barrera F, Bueno A, Morrone JJ, Barahona A, Espinosa D (2018) Recognizing spatial patterns of biodiversity during the nineteenth century: The roots of contemporary biogeography. J. Biogeo 45:995–1002
Kabat, AR (2017) [Book Review] Invention of Nature. Archives of Natural History 44(1):183–184
Kehlmann D (2005) Die Vermessung der Welt. Rowohlt, Reinbek (English translation 2006. Measuring the world. Pantheon Books)
Klein U (2012) The Prussian mining official Alexander von Humboldt. Annals of Science 69:27–68
Klein U (2015) Humboldts Preußen. Wissenschaft und Technik im Aufbruch. Wissenschaftliche Buchgesellschaft, Darmstadt
Knobloch E (2011) Alexander von Humboldts Naturgemälde der Anden. In: Markschies C, Reichle I, Brüning J, Deutlhard P (eds) Atlas der Weltbilder. Akademie Verlag, Berlin, p. 295–305
Köchy K (2002) Das Ganze der Natur. Alexander von Humboldt und das romantische Forschungsprogramm. Humboldt im Netz 3(5):1–16
König C (1895) Die historische Entwicklung der pflanzengeographischen Ideen Humboldts. Naturwissenschaftliche Wochenschrift 10:77–81, 95–98, 117–124

La Condamine CM (1751) Journal du Voyage fait par ordre du roi á l’équateur servant d’introduction historique a la mesure des trois premiers degres du meridien. Imprimerie Royale, Paris

Lack HW (2003) Alexander von Humboldt und die botanischen Sammlungen in Berlin. Algorismus. Studien zur Geschichte der Mathematik und der Naturwissenschaften 41:107–132

Lack HW (2009) Alexander von Humboldt und die botanische Erforschung Amerikas. Prestel, München

Larson J (1986) Not without a Plan: Geography and Natural History in the Late Eighteenth Century. Journal of the History of Biology 19:447–488

Leask N (2003) Darwin’s ‘Second Sun’: Alexander von Humboldt and the Genesis of The Voyage of the Beagle. In: Small H, Tate T (eds) Literature, Science, Psychoanalysis, 1830–1970. Oxford University Press, Oxford, p. 13–36

Lepenies W (1976) Das Ende der Naturgeschichte. Wandel kultureller Selbstverständlichkeiten in den Wissenschaften des 18. und 19. Jahrhunderts. Hanser Verlag, München

Lubrich O (2009) Die andere Reise des Alexander von Humboldt. In: Lubrich O (ed) Alexander von Humboldt. Zentral-Asien. Das Reisewerk zur Expedition von 1829, Fischer, Frankfurt am Main, p. 845–885

Lubrich O (2014) Alexander von Humboldt. Das graphische Gesamtwerk. Lambert Schneider, Darmstadt

May W (1904) Goethe – Humboldt – Darwin – Haeckel. Vier Vorträge. Quehl, Berlin

May W (1911) Alexander von Humboldt und Charles Darwin. Breitenbach, Brackwede

Moret P, Muriel, P, Dangles O (2019a) Humboldt’s Tableau Physique revisited. Proceedings of the National Academy of Sciences 116:12889–12894

Moret P, Muriel, P, Jaramillo R, Dangles O (2019b) Humboldt’s historical data are not messy, they just need expert examination. Proceedings of the National Academy of Sciences 116:21348–21349

Morrison DA (2016) [Book Review] The Invention of Nature. Systematic Biology 65(6):1117–1119

Morueta-Holme N, Engemann K, Sandoval-Acuña P, Jonas JD, Segnitz RM, Svenning JC (2015) Strong upslope shifts in Chimborazo’s vegetation over two centuries since Humboldt. Proceedings of the National Academy of Sciences 112:12741–12745

Morueta-Holme N, Engemann K, Sandoval-Acuña P, Jonas JD, Segnitz RM, Svenning JC (2019) Resurvey of Antisana supports overall conclusions of Chimborazo study. Proceedings of the National Academy of Sciences 116:21346–21347

Müller-Wille S, Böhme K (2020). “Jederzeit zu Diensten”. Karl Ludwig Willdenows and Carl Sigismund Kunths Beiträge zur Pflanzengeographie Alexander von Humboldts. In: Päßler U (ed) Alexander von Humboldt: Geographie der Pflanzen. Unveröffentlichte Schriften aus dem Nachlass, J. B. Metzler, Stuttgart, p. 75–108

Nicolson M (1987) Alexander von Humboldt, Humboldtian science, and the origin of the study of vegetation. History of Science 25:169–194

Nicolson M (1996) Humboldtian plant geography after Humboldt: the link to ecology. British Journal for the History of Science 29: 289–310

Norder S J (2019) Alexander von Humboldt (1769–1859): Connecting geodiversity, biodiversity and society. Journal of Biogeography 46(8):1627–1630

Osterhammel J (1999) Alexander von Humboldt: Historiker der Gesellschaft, Historiker der Natur. Archiv für Kulturgeschichte (81,1):105–132

Päßler U (2018a) Im freien Spiel dynamischer Kräfte. Pflanzengeographische Schriften, Manuskripte und Korrespondenzen Alexander von Humboldts. In: Ette O (ed) edition humboldt digital. Berlin-Brandenburgische Akademie der Wissenschaften, Berlin

Päßler U (2018b). Darwin. In: Ette O (ed) Alexander von Humboldt-Handbuch. Leben – Werk – Wirkung. Metzler, Stuttgart, p. 247–250

Päßler U, Werner P (2009) ‘Sie haben eine schöne Karriere vor sich’: Der erhaltene Briefwechsel zwischen Alexander von Humboldt und Charles Darwin aus der Staatsbibliothek zu Berlin und der Cambridge University Library. Eine Dokumentation. Staatsbibliothek zu Berlin, Berlin

Pratt ML (1992) Imperial Eyes. Travel writing and transculturation. Routledge, London
Ramakers G (1976) Die "Géographie des Plantes" des Jean-Louis Giraud-Soulavie (1752–1813). Ein Beitrag zur Problem- und Ideengeschichte der Pflanzengeographie. Die Erde 107:8–30
Raven PH, Gereau RE, Phillipson PB, Chatelain C, Jenkins CN, Ulloa Ulloa C (2020) The distribution of biodiversity richness in the tropics. Science Advances 6:eabc6228
Rupke NA (2008) [2005] Alexander von Humboldt. A metabiography. University of Chicago Press, Chicago
Schmuck T (2014) Humboldt, Baer und die Evolution. Humboldt im Netz 15(29):83–89
Schrodt, F, Santos, MJ, Bailey, JJ, Field, R. (2019) Challenges and opportunities for biogeography – What can we still learn from von Humboldt? J Biogeogr 46:1631–1642
Wallaschek M (2016) Zoogeographie in Werken Alexander von Humboldts (1769–1859) unter besonderer Berücksichtigung der wissenschaftlichen Beziehungen zu Eberhard August Wilhelm von Zimmermann (1743–1815). Beiträge zur Geschichte der Zoogeographie 5. Eigenverlag des Autors, Halle (Saale) (online https://www.evsa.de/images/evsa/PDF/Wallaschek_Fragmente/Beitr%C3%A4geGeschichteZoogeographie5.pdf)
Weigl E (2004) Wald und Klima: Ein Mythos aus dem 19. Jahrhundert. Alexander von Humboldt im Netz. Internationale Zeitschrift für Humboldt-Studien 5(9):22–49
Werner P (2009) Zum Verhältnis Charles Darwins zu Alexander von Humboldt und Christian Gottfried Ehrenberg. Humboldt im Netz 10(18):68–95
Werner P (2010) Charles Darwin und Alexander von Humboldt. Sitzungsberichte der Leibniz-Sozietät der Wissenschaften zu Berlin 105:107–121
Wolter JA (1972) The height of mountains and the lengths of rivers. The Quarterly Journal of the Library of Congress 29(3):186–205
Wulf A (2015) The invention of nature. The adventures of Alexander von Humboldt, the lost hero of science. John Murray, London
Zimmermann EAW (1778–1783) Geographische Geschichte des Menschen, und der allgemein verbreiteten vierfüßigen Thiere. Nebst einer hieher gehörigen Zoologischen Weltcharte. 3 vols. Weygand, Leipzig

Matthias Glaubrecht evolutionary systematist and historian of science, is Professor for Biodiversity of Animals and Director of the Center of Natural History at the University of Hamburg. During his internationally renowned research on gastropods, he also finds time to report for news magazines such as Die Zeit, Der Tagesspiegel or Frankfurter Allgemeine Zeitung and has published numerous successful popular science books.

Trendsetting - Observation of Interactions in the Earth System

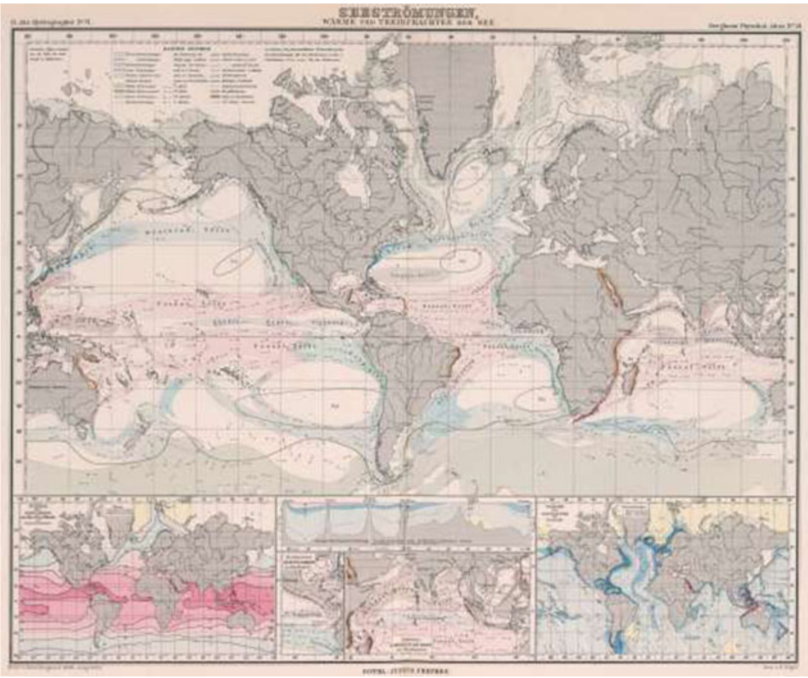


Fig. 1 Seestroemungen, warme und treibfrachte der see. Entw. v. Herm. Berghaus 1888, Ausg. 1889. Gest. v. F. Kogel. Gotha: Justus Perthes. (On upper margin) II. Abt. Hydrographie No. VI. Berghaus' physikal Atlas No. 21. Atlas der Hydrographie. (Berghaus' physikalischer Atlas, Abteilung II). (to Accompany) Berghaus' Physikalischer Atlas. (Begruendet 1836 durch Heinrich Berghaus) … Gotha: Justus Perthes. 1892. (insets) Waerme des Seewassers an der Oberflache. (with) Mexikanisches Monsun-Gebiet im Nordwinter. (with) Indisches Monsun-Gebiet im Nordwinter. (with) Waerme des Seewassers am Grunde. (David Rumsey Collection)

Alexander von Humboldt and Earth System Science

Stefan Brönnimann

Abstract Alexander von Humboldt is often depicted as a pioneer of "Earth System Science". He seems to have anticipated many of the current concepts of Earth System Science and described them in an accurate language. These concepts include the interconnectedness of the system, the human influence on it as well as consequent repercussions for humans. Alexander von Humboldt's "Earth System thinking" also expressed itself in the methodologies used and is an important basis of Humboldt's empiricism. Only an accurate notion of the Earth System allows to make optimal use of the myriads of individual observations collected by Humboldt. Moreover, his graphical depictions of the Earth System allowed him "drawing" conclusions. However, claiming Humboldt to be the first Earth System scientists is also a projection of our current view back onto Humboldt, all the more as there has been no continuity. Current Earth System Science developed independently, from different precedents and in a different scientific context. It has important roots in the 1950s, perhaps with Vernadsky as an even earlier forerunner, but developed mainly in the 1980s, without reference to Humboldt. Conversely, Humboldt's notion was broader than current Earth System Science in that it included sensual and aesthetical aspects and linked science to the human experience.

Keywords Climatology · Earth system sciences · Anthropogenic influence

S. Brönnimann (✉)
Institute of Geography and Oeschger Centre for Climate Change Research,
University of Bern, Bern, Switzerland
e-mail: stefan.broennimann@giub.unibe.ch

G. C. Falk et al. (eds.), *Alexander von Humboldt*,
https://doi.org/10.1007/978-3-030-94008-9_2

Introduction

From today's perspective, Alexander von Humboldt is often seen as a forerunner of Earth System thinking (Jackson 2009).[1]

At a time when man-made environmental changes such as global climate change, the threat to biodiversity or the contamination of soils and food are among the problems perceived as most urgent, Earth System thinking is called for (Steffen et al. 2020). None of these problems can be grasped—let alone solved—by considering an object in isolation. Climate change due to an increase in atmospheric greenhouse gases is not only expressed in raising air temperature. Also the oceans warm and they acidify, while polar ice sheets and glaciers melt and precipitation and dry zones shift (IPCC 2014). The loss of biodiversity is related to altered living conditions for animals and plants. In addition to climatic factors, these include increased pressure on land, the use of chemicals in food production, the fragmentation of habitats, overexploitation, and many others (IPBES 2019). The use of chemicals in agriculture and in industry as well as the transport of pollutants or microplastics (e.g. Scheurer and Bigalke 2018) via the atmosphere contaminates our soils. Some of these substances ultimately find their way into our food or drinking water via plants or animals (e.g. Wang et al. 2017).

In all three examples, different phenomena operating in different environments that are traditionally scientifically and spatially separated, are inextricably linked. Conceptualising these links and making them accessible to scientific study and eventually to problem-solving strategies are the core of Earth System thinking. Did Alexander von Humboldt have this thinking, as is often posited based on his notion that "everything is mutual interaction" ("alles ist Wechselwirkung")? According to the preface of his *Kosmos* (Humboldt 1845), his "main impetus was the endeavour to understand the phenomena of the physical world in their general context: nature as a whole, moved and animated by inner forces".[2] Numerous similar quotes could be added.

In this contribution I will show that we indeed find in Humboldt's work many aspects resembling current Earth System thinking (see Strobl 2019; Brönnimann and Claussen 2022, for more general overviews of Humboldt and climatology). However, current Earth System Sciences developed 150 years later, largely independently from Humboldt's thinking. Conversely, looking at Humboldt's work from the present does not do justice to his view of embracing nature with all senses, which is an important part of his understanding.

[1] This article partly draws from a book chapter published in German (Brönnimann 2021).

[2] Was mir den Hauptantrieb gewährte, war das Bestreben, die Erscheinungen der körperlichen Dinge in ihrem allgemeinen Zusammenhange, die Natur als ein durch innere Kräfte bewegtes und belebtes Ganzes aufzufassen.

Humboldt's Earth System Science

Earth System Science

In a recent note I argued that Humboldt indeed clearly expressed concepts that resemble current Earth System thinking (Brönnimann 2021). A very good example for this is a climate definition that can be found in the *Kosmos*:

> The word climate designates a specific nature of the atmosphere, but this nature is dependent on the perpetual interaction of the ocean surface, which is in steady motion and characterised by currents of very different temperatures, with the radiating land surface, which has a complex structure, is elevated, coloured, bare or covered with vegetation.[3] (Humboldt 1845: 304)

From a present-day perspective, this quote is an Earth System definition, the depiction of climate as the outcome of the workings of a system. Humboldt did not use the term system in this sense. However, his definition has all elements of an Earth System description: It defines the subsystems (atmosphere, ocean, land surface, biosphere), elements (currents) the spatial variability of properties across the elements (ocean temperature gradients, land surface heterogeneity), and the interaction between elements and subsystems through fluxes of mass, energy, and momentum. This is a perfectly apt, short description of an Earth System (Humboldt uses the term "das belebte Naturganze").

Today this system view is not just a definition or a heuristic tool, but is the basis of a mathematical description. This is realised, for instance, in the German ICON Earth System Model (Fig. 1). A mathematical description was, however, neither possible in the early nineteenth century (the first law of thermodynamics, for instance, was only formulated later), nor was Humboldt capable to produce one, although he highly admired mathematically expressed theories about the physics of the Earth (Knobloch 2019). Rather, Humboldt aimed at an understanding of nature as a whole that is accessible to human thinking; an empathic concept rather than a mathematical one.

Nevertheless, this understanding was based on an "appreciation for universal laws" (Jackson 2019), which remained the ultimate goal of his science. Amidst his overwhelming empiricism, Humboldt's writings often evidence a deep physical understanding of the processes. As an example, the following quote aptly describes the drivers of ocean currents:

> The ocean currents are animated by continuous winds, differences in the density of the more or less warmed or salty parts of the water, changes in barometric pressure, accumulation of water in the gulf (as in the Mexican) or disturbance of the level, through strong evaporation

[3] Das Wort Klima bezeichnet allerdings zuerst eine specifische Beschaffenheit des Luftkreises, aber diese Beschaffenheit ist abhängig von dem perpetuirlichen Zusammenwirken einer all- und tiefbewegten, durch Strömungen von ganz entgegengesetzter Temperatur durchfurchten Meeresfläche mit der wärmestrahlenden trockenen Erde, die mannigfaltig gegliedert, erhöht, gefärbt, nackt oder mit Wald und Kräutern bedeckt ist.

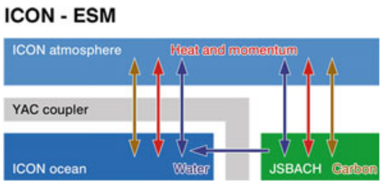


Fig. 1 Schematic depiction of the ICON Earth System Model with its submodules atmosphere, ocean, and land surface, coupled through fluxes of energy (heat), mass (water and carbon), and momentum. Humboldt's climate definition rather accurately depicts an Earth System such as sketched here (Max-Planck Institute for Meteorology)

> (as in the Mediterranean Sea), and finally, periodic melting of the polar ice. (…) The direction of flow is modified in manifold ways by the configuration of coasts, by the rotation of earth, when water masses move towards equator or poles only gradually take on the corresponding rotation speed, and by winds and counter currents.[4] (Humboldt 1837)

Although Humboldt did not arrive at a mathematical description of ocean currents, his description is precise and comprehensive and it applies his climate (or Earth System) definition to the problem of ocean currents.

As an interim conclusion, this section shows that Humboldt's climate definition given above accurately describes an Earth System according to its current definition, with its components and the interactions between them. Today this conceptual view forms the basis for Earth System models. A mathematical description was not attempted by Humboldt. Nevertheless, he accurately described many of the relevant Earth System processes, building on his definition.

Humans and the Earth System

Humans are part of the Earth System, in Humboldt's view as well as in the current view. This is another reason to argue for an Earth System thinking in Humboldt's work. In fact in Humboldt's view, humans were in the centre. This is also expressed in his famous climate definition given in his *Kosmos*:

[4] Die Meeresströmungen werden belebt durch anhaltend wehende Winde, Verschiedenheiten der spezifischen Schwere der mehr oder minder erwärmten oder salzigen Theile des Wassers, Veränderung des Barometer-Drucks, durch Anhäufung der Wasser im Meerbusen (wie im Mexikanischen) oder Störung des Niveaus, durch starke Verdunstung (wie im Mittelmeere), endlich durch periodisches Schmelzen des Polar-Eises (…). Die Richtung der Strömungen wird durch die Konfiguration der Küsten, durch die Rotation der Erde, wenn die Wassertheile im Fortschreiten gegen den Äquator oder gegen die Pole nur allmälig die jedem Breitengrade zugehörige Rotations-Geschwindigkeit annehmen, durch Winde und durch Gegenströmungen mannigfach modifizirt.

> The term climate in its most general sense refers to all changes in the atmosphere that noticeably affect our organs.[5] (Humboldt 1845: 340)

At the same time, humans also disturb the Earth System. Understanding the effects of human disturbance is a main goal of current Earth System Science, and it was an important element in Humboldt's work. The interconnections are manifold. Humans can exert a disturbance, but they also benefit from ecosystem services. Disturbances can reduce ecosystem services. An example of this thinking in Humboldt's work is his text on the causes of the drying-out of the endorheic lake Valencia in Venezuela (Fig. 2), which he eventually ascribed to the human interference, namely water use for irrigation and, in particular, deforestation (see Weigel 2004; Holl 2018). Generalising this experience, he wrote:

> If one destroys the forests, as the European settlers of all places in America do with careless haste, the springs dry up or diminish considerably. The riverbeds lie dry for part of the year and become torrential streams whenever heavy rain falls in the mountains. Together with the forests also grass and moss disappear on the mountain tops, the rainwater is no longer held back; instead of slowly feeding the streams through gradual infiltration, in the season of heavy rainfall it rips through the mountain slopes, washes away the torn soil and causes sudden floods that devastate the fields. From this it is clear that the destruction of the forests, the lack of continuously flowing springs and the existence of torrents are three phenomena that are causally related.[6] (Humboldt 1999: 638f)

Like in the three examples given in the Introduction, humans are the main actors on the environment, but they are also among the ones suffering from the decrease in ecosystem services. This dilemma was clearly laid out by Humboldt in the quote above. In another statement in the same text, he adds the term "future generations" and thus a notion of sustainability:

> By cutting down the trees that cover the tops and flanks of the mountains, men, in all climates, are generating for future generations two calamities at once, a lack of fuel and a shortage of water.[7] (Humboldt 1999: 638)

---

[5] Der Ausdruck Klima bezeichnet in seinem allgemeinsten Sinne alle Veränderungen in der Atmosphäre, die unsere Organe merklich afficiren.

[6] Zerstört man die Wälder, wie die europäischen Ansiedler aller Orten in Amerika mit unvorsichtiger Hast tun, so versiegen die Quellen oder nehmen doch stark ab. Die Flussbetten liegen einen Teil des Jahres über trocken und werden zu reissenden Strömen, sooft im Gebirge starker Regen fällt. Da mit dem Holzwuchs auch Rasen und Moos auf den Bergkuppen verschwinden, wird das Regenwasser in seinem Lauf nicht mehr aufgehalten; statt langsam durch allmähliches Einsickern die Bäche zu speisen, zerfurcht es in der Jahreszeit der starken Regenniederschläge die Berghänge, schwemmt das losgerissene Erdreich fort und verursacht plötzliche Hochwässer, welche die Felder verwüsten. Daraus geht hervor, dass die Zerstörung der Wälder, der Mangel an fortwährend fliessenden Quellen und die Existenz von Torrenten drei Erscheinungen sind, die in ursächlichem Zusammenhang stehen.

[7] Fällt man die Bäume, welche Gipfel und Abhänge der Gebirge bedecken, so schafft man in allen Klimazonen kommenden Geschlechtern ein zwiefaches Ungemach: Mangel an Brennholz und Wasser.

Fig. 2 Lake Valencia (Photo: Manuel Alberto Herrera Pereira, Wikimedia commons, CC). Humboldt's case study on the variations of the water level in the lake is seen by many as a cornerstone in environmental thinking

Though lack of fuel was no longer perceived as a problem by many of Humboldt's contemporaries (Weigel 2004), the quote is illustrative for its depiction of the dual position of humans in the system: cause of disturbance and beneficiary of multiple, interlinked ecosystem services.

Another example for Humboldt's thoughts on wide ranging human influence concerns the impact on climate, which for him clearly encompasses more than just runoff. In "Central Asia" (see Fig. 3), Humboldt provides a synthesis of snow line altitudes in different parts of the world and concludes the paragraph with a remarkable phrase:

> I could have concluded these reflections … with an examination of the changes of the land surface by humans through deforestation, through changes in river courses and through generating large masses of steam and gas at the centres of industry. These changes are undoubtedly more important than is generally assumed.[8] (Humboldt 1844: 214)

[8] Ich hätte diese Betrachtungen … mit einer Untersuchung der Veränderungen schliessen können, welche der Mensch auf der Oberfläche des Festlandes durch das Fällen der Wälder, durch die Veränderung in der Vertheilung der Gewässer und durch die Entwicklung grosser Dampf- und Gasmassen an den Mittelpunkten der Industrie hervorbringt. Diese Veränderungen sind ohne Zweifel wichtiger, als man allgemein annimmt.

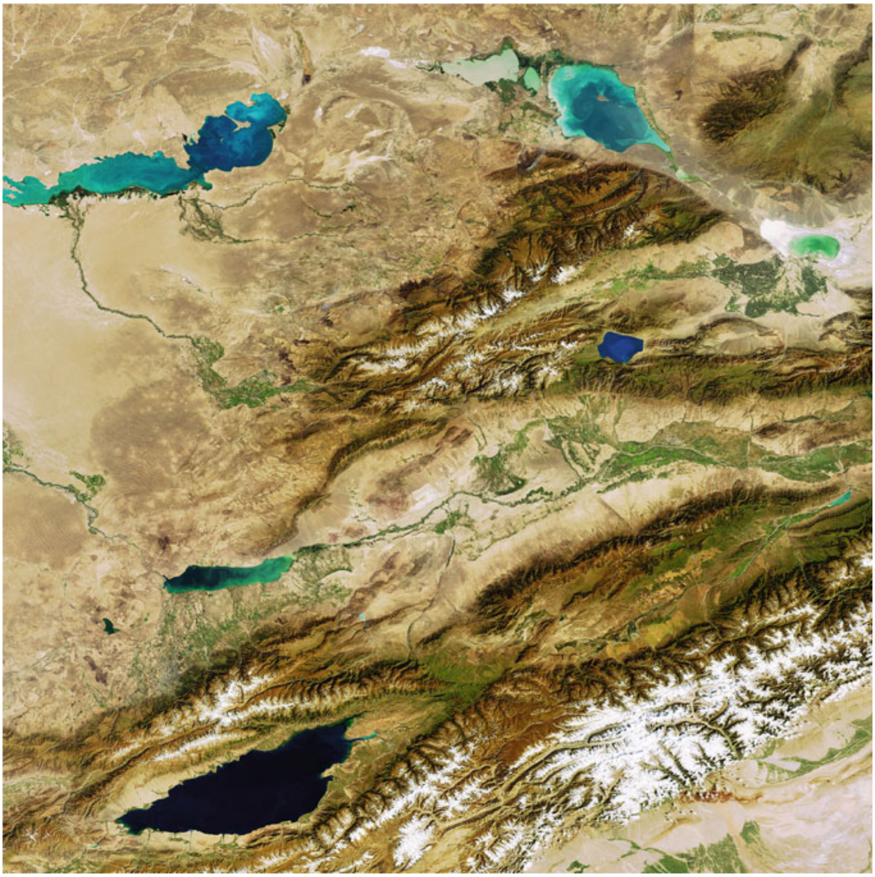


Fig. 3 A satellite view of lakes and mountain chains in Central Asia (south-eastern part of the Republic of Kazakhstan, north-eastern area of Kyrgyzstan). Image acquired on 12 September 2007 by ESA's Envisat's MERIS (Medium Resolution Imaging Spectrometer) instrument. *Source* Esa, www.esa.int/Our_Activities/Observing_the_Earth/Lakes_of_Central_Asia. Humboldt was interested in these lakes, but specifically also in the snowline altitude in Central Asia

He thus clearly identified land-use change, interventions in the water cycle, and emissions as climate factors. The description seems to refer to the regional scale and does not provide evidence for a global view. For a local perturbation, cause and effects are more directly linked and benefits and damages are felt in the same community. The notion of the possibility of a human influence on global climate (through emitting CO_2) only appeared around 1900 with Svante Arrhenius and others (Weart 2008). However, it is perhaps less the scale that matters here, but the fact that humans are affecting several connected components of the Earth System. In any case, the notion that "masses of steam and gas" might change the atmosphere is remarkable and new and arguably mirrors Humboldt's long-standing interest in the composition of the atmosphere.

The human effect on climate through land-use changes, in contrast, was not new. Humboldt himself had described this influence in a beautiful way already 35 years earlier (Humboldt 1809: 341):

> But humans, who plant herbs and cereals where forests used to stand, are gradually disturbing the original balance of the ocean of air.[9]

Obviously, Alexander von Humboldt was not the first to bring land-use change and climate together. The notion can be traced back to the Greek philosopher Theophrastus and was wide spread in the renaissance period (Glacken 1967, see also Weigel 2004). It became a dominant climate theory in the late eighteenth and early nineteenth centuries (see Brönnimann 2002). In 1771, Hugh Williamson had investigated the hypothesis that deforestation and reclamation were affecting the climate in North America (then an English colony) (Williamson 1771). In 1790, Abbé Mann linked this discussion with the question of climate change since ancient times and the role of deforestation in the Mediterranean (Mann 1790). A large number of studies followed on both sides of the Atlantic. In nineteenth-century Europe, deforestation was blamed to alter precipitation and lead to floods (or drought); discussions that were brought to a political level and even affected legislation, though discussed controversially by contemporarians (see discussion in Brückner 1890).

Today, land–atmosphere interactions and the effects of land-use change on climate are again in the spotlight of research (e.g. Seneviratne 2010). Land surface properties are increasingly seen as an important modulator of atmospheric processes, affecting the carbon cycle, the water balance, and the energy balance, but also affecting biodiversity and food production for humans. In terms of atmospheric feedbacks, land surface processes may amplify heat waves (e.g. Miralles et al. 2014), and these feedbacks may change in the future. Furthermore, changes of land use and land cover are considered as important drivers not just of biodiversity changes, but also of climate. Large-scale disturbances such as the Amazon fires in 2019 affect not only the regional climate, but also the continental water cycle and the global carbon cycle (Amigo 2020).

The intermediate conclusion of this section is that Humboldt's view of the role of humans resembles the view of current Earth System Science. Important here is the dual position of humans in the Earth System, interacting with different components and causing disturbances while at the same time suffering from decreasing ecosystem services. The example of Lake Valencia and the quote from "Central Asia" are clearly the expression of an interlinked thinking about nature, of

[9] [D]er Mensch aber, der Kräuter und Getraidearten dahin pflanzt, wo sonst Wälder standen, stört allmählig das ursprüngliche Gleichgewicht des Luftoceans.

the awareness of human disturbance, and of a notion of sustainability that is found in later ecological concepts and in today's Earth System concept.

Natural Drivers of Climatic Changes

Humans are not the only drivers of climatic changes. Humboldt saw the chaotic weather on the short time scale, human impacts on the regional scale, and gradual long-term changes evidenced in the history of the landscape. He tried to explain the distribution of plants from the historical development of the landscape, shaped by climatic forces. Like many others, he speculated on climate changes during Earth's history, being interested in the findings of fossils that (prior to the concept of continental drift) could not be explained with constant climate conditions. Like most other climatologists at the time, Humboldt did not see drivers of systematic secular changes. He saw the present as contingent on the history, but variability as such was not a primary topic.

Two aspects not addressed by Humboldt should briefly be mentioned here: Internal variability in the system such as El Niño/Southern Oscillation, and natural external forcing such as that caused by large tropical volcanic eruptions. The former is a product of internal system dynamics, of ocean currents of different temperature and their interaction with the atmosphere (e.g. Timmermann et al. 2018), as in Humboldt's climate definition. It concerns the cold ocean current at the coast of Peru, which Humboldt brought to the attention of the scientific world and whose effect on climate he studied carefully. He did not see or address the pronounced changes in this system that occur systematically over periods of 3–7 years. Although Humboldt described the seasonal warming of the sea-surface at the coast of Peru in northern winter and discussed specific phenomena such as occasional heavy precipitation in Peru (which we today associate with El Niño situations), he did not go further in making connections between the variability of the ocean and that of the atmosphere (Kortum 2002). He may have anticipated the importance, though, when writing:

> Only a physicist's stay of several years at this boundary, a true weather divide, would be able to satisfy us (…).[10] (Humboldt 1837: 579, see Kortum 2002)

Likewise, as to the role of volcanic eruptions, Humboldt did not link eruptions with climatic changes, despite his large interest in volcanism and his clear view of its role in the geological realms of the Earth System as a temporary imbalance. The Berghaus Atlas that accompanies Humboldt's *Kosmos* contains a map (shown in Fig. 4), which includes the ranges of the explosions of two massive eruptions, Tambora and Cosiguïna. This map is remarkable as today it is known that these two

[10] Nur der mehrjährige Aufenthalt eines Physikers an diesem Gränzpunkte, einer wahren Wetterscheide, würde uns befriedigen können (…).

Fig. 4 Map of volcanoes around the Pacific, from the Berghaus Atlas (see Berghaus 2014; David Rumsey Map Collection, Creative Commons). The map also shows the explosion range of the two eruptions, Tambora (1815) and Cosiguina (1835), which are today known to have affected global climate

eruptions (plus several more in the same period) caused global cooling, triggering the last phase of the so-called Little Ice Age (Brönnimann et al. 2019a). Humboldt did not make a link to climate, however. This link only emerged in the early twentieth century through the work of Humphreys (1913) and in the context of the discussion of the causes of ice ages. Today volcanic eruptions are seen as a major natural external forcing of the climate system (Robock 2000). Studying the effects of the Tambora eruption on climate and society is seen as a prime example of Earth System Science (Brönnimann and Krämer 2016; Raible et al. 2016).

Volcanoes took a central role in Humboldt's Earth System view. For him they were main actors in geological history (he long did not distance himself from the Neptunist perspective of his former teacher Werner, but eventually became an important Plutonist advocate, see Nehrlich and Strobl 2019), in shaping landscape and vegetation, and in the human spirit. He studied many volcanoes and published comparative studies, but did not address their effect on climate.

The intermediate conclusion of this section is that Humboldt, though being aware of climatic variations, of interaction between ocean and atmosphere, and obviously of the crucial role of volcanoes, did not address two of the most important drivers of climate variability: coupled ocean–atmosphere modes such as El Niño-Southern Oscillation, and the role of volcanic eruptions. Today, these two effects are key not only as climate processes—they are the most important climate mechanisms on interannual-to-decadal scales—but as examples of Earth System's workings.

Humboldt's Earth System Methods

Earth System thinking is about the connectedness of phenomena and processes. This also expresses itself in the methodologies used. In this section I briefly touch upon three methodological aspects of Humboldt's work in relation to Earth System thinking: "Earth Science" measurements, empiricism, and the role of graphical depictions.

Interconnected Measurement

The Earth System view allows gaining knowledge on one part of the system by measuring another. Humboldt was aware of that. He not only performed numerous individual measurements of latitude, pressure, temperature, air composition, and other variables, but he also saw their interconnections. In his paper "Experiment on astronomical refraction", Humboldt argues that the prism has become an equally valid tool to measure the composition of air as chemical methods:

> In this way, the mathematician could have long ago proved to the chemist, by simply measuring the angle of refraction, that atmospheric air does not contain 0.27 or 0.28 oxygen gas. In such an admirable way the natural phenomena are interlinked.[11] (Humboldt 1809)

Humboldt alludes to the fact that the refraction angle of light on an inclined path through a medium (one of the column in Humboldt's famous "Tableau" (Humboldt and Bonpland 1807)) depends on that medium and thus on the composition of the atmosphere (Fig. 5). This is important for astronomers, but Humboldt turns this around, following the today often-heard motto "one person's noise is another person's signal". Humboldt's suggested method to measure the composition of the atmosphere is widely used. Today, refraction angles measured by the Global Positioning System, for instance, are used to derive atmospheric humidity and other variables.

[11] Schon längst hätte auf diese Art der Mathematiker durch das blosse Messen eines Brechungswinkels dem Chemiker beweisen können, dass die atmosphärische Luft nicht 0.27 oder 0.28 Sauerstoffgas enthält; auf eine so bewundernswürdige Weise sind die Naturerscheinungen miteinander verkettet.

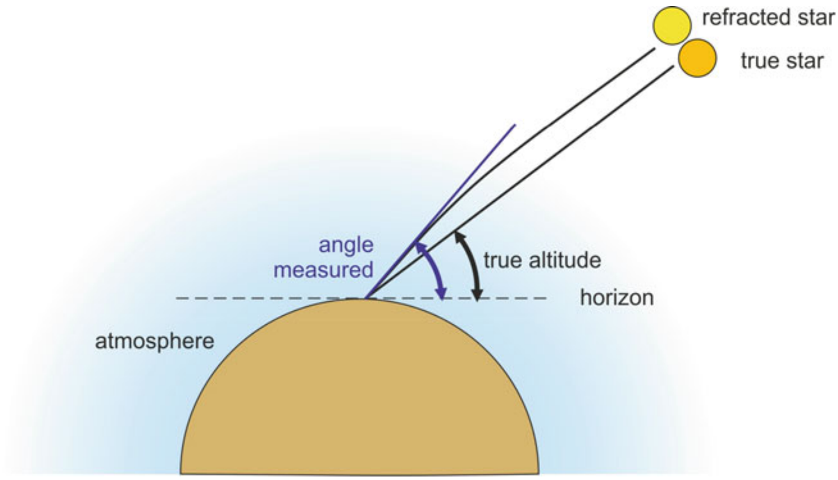


Fig. 5 Correcting for the effect of refraction is important for astronomical observations. Humboldt also saw in it an opportunity to study the composition of the air

Earth System Thinking as Basis of Empiricism

The Earth System view allows a complex interpretation of measurements. This directly relates to Humboldt's empiricism, which is shortly introduced in the following. Humboldt said of himself to be "obsessed with numbers" (Knobloch 2019). This trait is also depicted in the famous novel by Daniel Kehlmann "Die Vermessung der Welt" (Kehlmann 2005), where Humboldt's zealotry for numbers is contrasted with Gauss' theoretical approach. In fact, Humboldt, though admiring Laplace and the French mathematicians, was not a strong mathematician and did not aim at a mathematical description (see Sect. 2.1; Knobloch 2019). He expressed this in clear words:

> The empiricist counts and measures what the phenomena directly present. It is reserved to philosophy to understand what is common to all and to trace it back to principles.[12] (Humboldt and Bonpland 1807: 90)

Instead, Humboldt reverted to observing and collecting information, acknowledging that theories were laden with local contingencies, while still searching for broad principles (Jackson 2019, see also Knobloch 2018):

[12] Der Empiriker zählt und misst was die Erscheinungen unmittelbar darbieten. Der Philosophie ist es vorbehalten, das allen Gemeinsame aufzufassen und auf Prinzipien zurückzuführen.

> If an entangled phenomenon cannot be traced back to a general theory, then it is already a gain if one achieves to determine the numerical proportions by which a large number of scattered observations can be linked together, and to subject the influence of local causes of the disturbance to purely empirical laws.[13] (Humboldt 1853: 207)

At the same time, Humboldt's ultimate goal was to find principles. Despite his distinctively empirical approach, he was incessantly striving to understand the underlying mechanisms and complained that others remained purely descriptive and neglected "to trace the fundamental and universal laws of nature, which show themselves in the rapid change of phenomena and their interplay"[14] (Humboldt 1806). Empiricism, from sensual to instrumental, was important for his understanding of nature.

So, how does Humboldt's empiricism relate to Earth System thinking? Humboldt realised that spatially and temporally referenced data can be combined into a picture of the global Earth System from which principles, or at least mechanisms can be derived (Jackson 2019). But the process of combining scattered local observations already requires an Earth System understanding.

Collecting data does not automatically generate knowledge on the Earth System. Even the large amounts of data we gather today do not nearly give us a complete view of the Earth System. This is because the Earth System is huge and underdetermined. Constructing a complete picture of, say, the atmosphere from measurements is a big challenge even in the satellite era. These so-called ill-posed inverse problems are typically solved by combining the empirical data with prior information. For instance, weather charts are produced by combining observations with a weather prediction model.

Humboldt took great care that his collected data are theory independent. Nevertheless, an Earth System view is necessary to connect them. As an example, take Humboldt's attempt to draw the global temperature distribution. Even though Humboldt collected large amounts of temperature measurements, this was still a hugely insufficient basis for drawing a world temperature map. However, Humboldt made best use of it. In this text on isothermal lines (Humboldt 1817), he writes that, in the absence of long meteorological series, the October mean temperature should be closest to the annual mean. This allowed him to use even short records. To draw the map, it was further necessary to reduce temperatures to sea-level, which entails a concept of vertical temperature change.

[13] Kann man eine verwickelte Erscheinung nicht auf eine allgemeine Theorie zurückführen, so ist es schon ein Gewinn, wenn man das erreicht, die Zahlen-Verhältnisse zu bestimmen, durch welche eine grosse Anzahl zerstreuter Beobachtungen miteinander verknüpft werden können, und den Einfluss localer Ursachen der Störung rein empirischen Gesetzen zu unterwerfen.

[14] (…) den grossen und steten Naturgesetzen, die sich in dem raschen Wechsel der Erscheinungen zeigen, und dem Ineinanderwirken, gleichsam dem Kampfe der entzweiten Naturkräfte, nachzuspüren.

Graphical Methods

This brings us to a further important aspect. In the process of combining observations with process understanding to generate insights into the Earth System, e.g., the distribution of plants, graphical depictions played an important role. They condense empirical material in an overlookable form. However, the graphical depictions were not just illustrations of empirical material, but also a tool to generate knowledge (Böhme 2019). They require abstraction (such as the reduction of temperatures to sea-level) and generalisation (partitioning a noisy pattern, into error, local contingencies and large-scale Earth System processes). Doing this Humboldt was literally "drawing conclusions". Rightly, he considered his concept of isothermal lines one of the most important contributions to science. Lines subpartition areas into zones; isothermal lines intersect other lines or zones. Lines played an important role in Humboldt's ecological questions, such as the snow line or the tree line. Isothermal lines were therefore not only a graphical depiction, but an important method in its own right (Brönnimann 2019).

In summary, Humboldt saw phenomena as consequences of underlying forces, whose study must remain the ultimate goal of science. Capturing the phenomena at Humboldt's scale of interest—such as the global distribution of plants and of the snow line—requires not only measuring and collecting huge amounts of information, but also processing and digesting them. This requires system knowledge, a very conception of climate. Constructing a global temperature map from sparse data (sometimes not even covering an entire year) is an ill-posed inverse problem. Solving such problems requires a priori knowledge. Today we often use models and the theory embodied therein for that purpose. Humboldt used scientific intuition, empathy, and graphical methods, which are not only displays, but part of the method.

Fate of Humboldt's View

Humboldt's "Earth System" view did not prevail, despite the popularity of Humboldtian science in the nineteenth century. Analysing the fate of his two climate definitions, we may ask whether Humboldt himself is perhaps to blame for this development. Seeing the need for more and regular observations, he helped promoting geomagnetic, meteorological, and other geoscientific observation networks at the global and national scale. He helped initiating the Prussian meteorological network, and other countries followed this step. Empirical approaches were further facilitated and found an increasing data basis, whereas, at least in the case of meteorology and climatology, theoretical concepts were lagging far behind.

The following numbers illustrate the growth of climate data. Humboldt's original paper on isothermal lines was based on 58 stations. The "Berghaus Atlas"

(Berghaus 2014), some 30 years later, lists already over 300 sites with temperature measurements. Another decade later, Dove (1838, 1839, 1842, 1845, 1852) compiled a first global climate atlas for which he used ca. 1500 stations (see also Brönnimann et al. 2019b). Furthermore, from the second half of the nineteenth century onward, statistics developed new tools for science that allowed making better use of measurements. Methods such as correlation (Galton 1888) soon found their way into climatology (e.g. Walker 1910).

The statistical turn led to a new definition of climate. In 1883, Julius von Hann proposed a definition of climate as the statistics of weather:

> By climate we mean the entirety of meteorological phenomena that characterize the average state of the atmosphere at any point on the earth's surface.[15] (Hann 1883)

There is no longer the notion of Earth System components interacting with each other, and of climate as the outcome of the workings of a system as in Humboldt. The human being is not part of the definition. For practical reasons, the International Meteorological Organisation later recommended 30-year periods for calculating the average (only few longer series were available at that time), and 1901–1930 became the first standard period.

However, defining climate as the average over 30 years entails the notion of a stable climate, a stationary climate that can be described time-independently, its description only being limited by the availability of data. Except for dramatic changes in the distant past such as ice ages and except for local changes due to changes in the land surface, climate was considered stable. Only few scientists in the late nineteenth century, among them Brückner (1890), suggested systematic decadal or multidecadal changes (see Brönnimann 2015).

As a consequence of these developments, both climate definitions of Humboldt—the human-centred view of climate as all changes that affect humans as well as the "Earth System" view of climate as the outcome of a system—gave way to a statistical definition of Julius von Hann, which was then also followed by the International Meteorological Organisation. Even if Humboldt's original quote described what we today would call an Earth System, this view was discontinued already few decades after his death, in the nineteenth century.

Development of Current Earth System Science

Humboldt's Earth System Science is not the same as current Earth System Science. The latter also relates to system theory and the theory of system dynamics, which originates in the 1970s. Concepts like feedbacks or homeostasis were not laid out at the time of Alexander von Humboldt, terms like complexity and chaos had a

[15] Unter Klima verstehen wir die Gesamtheit der meteorologischen Erscheinungen, welche den mittleren Zustand der Atmosphäre an irgendeiner Stelle der Erdoberfläche charakterisieren.

different meaning, and tipping points were unknown to Humboldt. Certainly, balance (and temporary phases of imbalance) was a very important concept of his Earth System view. However, Humboldt did not have a theory of systems' behaviour. He did not constrain equations by balance assumptions.

Current Earth System Science is applying systems theory to the Earth System. It is rooted mostly in the 1980s, when in particular NASA advanced the concept (National Research Council 1986) both in the context of their Earth Observing System (EOS) as well as modelling and process studies (Steffen et al. 2020). Earth System Science then found its international breakthrough in the International Geosphere-Biosphere Programme (IGBP), which extended the already existing World Climate Research Programme (WCRP) and was later further expanded to include biodiversity (DIVERSITAS) and human dimensions (IHDP). Current Earth System Science considers itself a new science without historical precedents. At most, reference is sometimes given to Vernadsky's work (Vernadsky 1926). Mostly, later concepts such as John Lovelock's Gaia theory (Lovelock and Margulis 1974) or the "Limits to Growth" report (Meadows et al. 1972) are mentioned, but not Humboldt.

Clearly the concept originated, grew and matured in a completely different environment than that of the early nineteenth century. It was enabled by the International Geophysical Year 1957/58, the first "big science" (and "big data") project (Aronova et al. 2010, see also Edwards 2010), when global observing systems were put in place and modelling was about to become a new branch of Earth science, but it started only in the 1980s in a different societal, political, technical, and scientific context. With reference to Humboldt's Earth System view, we can clearly say that current Earth System Sciences did not evolve out of Humboldt's view.

Discussion and Conclusions

After having discussed to what extent current Earth System concepts can be found in Humboldt's thinking, we should turn the question around and ask ourselves what, then, was Humboldt's special view. Humans undoubtedly plays the most important role. We have already discussed the dual position of humans as a disturbing force of the Earth System and as beneficiary of ecosystem services, on which humans depend for survival. In Humboldt's writings, humans have a third, even more central role: Humans are the species that think about the environment, the species that experience the environment with all senses.

Nature is an aesthetic object, which in Humboldt always comes together with science. Or, as Jackson (2019) puts it, Humboldt was linking science with the broader human experience. At the same time, Humboldt's graphical depictions are aesthetic and communicate science with the means of arts. These aspects are not included in the present-day view of Earth science.

In summary, while we see many aspects of current Earth System Science seemingly anticipated by Humboldt—in *Kosmos* he describes an Earth System model in just two sentences, he studies human interference with the system and he uses Earth System thinking to analyse data and "draw" conclusions—this is also a back projection of our current view. Humboldt's view did not prevail, and Earth System Science was reinvented more than a century later in a different context, without reference to Humboldt.

References

Amigo I (2020) When will the Amazon hit a tipping point? Nature 578:505–507
Aronova E, Baker KS, Oreskes N (2010) Big Science and Big Data in Biology: From the International Geophysical Year through the International Biological Program to the Long Term Ecological Research (LTER) Network, 1957–Present. Historical Studies in the Natural Sciences 40:183–224
Berghaus H (2014) Physikalischer Atlas oder Sammlung von Karten, auf denen die hauptsächlichsten Erscheinungen der anorganischen und organischen Natur nach ihrer geographischen Verbreitung und Vertheilung bildlich dargestellt sind; zu Humboldt, Alexander von Kosmos, Entwurf einer physischen Weltbeschreibung, [Ette O, Lubrich O (ed)] Berlin
Böhme H (2019) Das Wissen der Künste. In: Lubrich O, Nehrlich T (ed) Alexander von Humboldt. Sämtliche Schriften. Vol. 10. p 589–632
Brönnimann S (2002) Picturing Climate Change. Clim Res 22:87–89
Brönnimann S (2015) Climatic changes since 1700. Springer, Advances in Global Change Research 55, 360 pp
Brönnimann S (2019) Dem Empiriker über die Schulter geschaut. Messen, Sammeln, Ordnen, Darstellen: Humboldts Umgang mit Klimadaten. GeoAgenda 2019(2):22–25
Brönnimann S (2021) «Perpetuirliches Zusammenwirken» – Das Klima als System. In: Bloch SK, Lubrich O, Steinke H (ed) Alexander von Humboldt – Wissenschaften zusammendenken. Haupt, Bern (Berner Universitätsschriften 62): 127–147
Brönnimann S, Claussen M (2022) Vorwort. In: Strobl M (ed) Humboldt, Alexander von Ueber die Hauptursachen der Temperatur-Verschiedenheit auf dem Erdkörper: Meteorologische und und Klimatologische Schriften. Wehrhahn Verlag, Hannover (in press)
Brönnimann S, Krämer D (2016) Tambora and the „Year Without a Summer" of 1816. A Perspective on Earth and Human Systems Science. Geographica Bernensia G90, https://doi.org/10.4480/GB2016.G90.01
Brönnimann S, Franke J, Nussbaumer SU et al (2019a) Last phase of the Little Ice Age forced by volcanic eruptions. Nature Geosci 12:650–656
Brönnimann S, Allan R, Ashcroft L et al (2019b) Unlocking pre-1850 instrumental meteorological records: A global inventory. Bull Amer Meteorol Soc 100:ES389–ES413
Brückner E (1890) Klimaschwankungen seit 1700, nebst Bemerkungen über die Klimaschwankungen der Diluvialzeit. Hölzel, Wien
Dove HW (1838) Über die nichtperiodischen Änderungen der Temperaturverteilung auf der Oberfläche der Erde. 1. Teil. Reimer, Berlin
Dove HW (1839) Über die nichtperiodischen Änderungen der Temperaturverteilung auf der Oberfläche der Erde. 2. Teil. Reimer, Berlin
Dove HW (1842) Über die nichtperiodischen Änderungen der Temperaturverteilung auf der Oberfläche der Erde. 3. Teil. Reimer, Berlin
Dove HW (1845) Über die nichtperiodischen Änderungen der Temperaturverteilung auf der Oberfläche der Erde. 4. Teil. Reimer, Berlin

Dove HW (1852) Die Verbreitung der Wärme auf der Oberfläche der Erde erläutert durch Isothermen, thermische Isanomalen und Temperaturcurven. 2. Aufl., Reimann, Berlin
Edwards PN (2010) A vast machine: Computer models, climate data, and the politics of global warming. MIT Press, Cambridge
Galton F (1888) Co-relations and their measurement, chiefly from anthropometric data. Proc Roy Soc London 45 135–145
Glacken C (1967) Traces on the Rhodian shore: nature and culture in western thought from ancient times to the end of the eighteenth century. University of California Press, Berkeley
Hann Jv (1883) Handbuch der Klimatologie. Engelhorn, Stuttgart
Holl F (2018) Alexander von Humboldt und der Klimawandel: Mythen und Fakten. HiN – Alexander von Humboldt im Netz 19(37):37–56
Humboldt Av (1806) Beobachtungen über das Gesetz der Wärmeabnahme in den höheren Regionen der Atmosphäre, und über die untern Gränzen des ewigen Schnees, Annalen der Physik 24:1–49
Humboldt Av (1809) Versuch über die astronomische Strahlenbrechung in der heißen Zone für Höhenwinkel unter 10°, insofern sie von der Wärmeabnahme abhängt. Annalen der Physik 31 (4):337–397
Humboldt Av (1817) Des lignes isothermes et de la distribution de la chaleur sur le globe. Annales de Chimie et de Physique 5:102–112
Humboldt Av (1837) Über die Meeresströmungen im allgemeinen und besonders über eine kalte Meeresströmung an der Westküste von Südamerika, in: Berghaus H (ed) Allgemeine Länder- und Völkerkunde, Vol 1, p 415–423, 575–583, 586–592, 610–611
Humboldt Av (1844) Central-Asien: Untersuchungen über die Gebirgsketten und die vergleichende Klimatologie. Kleemann, Berlin
Humboldt Av (1845) Kosmos. Versuch einer physischen Weltbeschreibung. Vol 1. Cotta, Tübingen
Humboldt Av (1853) Kleinere Schriften. Geognostische und physikalische Erinnerungen. Cotta, Stuttgart
Humboldt Av (1999) Reise in die Äquinoktial-Gegenden des Neuen Kontinents. [Ette O (ed)] Insel, Frankfurt a M
Humboldt Av, Bonpland A (1807) Ideen zu einer Geographie der Pflanzen. Cotta, Tübingen
Humphreys WJ (1913) Volcanic dust and other factors in the production of climatic changes, and their possible relation to ice ages. J Franklin Inst 176:131–160
IPBES (2019) Summary for policymakers of the global assessment report on biodiversity and ecosystem services of the Intergovernmental Science-Policy Platform on Biodiversity and Ecosystem Services. Díaz S, Settele J, Brondízio ES et al (eds). IPBES secretariat, Bonn
IPCC (2014) Climate Change 2014: Synthesis Report. Contribution of Working Groups I, II and III to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change. IPCC, Geneva
Jackson ST (2009) Alexander von Humboldt and the general physics of the Earth. Science 324:596–597
Jackson ST (2009) Humboldt for the anthropocene. Science 365:1074–1076
Kehlmann D (2005) Die Vermessung der Welt. Rowohlt, Leipzig
Knobloch E (2018) Naturwissenschaften. In: Ette O (ed) Alexander von Humboldt-Handbuch. J.B. Metzler, Stuttgart
Knobloch E (2019) Zahlenwissen. In: Lubrich O, Nehrlich T (ed) Alexander von Humboldt. Sämtliche Schriften. Vol. 10. p 535–558
Kortum G (2002) Alexander von Humboldt" als Name für Forschungsschiffe vor dem Hintergrund seiner meereskundlichen Arbeiten. HiN - Alexander von Humboldt im Netz 3(5):1–22
Lovelock JE, Margulis L (1974) Atmospheric homeostasis by and for the biosphere: the Gaia hypothesis. Tellus. A 26: 2–10
Mann (Abbé) (1790) Mémoire sur le changement successif de la température & du terroir des climats, avec des recherches sur les causes de ce changement. Historia et Commentationes Academiae Theodoro-Palatinae Physicum 6:82–111

Meadows DH, Meadows DL, Randers J, Behrens III WW (1972) The Limits to Growth; A Report for the Club of Rome's Project on the Predicament of Mankind. New York

Miralles D, Teuling A, van Heerwaarden C et al. (2014) Mega-heatwave temperatures due to combined soil desiccation and atmospheric heat accumulation. Nature Geosci 7:345–349

National Research Council (1986) Earth System Science: Overview: A Program for Global Change. Washington, DC: The National Academies Press. https://doi.org/10.17226/19210

Nehrlich T, Strobl M (2019) Bergwerke und Vulkane. In: Lubrich O, Nehrlich T (ed) Alexander von Humboldt. Sämtliche Schriften. Vol. 10, p 241–272

Raible CC, Brönnimann S, Auchmann R et al (2016) Tambora 1815 as a test case for high impact volcanic eruptions: Earth system effects. WIREs Climate Change 7:569–589

Robock A (2000) Volcanic eruptions and climate. Rev Geophys 38(2) 191–219

Scheurer M, Bigalke M (2018) Microplastics in Swiss Floodplain Soils. Environ Sci Technol 52:3591–3598

Seneviratne S (2010) Investigating soil moisture-climate interactions in a changing climate: A review. Earth-Science Reviews 99:125–161

Steffen W, Richardson K, Rockström J et al (2020) The emergence and evolution of Earth System Science. Nature Reviews, Earth and Envorinment 1:54–63

Strobl M (2019) Umwelt und Klima. In: Lubrich O, Nehrlich T (ed) Alexander von Humboldt. Sämtliche Schriften. Vol. 10, p 311–341

Timmermann A, An S, Kug J et al (2018) El Niño–Southern Oscillation complexity. Nature 559:535–545

Vernadsky V (1926) *Biosphera (The Biosphere),* Nauchnoe khimiko-technicheskoye izdatel'stvo (Scientific Chemico-Technical Publishing), Leningrad

Walker G (1910) Correlation in Seasonal Variations of Weather, II. Mem. India. Meteorol. Soc 21:22–45

Wang S, Wu W, Liu F et al (2017) Accumulation of heavy metals in soil-crop systems: a review for wheat and corn. Environ Sci Pollut Res 24:15209–15225

Weart SR (2008) The Discovery of Global Warming - A History. 2nd Edition. Harvard University Press, Cambdrige

Weigel E (2004) Wald und Klima: Ein Mythos aus dem 19. Jahrhundert. HiN – Alexander von Humboldt im Netz 5(9):80–99

Williamson H (1771) An attempt to account for the change of climate, which has been observed in the Middle Colonies in North-America. Trans Am Phil Soc 1:272–280

Stefan Brönnimann heads the Climatology Group at the Institute of Geography at the University of Bern. He and his team are also part of the Oeschger Center for Climate Research. Brönnimann and his research group process historical atmospheric data from the last century and use it to create three-dimensional data sets for the time period prior to the start of modern measurement series.

Humboldt's Influence on Bio-Geo-Sciences

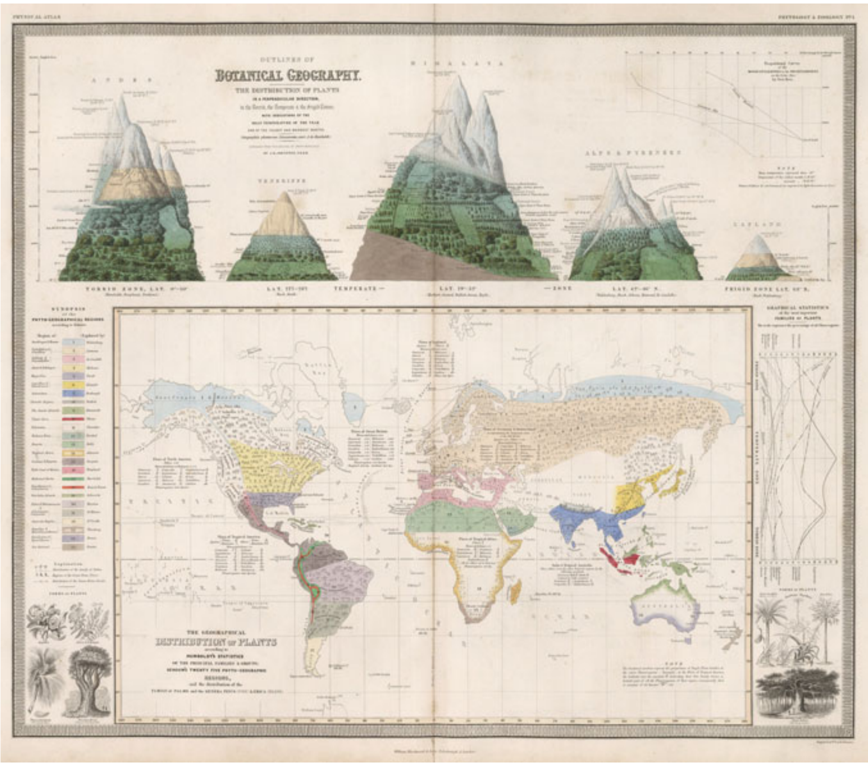


Fig. 1 The geographical distribution of plants. Outline of botanical geography, the distribution of plants in a perpendicular direction. By Johnston, Alexander Keith, 1804–1871; Humboldt, Alexander von. The physical atlas, a series of maps and illustrations of the geographical distribution of natural phenomena embracing: (I) geology, (II) hydrography, (III) meteorology, (IV) natural history. By Alexander Keith Johnston, F.R.G.S., F.G.S. geographer at Edinburgh to her majesty; honorary member of the Geographical Society, Berlin. William Blackwood & Sons … Edinburgh … London. 1850. (Courtesy of David Rumsey Collection)

Humboldt, Biogeography, and the Dimension of Time

Carina Hoorn, Jana Ebersbach, and Alexandra Muellner-Riehl

Abstract In the nineteenth century, Alexander von Humboldt and Alfred Russel Wallace laid out the basis for the field of biogeography, the discipline that studies the relation between organisms and their geographic distribution. Almost in parallel with the birth of biogeography, the foundations of geology were laid out, providing a dimension of time to spatial changes of the landscape. In this paper, we review the historical context of the early biogeographers and explore what the lasting significance of the nineteenth-century holistic research approach is in present research. We also discuss the historical context in which biogeography and geology developed, and how the concept of deep time, plate tectonics, and mountain building provided a broader perspective to biogeography. To illustrate the benefits of integrating geological and biological methods, we focus on the genesis and chronology of the elevational gradient, core to Humboldt's work. In particular, we use as example the evolution of two mountain systems, the Andes in South America, and the Tibet-Himalaya-Hengduan region in Asia. We conclude that in the nineteenth century, an interdisciplinary approach and progress in the different scientific fields led to a paradigm shift in the understanding of drivers of biogeography. Implementing such integrative vision today, and aided by advances in molecular phylogenetics and geology, has enabled biogeographers to form new, and more accurate, models of mountain building, climate, and species evolution. These models are particularly relevant in view of present scenarios of climate change and conservation strategies.

C. Hoorn (✉)
Institute for Biodiversity and Ecosystem Dynamics, University of Amsterdam, Science Park 904, 1098 XH Amsterdam, The Netherlands
e-mail: m.c.hoorn@uva.nl

J. Ebersbach · A. Muellner-Riehl
Department of Molecular Evolution and Plant Systematics and Herbarium (LZ), Institute of Biology, Leipzig University, Johannisallee 21-23, 04103 Leipzig, Germany

A. Muellner-Riehl
German Centre for Integrative Biodiversity Research (iDiv) Halle-Jena-Leipzig, Puschstraße 4, 04103 Leipzig, Germany

G. C. Falk et al. (eds.), *Alexander von Humboldt*,
https://doi.org/10.1007/978-3-030-94008-9_3

Keywords Biogeography · Evolution · Geology · Humboldt · Mountain geobiodiversity hypothesis

Introduction

Alexander von Humboldt (1769–1859) is one of the most famous explorers of all times (Rupke 2008; Wulf 2016; Daum 2019). Together with Aimé Bonpland, he ventured into the Amazon and later climbed the volcanoes in the Andes (Humboldt and Bonpland 1807). His integrative approach, meticulous data collection, and magnificent illustrations were unique at the time and made the concept of elevational and latitudinal gradients in plant geography available to a broader public (Nicolson 1987; Jackson 2009a, b, 2019).

In 2019, Humboldt's 250th birth anniversary was celebrated across the world, and scientists discussed the importance and impact of his work on the development of different scientific disciplines, and biogeography and ecology in particular (Daum 2019; Hoorn et al. 2019; Jackson 2019; Linder et al. 2019). Humboldt is known as one of the founding fathers of the field of biogeography, but what was Humboldt's historical context? And how does his work still inspire us today?

In this paper, we define the concepts of ecological and historical biogeography and explain the historical context in which biogeography developed. Although our focus is on plant geography, we also will refer to animal biogeography. First, we discuss the transition from "the species" as the prime object of study (early eighteenth century), to the perception of species as part of a larger entity, namely the geographic landscape that is controlled by abiotic variables (late eighteenth century). Towards the end of the eighteenth century, a renewed understanding of the dimension of time emerged, through the work of savants (as scientists were called then) such as Buffon, de Luc, and Hutton, but especially through Charles Lyell's publication on the "*Principles of Geology*" (1830–1833). It became clear that the age of the Earth transcended well beyond the biblical timescale that was accepted previously (Rudwick 2005). This enabled natural philosophers to integrate the time component in biogeography (Wallace 1863; Galli 2020), forming the basis of paleobiogeography (Lieberman 2000), and propelled Darwin to formulate the *Theory of Evolution by Natural Selection* (Darwin and Wallace 1858; Darwin 1859).

Towards the end of the nineteenth century, spatial changes over time (including mountain formation) and its influences on flora and fauna were widely debated (Oreskes 1999). In 1912, this culminated in the *Theory of Continental Drift*, proposed by Alfred Wegener, which suggested that in the past continents were configured differently than at present. However, his theory was controversial, and explanatory mechanisms remained elusive (Oreskes 1999). Finally, in 1960, the mechanism for continental drift was found, forming the basis for the *Theory of Plate Tectonic* (Hess 1960, 1962). This influential paradigm shift in geology proved transformative for biogeography, profoundly changing the perception of spatial changes over time (Raven and Axelrod 1974; Trewick 2016). At the turn of the millennium, new advances in both geology and molecular biology once more extended the horizons of biogeography, enabling scientists to view species diversification and the dynamic nature of geography and landscapes using time-calibrated phylogenetic trees (Renner 2005).

Here we follow Humboldt's conviction towards his final years of life that one would have to take a "higher stand" (Humboldt 1845) to fully understand nature (Wulf 2016). To honour Humboldt, we illustrate the value of the integrated approach that he advocated and place it into a temporal context. We explore the genesis of the elevational gradient in two mountain ranges, the Andes and Tibet-Himalaya-Hengduan (THH) in Asia, the former a cornerstone of Humboldt's own work, and the latter an inspiration for his own insights. Based on present-day knowledge, we summarize the geological, geographic, phylogenetic, and climatic factors that can explain characteristic distribution patterns of biodiversity. Some of such patterns Humboldt already observed in his time and popularized with his work.

What Is Biogeography?

Biogeography is a branch of science that attempts to document and understand spatial patterns of biological diversity. Traditionally, it has been defined as the study of the distribution of organisms, both past and present. In a more modern definition, biogeography includes the study of all patterns of geographic variation in nature, from genes to entire communities and ecosystems and of elements of biological diversity that vary across geographical gradients, including those of area, isolation, latitude, depth, and elevation (Lomolino et al. 2017).

With regard to the dimension of time, biogeography may be divided into two basic branches (de Candolle 1820; Morrone and Crisci 1995; Sanmartín 2012). "Ecological biogeography" studies the environmental factors shaping the distribution of individual organisms at local spatial scale, while "historical biogeography" aims to explain the geographic distribution of organisms in terms of their evolutionary history. The latter usually deals with the distribution patterns of species or higher taxa (e.g. genera or families), larger spatial scales (e.g. continental landmasses), and longer timescales (millions of years). Disciplinary boundaries have, however, become more blurred in recent years and may be viewed circumstantial. This may be exemplified by the relatively young discipline of phylogeography (Avise 2000), which addresses questions of historical biogeography in the more recent time period, often on finer spatial scales and influenced by the climatic variations of the Pleistocene. It studies the geographic distributions of genealogical lineages within species and among closely related species and attempts to distinguish between historical and current processes leading to the development of the observed patterns. Another example of both branches merging is the recently increasing incorporation of ecological information into biogeographic reconstructions through techniques like ecological niche modelling (Lieberman 2000; Stigall and Lieberman 2005) and new analytical statistical methods (Ronquist and Sanmartín 2011; Matzke 2018). Thus, while the division between ecological and historical biogeography may reflect the past predominance of narrative rather than analytical methods (Morrone and Crisci 1995), what we currently experience in the field of biogeography is that we may move towards a more holistic approach.

The beginnings of biogeography date back to a time when early naturalist explorers, such as Humboldt, and several before him, were intrigued by the fact that regions with similar climates exhibited faunas and floras with similar life forms, but in which the inhabiting species were very different. Conversely, continents in the Southern Hemisphere, such as South America, Africa, and Australia, separated by large geographic barriers like the Atlantic Ocean, showed faunas and floras of similar taxonomic composition. One well-known example of this type of disjunct geographic distribution for plants is that of Araucariaceae, an ancient family of conifers dating back to the Jurassic, with a modern distribution in southern South America, Malesia to Australia, and New Zealand (Stockey 1982; Escapa and Catalanot 2013). A famous example for animals is that of the flightless palaeognathous birds ("ratites"), including the ostriches, cassowaries, emus, rheas, and kiwis, distributed in all major southern continents (Sanmartín 2012; Mayr 2022). How did these plants and animals come to be scattered across different continents, separated by thousands of miles of ocean? These and other questions of historical biogeography have fascinated researchers since Humboldtian times, and even before, the history of which will be further outlined below.

Humboldt and the Birth of Biogeography

The field of biogeography started to become a genuine and integrative endeavour over the course of the eighteenth and early nineteenth centuries (Fig. 1). The time of European exploration to other parts of the world, primarily motivated by economic and political gain, enabled the first global-scale views of the natural world. The period proved foundational to the fields of geology, meteorology, evolutionary biology, and ecology, all of these ultimately contributing to a more integrative and holistic understanding of geographic variation of life, i.e. biogeography (Fig. 1). Many of the persistent themes central to modern biogeography have their origins in this pre-Darwinian period (Ebach 2015; Lomolino et al. 2017). As such, modern biogeography is "standing on the shoulders of giants" (Newton 1675), like those of Alexander von Humboldt.

Until the mid-eighteenth century, the prevailing belief was that Earth, its climate, and its species were immutable (Lomolino et al. 2017). However, two matters of concern emerged: first, the wealth of newly collected specimens of plants and animals during explorative expeditions deserved the development of a standardized and systematic scheme to classify those organisms. Second, it seemed important to establish how plants and animals, now isolated and adapted to dramatically different

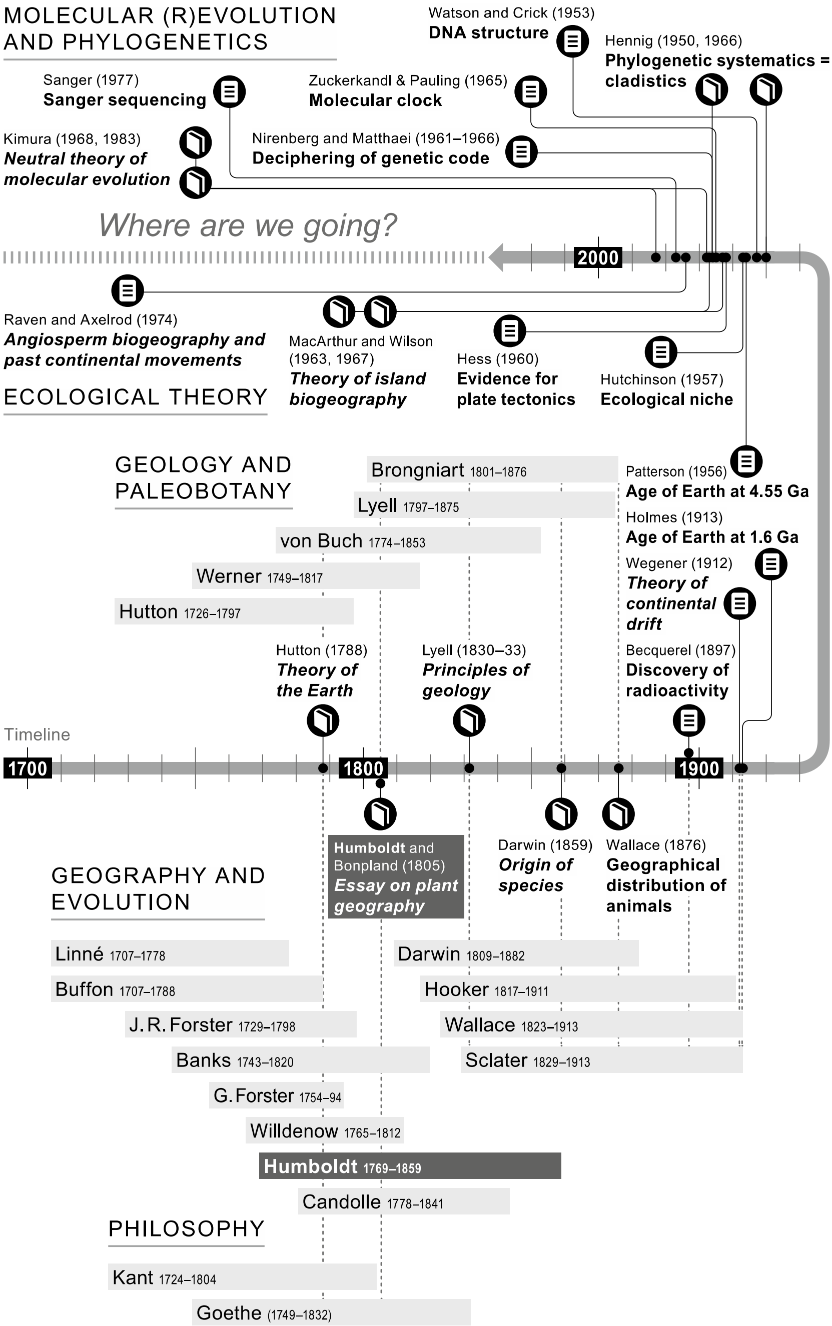


Fig. 1 Overview of key persons and key developments in the development of the field of historical biogeography

climates and environments, could have coexisted at the sites of their biblical origin. The first issue was solved by Linné (Carolus Linnaeus, 1717–1778), to whom we owe the establishment of the binomial nomenclature for naming plants and animals consistently, which is still in use today (Müller-Wille 1999). According to him, life forms would have been placed along the slopes of a paradisiacal mountain, like an island in the sea, and as the flood receded, life would have been distributed across the globe (Lomolino et al. 2017). Like several of his contemporaries, however, Linné later in his life struggled to believe that Earth, climate, and species were immutable and showed that hybridization produced new species of plants (Larson 1968).

Linné's contemporary, Buffon (Georges-Louis Leclerc, Comte de Buffon, 1707–1788) noted two problems with Linné's explanations. First, he observed that environmentally similar but geographically isolated regions had distinct biotic assemblages (Buffon 1761). For example, he considered and established that the animal species of the New World tropical zone were not the same that inhabited the Old World tropics. This observation is also known as "Buffon's law" and constitutes the first principle of biogeography (Lomolino et al. 2017). Second, if (most) species were immutable, they would have been incapable of adapting to new environments and thus on their travel would have been blocked by unfavourable conditions, then acting as environmental barriers. Buffon instead hypothesized that life had originated in the Northern Hemisphere at times when climatic conditions were more equable. He speculated that when climates later cooled, life forms would have migrated southward to colonize the Southern Hemisphere of both the New and Old Worlds (Buffon 1778). During this migration, they would have become separated and increasingly modified until tropical biotas of the New and Old World shared few, if any, forms. Buffon's considerations provided two key elements of what would become central components of modern biogeographic theory (Lomolino et al. 2017). Not only were Earth (both land and sea) and its climate dynamic, but so were its species (Buffon 1749, 1766). "Improved" forms would survive at the expense of those that could not change or "degenerated" (Buffon 1766). This process would later be called "natural selection" by Darwin and Wallace (1858).

From 1750 to the early 1800s, natural scientists continued to explore the diversity and geography of nature and to write systematic catalogues and general syntheses of their expanding knowledge. One of the most prominent explorers was Sir Joseph Banks (1743–1820), who contributed ca. 1400 plant species not previously known to science (Gooley 2012). Through his and his contemporaries' work, Buffon's law could be affirmed and generalized to other taxa and regions in addition to the tropics. Banks and his colleagues also discovered exceptions to Buffon's law, specifically the existence of cosmopolitan species. Two additional naturalists who were influential for Humboldt's work were Johann Reinhold Forster (1729–1798), known for his work confirming Buffon's law for plants, mammals, and birds, also outside the tropics and early insights into what would later become known as island biogeography and species diversity theory (Forster 1778), and his son Johann Georg Adam Forster (1754–1794), renowned for having accompanied James Cook on his second South Sea expedition between 1772 and 1775 (Forster

1778; Mariss 2015; Jovanović 2020). As Banks, the scientific companion of Captain James Cook on his first voyage, refused to accompany Cook on his second voyage to the South Seas, the British Admiralty made Forster senior an offer to join the expedition in 1772, to prepare a scientific report of the voyage and to publish it after his return. He agreed under the condition that his only seventeen-year-old son Georg was allowed to come along as a draughtsman and scientific assistant.

Humboldt met Georg Forster at the occasion of his first research adventure in 1789. With a companion, Humboldt travelled from Kassel to Frankfurt am Main, along the mountain road to Heidelberg and Mannheim, and finally to Mainz, where they lodged with Forster junior (Jovanović 2020). Forster junior, as a natural scientist with experience of circumnavigating the world, embodied the type Humboldt himself aspired to be (Daum 2019; Jovanović 2020). Only a year later, Humboldt and Georg Forster, then possibly one of the most-travelled German explorers, embarked on a journey along the Lower Rhine to Holland, Belgium, England, and ultimately to Paris. The voyage was followed by Forster's second most popular publication (Forster 1791–1794) and Humboldt's first scientific publication on mineralogy (1790). More importantly, Humboldt acquired lasting influence from the time spent with Forster, which echoed through his monumental work in the following years of his life (Jovanović 2020).

In 1788, only shortly before Humboldt met Georg Forster, and before he enrolled at the University of Göttingen in spring 1789, the then 18-year-old Humboldt visited Karl Ludwig Willdenow (1765–1812), a former student of Forster senior (Müller-Wille and Böhme 2020). This visit also had a lasting impact on the young Humboldt and initiated his passion for botany. Humboldt owed fundamental botanical knowledge to the work "*Florae Berolinensis Prodromus*", which had been published by Willdenow in 1787 (Böhme and Müller-Wille 2013; Müller-Wille and Böhme 2020). After the visit, a friendship and scientific exchange began, which lasted until Willdenow's early death in 1812 (Hesse 2012; Müller-Wille and Böhme 2020). In 1793, Humboldt published his own botanical paper with the title "*Florae Fribergensis specimen*", which he dedicated to Willdenow. Humboldt sent plants that he had collected in Spain to Willdenow and later also sent him plants from his trip with Bonpland through South and Central America for botanical determination (Hesse 2012). Humboldt's plant geography is closely connected with Willdenow, who had already published similar ideas in his work "*Grundriss der Kräuterkunde*" (Outline of Herbology, Willdenow 1798), an impressive and well-structured piece of work of almost 600 pages summarizing the then state-of-the art knowledge about botany and plant geography in its broadest sense. The friendship and scientific cooperation of Humboldt and Willdenow led to an expansion of knowledge about nature with lasting impact today (Müller-Wille and Böhme 2020). In his major synthesis, Willdenow (1798) provided detailed descriptions of the floristic provinces of Europe, with plant geography reflecting climatic conditions. He suggested a novel explanation for the origin of distinct, regional floras, namely many sites of origination, instead of only one site of creation or survival during the biblical flooding. Willdenow offered this could have been isolated mountain chains across the continents separated by global seas, each of which could have been inhabited by a distinct assemblage of locally created plants. After retreat of the flooding, plants could have spread downwards to form the floristic assemblages of each region. Once again, this exemplifies the importance that mountains were attributed to with respect to plant biogeography.

Towards the end of the eighteenth century, the first true development of a world view of nature drove intellectuals to question, and often reject, authoritative doctrines and religious dogma, in favour of careful observation and rationalism as the primary means of advancing human understanding of all aspects of the natural world. This period was characterized by a holistic view of nature, which included all phenomena of the cosmos, the natural world with its diversity of species and distributions, and its human population. It was also the time of the rise of a new type of expert in late eighteenth-century Prussia, Humboldt being a prime example (Klein 2015). Humboldt was one of the most influential scientists and intellectuals of this period and is today widely recognized as one of the fathers of phytogeography (Müller-Wille and Böhme 2020). For Humboldt, geography, archaeology, volcanology, meteorology, geomagnetism, oceanography, and anthropology were all interrelated and essential means to comprehend the unity and universal harmony of nature. Inspired by his teacher Willdenow and friend Georg Forster, among several others, Humboldt investigated the relationship between geography, climate, and vegetation. He achieved this through the careful study of spatial variation in climates, soils, and associated life forms. Although he was predominantly interested in plants, Humboldt also studied works on arthropods and reptiles, and he further generalized Buffon's law to include most terrestrial biota. He noted that the floristic zonation, described by father and son Forster, along latitudinal gradients, could also be observed at local scale along elevational gradients (Fig. 2). This led him to realize that ascending mountains resembled a botanical journey from the Equator to the poles, whereby vegetation zones replace each other successively as elevation increases, ranging from equatorial tropical equivalents at low elevations to boreal and arctic equivalents at the summits (Humboldt and Bonpland 1807). Before him, Linné (1741) and Buffon (1756) already had considered that there is correspondence between the kinds of vegetation that can be found in different latitudes and those that could be found at different elevations.

Swiss botanist Augustin Pyramus de Candolle (1778–1841), one of Humboldt's friends and colleagues, added another significant insight that would become fundamental to ecology and biogeography. Following Buffon's earlier considerations about animals (Buffon 1749), Candolle further elaborated that organisms are not only influenced by abiotic conditions, such as light, heat, and water, but they compete for these resources as well, so that their distributions are influenced by interactions with other species. Candolle (1820) appears to have been the first to write about competition and survival, a theme that proved central to the development of the *Theory of Evolution by Natural Selection* (Darwin and Wallace 1858; Darwin 1859). Candolle also differentiated between "habitations" (biotic provinces or regions) and "stations" (local habitats) (Browne 1983). Both competition and species abiotic preferences would later become central elements for ecological niche theory (Hutchinson 1957). Candolle also further developed the

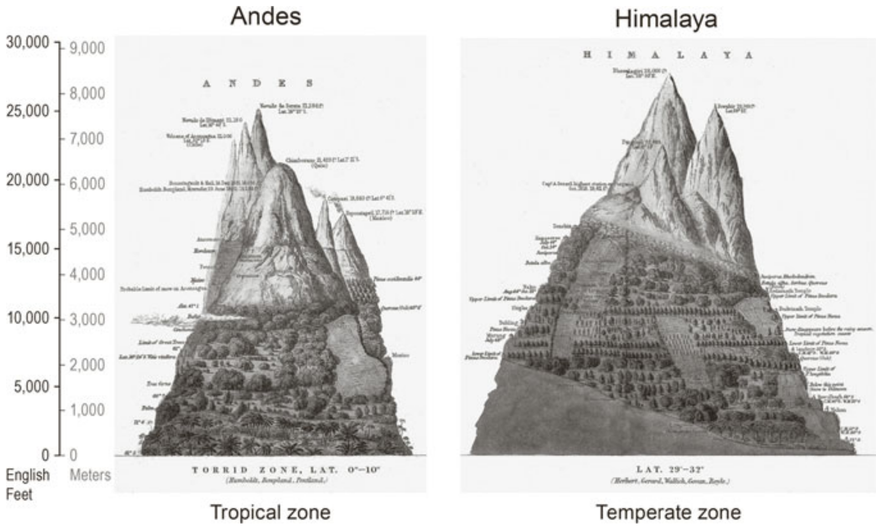


Fig. 2 Depictions of the Andes and the Himalaya with their elevational zonation of vegetation. The figures are part of the map "Outlines of Botanical Geography" which appeared in W. K. Johnston's Physical Atlas (1848/1850). Humboldt played an important part in the design and production of this map

Forsters' earlier observations on insular island floras (Forster 1778). While species numbers were known to be most strongly influenced by island size, Candolle added island age, volcanic activity, climate, and isolation from the mainland as factors influencing floristic diversity (Lomolino et al. 2017). Some of what are nowadays regarded key elements of (ecological) biogeography and ecology had thus been established by the beginning of the nineteenth century.

New discoveries in geology and palaeontology brought additional insights but also challenged existing, still predominant, views of a static Earth inhabited by immutable species. Adolphe Brongniart (1801–1876) and Charles Lyell (1797–1875), often regarded as founding fathers of palaeontology and geology, respectively, used the fossil record to infer conditions of past climate (Ospovat 1977; Lomolino et al. 2017). They found that Earth's climate was highly mutable and that tropical life forms had once flourished in currently temperate regions of Europe. Sea levels would have changed through time, and the Earth's surface would have been transformed by uplift and erosion of mountains, explaining the existence of marine fossils on mountain slopes. Episodes of extinctions of species would have been followed by periods of creation (Lomolino et al. 2017). Although Lyell denied that species could arise from other species, he still played a key role in the maturation of biogeography to become an integrative science, owing to his work on the principles of geology (Lyell 1830–1833). It would be left to four British scientists, Charles Darwin (1809–1882), Joseph Dalton Hooker (1817–1911), Alfred Russel Wallace (1823–1913), and Philip Lutley Sclater (1829–1913), to revolutionize biogeography, building upon the works of their predecessors.

Importantly, beside his acquaintance with many fellow explorers and naturalists, Alexander von Humboldt was also friends with the twenty years older Johann Wolfgang von Goethe (1749–1983). They met in Jena in 1794 through Alexander's brother Wilhelm, who had moved to Jena to get in closer connection with Goethe and Schiller (Hesse 2005). Humboldt was still inspecting mines at that time, whereas Goethe was already considered the most famous German poet in Germany. While Goethe was inspired by Humboldt's versatility, Humboldt drew inspiration from Goethe's emotional appreciation of nature.

Whereas Schiller in 1794 had already moved towards poetry instead of medicine, Goethe and the Humboldt brothers were still united in their interest in natural sciences and medicine (Hesse 2005). What united Humboldt and Goethe was morphology. Goethe wrote to his younger contemporary in 1795 that while Humboldt's observations started from the element, but his from the shape (*Gestalt*), "we cannot hurry enough to meet in the middle" (Goethe 1795). Humboldt took up this impulse and finally brilliantly showed it to advantage in his monumental "*Kosmos*" (Humboldt 1845–1850).

Goethe was impressed by Humboldt's unique creativity and stated that in eight days it would be impossible to read from books what Humboldt told one in an hour only (Goethe 1797). Likewise, Humboldt, after returning from America, stated in 1806 that everywhere he was penetrated by the feeling how powerful those encounters with Goethe had been on him back at the times in Jena, and how he, elevated through Goethe's views of nature, felt as if he was equipped with "new organs" (Biermann 1985). Although Humboldt's appreciation of Goethe, and vice versa, varied through time, Humboldt drew inspiration from this and many others of his contemporaries, and this contributed to his holistic view and perception of the world. Likewise, Alexander von Humboldt had a lasting impact on many people and still is an inspiration today.

As shown above, Goethe, Willdenow, and father and son Forster (see above), among many others, formed the intellectual context in which Alexander von Humboldt formed his ideas and planned his future work. This movement was called the German Romanticism or *Naturphilosophie*, and it laid out the foundations for plant geography (Nicolson 1987) (Fig. 1). What set Humboldt apart from the *Naturphilosophie* movement was his unique and novel approach, which is sometimes referred to as "Humboldtian Science" (Cannon 1978; Nicolson 1987; Dettelbach 1996). This term is also used as a cypher for the brand of science which was characterized by an objective, empirical, and quantitative approach, with scepticism towards existing theories and new conceptual tools (see Buttimer 2001; Nicolson 1987; Jackson 2009b, 2019). In addition, Humboldt's vast family fortune further enabled him to buy the most advanced scientific equipment of the time and put his desire for precise scientific measurements into practice during his voyages (Egerton 2009; Böttcher 2020). Humboldt's innovative approach and perception of the interconnectedness of life on Earth are best illustrated in the iconic profile, the *Naturgemälde*, in the "*Essay of Plant Geography*" (Humboldt and Bonpland 1807). In this profile, he synthesized geographic and climatic information that he related to the plant distribution on the slopes of the Ecuadorian Andes. The *Essay* presented his ideas on vegetation structure in mountain systems, but also shared with a wide audience the concepts of the elevational gradient and the latitudinal gradient in plant geography by graphic comparison of mountains from the tropics to temperate regions (Humboldt and Bonpland 1807; Jackson 2009a) (Fig. 2).

Humboldt's vast body of work inspired many naturalists at the time and thereafter, for example, Danish botanist Joakim Frederik Schouw (1789–1852) who is considered one of the earliest plant geographers that followed the Humboldtian tradition (Nicolson 1996). Schouw was particularly interested in global units of vegetation (phytogeographical regions) and expanded on Humboldt's ideas by embedding them into a more theoretical framework, for example by making a clear distinction between plant geography and plant history (Schouw 1823; Ebach 2015).

Following Schouw, Franz Unger (1800–1870), an Austrian botanist, picked up the subject of plant history (palaeobotany), in the intention to historically explain the phenomena of plant distribution (1852). In his book "*Versuch einer Geschichte der Pflanzenwelt*" (Essay on the History of the Plant Kingdom, Unger 1852), dedicated, as a sign of veneration, to Schouw, Unger quotes Humboldt prominently at the beginning: "Unsere Kenntniss von der Urzeit der physikalischen Weltgeschichte reicht nicht hoch genug hinauf, um das Dasein als etwas Werdendes zu schildern" ("Our knowledge of the beginnings of the physical world history does not go far enough as to describe existence as something in the making"). This may be understood as a tribute to the inspiration that both Schouw, as Unger explains in his dedication, and Unger himself, drew from Humboldt's work, importantly also from the limitations he reported at his time concerning the knowledge about Earth history and the gradual evolution of geological and biological existence. Unger (1852) emphasized that it was not contemporary climatic conditions alone which were responsible for current plant distributions, but that the latter were the result of past, gradual development. Plant fossil evidence would allow inferences about the past physical conditions on the Earth surface.

Güttler (2014) provides an overview about the history of maps and their users in plant geography of the nineteenth century. Augustin Pyramus de Candolle with his "*Carte botanique de France*" (1805) was among the first to produce a plant geographic map. Apart from using different colour shading for the different botanical regions for mere visual argumentation, Candolle also included another dimension, the network of observations his plant geographic classification was actually based upon. Candolle's map thus also should lead natural scientists to the yet unknown "blind spots". Güttler (2014) argues that only through this connection between the epistemic and social dimension of those vegetation maps, map drawing finally became a widespread research practice.

In June 1799, right at the time when Aimé Bonpland and Alexander von Humboldt went on their explorative trip to Pico del Teide on Tenerife, prior to their later exploration in the American tropics, Candolle had started his material collection for his *Carte botanique* at the Paris Botanical Garden (Güttler 2014). Only shortly before, Bonpland had finished his botanical education there. Bonpland accompanied Humboldt as a botanical expert. The observations on Pico del Teide would help Humboldt to prove his hypothesis on the dependence of vegetation on temperature and altitude above sea level, which would become one of the cornerstones of his plant geography (Güttler 2014).

Bartholomew, a Scottish publisher of maps, characterized the recognition potential of distribution geographical charts very accurately when he wrote: “An atlas is truly a Cosmoscope for those who know how to use it” (Bartholomew 1902). With a good atlas, according to Bartholomew, the entire cosmos—and in this case that meant primarily all phenomena on Earth—could be viewed in a new light. An atlas would then become a cosmoscope, thus an instrument for the observation of the cosmos (Güttler 2014). Likewise, one might view Humboldt’s vegetation maps as a “cosmoscope” to explain plant cover on the Earth surface by climatic and geological parameters.

Geology, the Age of Earth, and the Role of Deep Time in Biogeography

The temporal changes on Earth’s surface and subsurface are central to geology. For this reason, the progress of geological sciences had huge implications for developments in the field of biogeography. Modern conceptualization of the landscape as a spatial continuum was initiated around the sixteenth century, during the Renaissance (Rosenberg 2009a). However, it was during the Enlightenment (c. 1715–1789, but exact dates for this time period vary) that the concept of time truly evolved, and scientists realized that the biblical time estimate—ranging in the order of millenia—for the age of the Earth was implausible (Rudwick 2005).

Cutler poignantly states, “the concept of vast age of Earth, arguably is geology’s major contribution to human thought”. The age of the Earth has puzzled humans since the time of the Greeks. However, it was Leonardo da Vinci (1452–1519) who first displayed a structured way of geological thinking (Rosenberg 2009b), while Nicholas Steno (1638–1686), a Danish clergyman, first appreciated the true meaning of rocks as historical archives. Steno’s observations on a dynamic Earth can be found in his notebook “*Chaos*” (1659), and his complete views on the duration of time and geological processes are formulated in the book “*Prodromus*” (1669) (Ziggelaar 1997, 2009; Rosenberg 2006; Cutler 2009). Until the seventeenth century, the age of the Earth was based on estimates from biblical time, with Archbishop James Ussher of Ireland in 1654 proposing that the age of the Earth dated back to 4004 B.C. (see Braterman 2013). Since the bible was considered infallible, scientists were not easily diverted from the millennial timescale that seemed to determine the age of the Earth (Cutler 2009).

In the eighteenth century, however, scientists such as Buffon, de Luc and Hutton, engaged in working towards a *Theory of Earth*. From field observations on volcanic deposits, valley incision, and stratification, it became clear that the age of the Earth was incompatible with the biblical timescale and the age of Earth had to be revised (Rudwick 2005). In 1775, Buffon (who was already discussed in the section on “Birth of Biogeography”) proposed a revolutionary model in which he estimated the age of the Earth at 3 million years, a tremendous leap forward for the standards of the eighteenth century. In his model, he took into account the simultaneous origin of Earth and other planets (see Rudwick 2005, p. 127). About a decade later, in 1788, James Hutton published his "*Theory of the Earth*" (Fig. 1). In this foundational work, he shows that rocks are archives of Earth history and suggests that the Earth had an indefinite age. Lord Kelvin (1844 and 1846) strongly opposed this idea of infinite age, and based on physics calculations, he estimated the age of the Earth ranged from 24 to 400 million years (England et al. 2007). However, it would still take a century—until the discovery of radioactivity by Henri Becquerel (1896a, b) and new methods in isotope analyses—before the age estimates became accurate. In 1913, Arthur Holmes proposed an age of 1.6 billion years for the Earth in his "*The Age of the Earth*" and later corrected this to 3.3 billion years (Holmes 1946). Conclusive evidence was provided by Clair Patterson in 1956, who used meteorites and set the age at c. 4.5 billion years, the estimate that is still accepted today (Ziggelaar 2009; Cutler 2009) (Fig. 1).

The most influential geological work of all was "*Principles of Geology*" by Charles Lyell, which was published in three volumes between 1830 and 1833 (Fig. 1). *Principles* comprehensively explained the successive formation of rock strata and formed a keystone for development of natural sciences in the nineteenth century. This work formed an inspiration for Charles Darwin, and together with the geological training that he received in Edinburgh and Cambridge (Secord 1991), it enabled to formulate his theory of evolution by natural selection (Darwin and Wallace 1858; Darwin 1859). Lyell's discussion of biogeographic provinces and Sclater's work on bird geography (1858) also influenced Wallace's ideas on regionalization in biogeography (see Whitaker et al. 2013). In 1863, this work led Wallace to present his paper on "*The physical geography of the Malay Archipelago*" to the Royal Geographic Society, in which he highlighted the importance of geology and biology for understanding the faunal division between the Archipelago and Australasia (Camerini 1993). Taken together, the geological concepts on space and time, that were developed in the nineteenth century, significantly advanced the field of biogeography by adding new dimensions to the field.

The final paradigm shift in geological understanding, which also would rock the biogeographic foundations, occurred almost a century after Lyell's publication. In 1912, Alfred Wegener presented his unifying *Theory of Continental Drift*. This would provide an explanation for the mystery of the clade resemblance between the southern continents and many other puzzling geological features (see Oreskes 1999). In 1960, long after Wegener's death, Harry Hess discovered the process of sea-floor spreading, providing the mechanism behind continental drift. He presented the conclusive evidence in 1962, and the *Theory of Continental Drift* was finally validated albeit that the mechanisms were different than Wegener proposed in his original theory (Oreskes 1999). This was an absolute revolution in geology that also had implications for biogeographic history. An example of this is the seminal paper "*Angiosperm biogeography and past continental movements*" by Raven and Axelrod (1974) (see also Trewick 2016) in which global plant dispersal patterns are explained in the light of plate tectonic theory.

At the turn of the millennium, methodological advances in both geology and biology enabled scientists to explore new frontiers in biogeography. Progress in the methodologies of isotope chemistry and thermochronology (temperature history of minerals) enabled accurate erosion and exhumation models in mountain building, providing a chronology for the formation of elevational gradients (see for overview Antonelli et al. 2018; Hoorn et al. 2018; Perrigo et al. 2020; Muellner-Riehl et al. 2019). Furthermore, dynamic topography, a development within the field of geophysics, provided novel models that explained the reshaping of the Earth surface as a consequence of plate–mantle interaction (e.g. Eakin and Lithgow-Bertelloni 2018). Such subsurface processes, for instance, can explain how the relief is modified while influencing depositional environments and speciation (e.g. Bicudo et al. 2019).

The growing amounts of scientific databases, both geological and biogeographical, also have expanded the possibilities to identify large-scale patterns and biogeographic regionalization. Global assessments of rock lithology are thought to control biodiversity in mountain systems, with mafic and ultramafic rocks (i.e. dark igneous rocks, rich in iron and magnesium) being more species rich than felsic rocks (silica-rich); carbonate rocks are relatively poorer than other rock types when it comes to biodiversity (Fjeldså 2018; Rahbek et al. 2019). Rock composition also controls topography and nutrient properties in the overlying soils (Ott 2020). Another example of this is the differences in sediment types and species richness in Amazonia, which show that soil chemistry and biodiversity on siliciclastic sediments vary depending on the geological unit they are on (Higgins et al. 2011). Other geological features, besides lithology, may also cause biogeographic regionalization. An example of this are the multiple biogeographic regions in the Northern and Central Andes, which are thought to be related to geological structures that formed at the interface of plate tectonic boundaries. However, the exact relation still remains to be explored (Hazzi et al. 2018).

New Advances in Biogeography, the Molecular Revolution

The early eighteenth-century predominant belief of a static Earth and life meant that dispersal of biota formed the prevailing explanation for movement from an area of origin towards present-day ranges. This immutable view of species was finally generally abandoned by Darwin and Wallace (1858), by identifying natural selection as the mechanism by which organisms evolve into new species. Before Wegenerism was generally accepted, and despite Darwin's and Wallace's insights, species were believed to have evolved in a "centre or origin", from where they subsequently dispersed to other areas (Lomolino et al. 2017). This belief continued to be dominant through the first half of the twentieth century, with Matthew (1915), Darlington (1957), and Simpson (1953) as important proponents.

In the second half of the twentieth century, the surge of cladistics (Hennig 1966) and the final acceptance of the *Theory of Plate Tectonics* (introduced by Wegener already in 1912 as *Theory of Continental Drift*, but without sound causal mechanism) contributed to a new paradigm in historical biogeography. It allowed for the consideration that plant and animal lineages could have passively drifted on continents as they split and dispersed across the Earth, which led to the concept of vicariance. Cladistic vicariance biogeography (Rosen 1978; Platnick and Nelson 1978; Nelson and Platnick 1981; Wiley 1988) represented an important step forward, because it provided an analytical framework with which to reconstruct the biogeographic history of lineages and biota, in contrast to the previous narrative dispersal scenarios. Plant and animal taxa sharing similar phylogenetic and distribution patterns were assumed to have shared a common biogeographic history. They could be considered part of the same ancestral biota that later became isolated by geological or climatic vicariance events. Vicariance hypotheses could thus be tested by searching for congruence in phylogenetic and distribution patterns among different organisms (Humphries and Parenti 1986, 1999; Parenti 2007). In addition, cladistic biogeography moved approaches from being taxon-based (e.g. Brundin 1966) towards a comparative "area biogeography" approach, aiming to understand global distribution patterns through the comparison of area cladograms (Crisci et al. 1991; Humphries and Parenti 1986, 1999).

However, cladistic biogeography still had limitations, because it denied dispersal as being of any major importance for generating global biodiversity patterns. Event-based biogeographic approaches, integrating both processes and patterns, were subsequently developed as a response to these limitations (Sanmartín 2012; Lomolino et al. 2017). These methods apply a deterministic cost model approach in which each event or biogeographic process (e.g. dispersal, extinction, duplication, vicariance) is assigned a given cost according to its likelihood of occurrence. Processes are not inferred "a posteriori" from the area cladogram, as in cladistic biogeography, but instead the inference of processes is directly tied to the inference of biogeographic patterns through the cost-matrix model. The reliance on parsimony and the possibility of pseudocongruence were, however, still limiting factors in event-based and cladistic biogeographic approaches.

While cladistics allowed to make inferences about the evolutionary history and sequence of divergence events in biotic lineages, and continental drift provided an important geological background for developing hypotheses on past vicariance events, it was not possible until the application of the "molecular clock" (Zuckerkandl and Pauling 1965) to actually put absolute dates on evolutionary events in phylogenetic trees. In other words, while patterns in phylogenetic trees could be matched with continental breakup scenarios, it was impossible to test for actual temporal congruence in addition to topological congruence, allowing to exclude pseudocongruence. This changed with the advent of using the mutation rate of biomolecules to deduce the time in the past when lineages diverged.
The biomolecular data used for such molecular clock calculations in modern biogeographic analyses are usually nucleotide sequences (DNA). Knowing how lineages assembled and evolved within a region is key to understanding the evolution of traits, the evolution of biotic interactions, and the evolution of floras, and thus key to modern historical biogeography. Various analytical methods,

developed over the past ca. 20 years (e.g. see early review of methods by Renner 2005), model change in substitution rates along individual branches of a phylogenetic tree by combining molecular data with time constraints, usually from fossils. Meta-analyses of plant and animal studies from the same geographic region can identify directional biases because of prevailing wind or water currents and the relative position and size of landmasses (e.g. Sanmartín and Ronquist 2004). The application of molecular clocks and more sophisticated parametric statistical approaches in biogeographic reconstruction (Sanmartín 2012; Matzke 2018) has led to a new revival and popularity of historical biogeography in the biological sciences. All this would have been impossible without the advances in genetics (Watson and Crick 1953; Crick et al. 1961), theories of molecular evolution (Kimura 1968, 1983), and sequencing techniques (Sanger et al. 1977), sometimes also referred to as part of the "molecular revolution" in biological sciences.

The Biogeography of Mountain Systems: Chronology of Humboldt's Elevational Gradient

Humboldt's most influential work, the "*Essay on the Geography of Plants*" (Humboldt and Bonpland 1807; Jackson 2009a), is centred around the *Naturgemälde*, a composite figure that features the plant composition along the slopes of an idealized Chimborazo volcano (Ecuadorian Andes). The two side panels feature mainly environmental data such as humidity, atmospheric pressure, and temperature with respect to elevation, but also geology. Importantly, these side panels also include the elevations of other well-known mountains (e.g. Mont Blanc, Antisana, Mt. Vesuvius), as well as the elevation of the nival belts at different latitudes, allowing the reader to put the information into a global context. What makes the *Naturgemälde* so unique is the combination of both biotic and abiotic variables, linking plant distributions to elevations and latitudes, something completely new at the time and which summarizes the essence of plant geography. Humboldt had actually recorded these plants on the Antisana but for artistic benefit placed them on the Chimborazo (Glaubrecht 2019). In his *Essay*, he explains the difficulties of compromises when making an aesthetically pleasing figure while remaining scientifically accurate. Even though some discrepancies between Humboldt's depiction of his observations and our current knowledge of plant distributions along alpine gradients have emerged (Moret et al. 2019a, b), this iconic figure and its impact are still considered groundbreaking.

Humboldt had a background as a mining inspector in Freiberg which meant that he was familiar with the advances in geological knowledge that were taking place in the eighteenth and nineteenth century. One of his teachers was for example Abraham Gottlob Werner (1749–1817) (Fig. 1) who became known as the 'father of German geology' and he was friends with Leopold von Buch (1774–1853) (Fig. 1) who went on to become a well-known palaeontologist (Guntau 2009). It is therefore no surprise that in his *Essay*, Humboldt mused about the role of geology in establishing plant geography. In the right side panel of the *Naturgemälde*, the geological information is represented, while in the main text he ponders whether periodical climate change might have permitted tropical organisms to expand to the poles. Such reduced pronounced latitudinal gradients are now known to have occurred during periods of global warming such as the Paleocene-Eocene Thermal Maximum and the Early Eocene Climatic Optimum (e.g. Bijl et al. 2009; Crame 2020). Furthermore, Humboldt remarks on the presence of molluscs and marine-like organisms at high elevations and wonders about the mechanisms that would have caused organisms living at sea level to be found in rocks in the high mountains (Humboldt and Bonpland 1807). However, the mechanisms of mountain building were not known at the time of Humboldt's visit to the Chimborazo, depriving him of the opportunity to view his observations in a precise temporal perspective.

Here we follow Humboldt's integrative approach and present two examples, the Tropical Andes and the Tibet-Himalaya-Hengduan region (Figs. 3 and 5), which showcase the current state of the art of our understanding of the evolution of mountain species assemblages, based on time-calibrated phylogenies, the fossil record, and climate and geological histories. Together, these data show that the elevational gradient of biodiversity distribution is a product of time and the interaction of several natural forces, which Humboldt had already recognized in his seminal work.

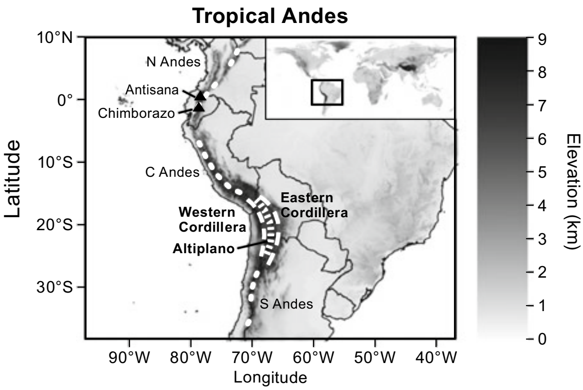


Fig. 3 Geographic locations of Andean mountain regions. Dotted lines indicate stylized location of the Andean mountain range. Dashed lines show stylized location of the Western and Eastern Cordillera and the Altiplano

The Tropical Andes

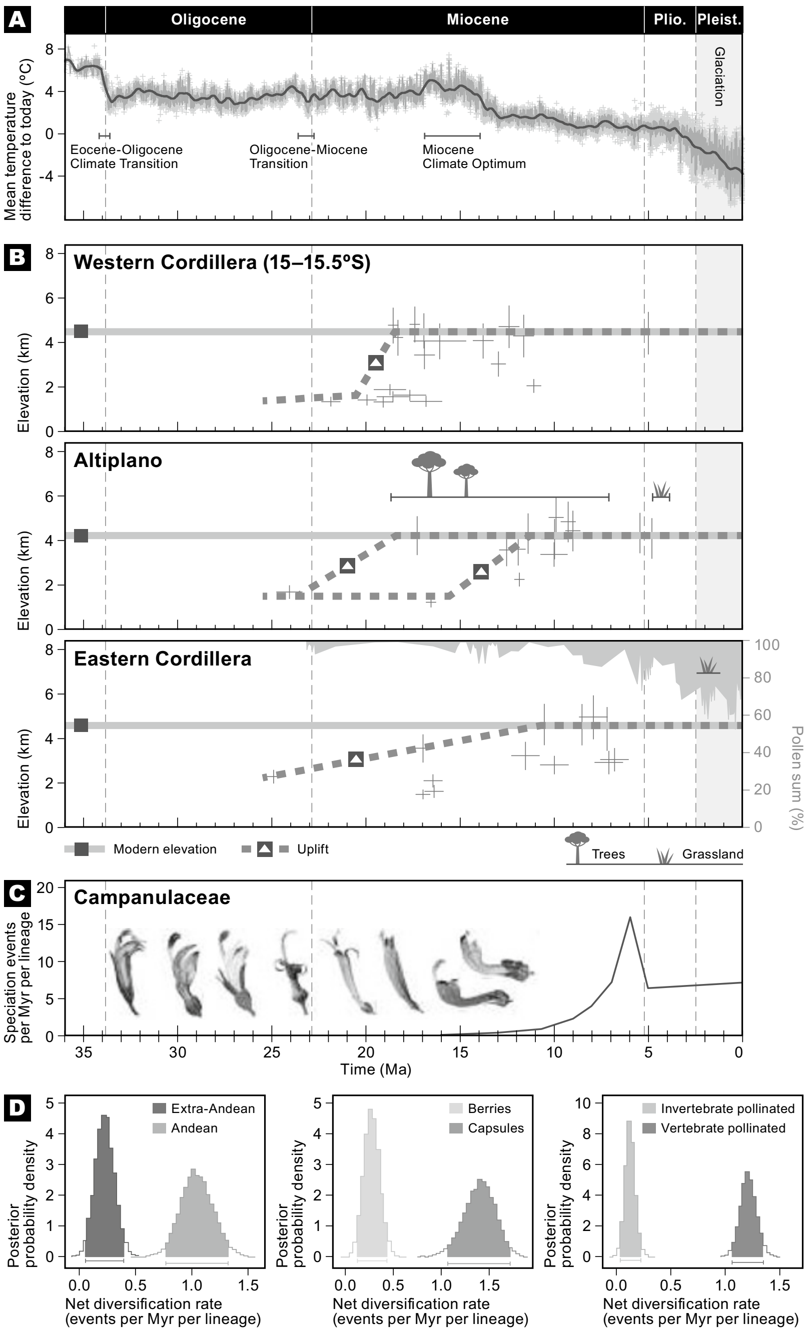
The Tropical Andes stretches from Venezuela to northern Argentina and has a length of more than 3000 km. With its rugged topography, towering volcanoes, and climatic and geological diversity, it hosts the largest number of endemic plants and vertebrates, which makes it the world's number one biodiversity hotspot (Myers et al. 2000). It is therefore no surprise that Humboldt on his arrival in the Americas made the Andes his prime research target.

In the central panel of the *Naturgemälde*, Humboldt synthesized the results of his botanical expeditions to the Antisana and Chimborazo (Humboldt and Bonpland 1807), representing the plant species composition, “regions”, and vegetation “limits”. In essence, these correspond to the ecological (or floristic) zones that presently are known as lower tropical forest (<1000 m), sub-Andean forest (>1000 to <2500 m), Andean forest (>2500 to <3500 m), paramo (Andean alpine tundra, >3500 to <4800 m), and nival belts (>4800 m) (Eastern Cordillera, Colombia; Cuatrecasas 1958; Van der Hammen 1974; Van der Hammen and Cleef 1986; Christmann and Oliveras 2020).

To understand the origins of Humboldt’s floristic zones, we should look back in time and evaluate the formation of the Tropical Andes. When did high mountain peaks form? And when was the Tropical Andes colonized by plants? Currently, there are two scenarios that are thought to have acted simultaneously: on the one side colonization by taxa pre-adapted to cold, and on the other upslope migration from the Amazon lowlands (Gentry 1982; Luebert and Weigend 2014; Antonelli et al. 2018). Luebert and Weigend (2014) estimated that migration from austral and boreal regions into the Tropical Andes started as early as 23 million years ago (Ma) (early Miocene), with immigration of cold-tolerant taxa particularly favoured during the glacial intervals of the Pleistocene (e.g. Troll 1968; Van der Hammen 1974; Torres et al. 2013). According to Cleef (1979) ~10% of the páramo taxa is of Holarctic [boreal] origin, and ~10% of austral-antarctic origin, together that makes ~20% pre-adapted taxa. Together, evidence from mountain building and the fossil record can provide further background to this.

The Andes has a long history that started around 190 Ma, with the latest tectonic cycle starting around 80 Ma, and from 50 Ma subduction extending across the entire Andean margin (Chen et al. 2019). However, models diverge on whether Andean uplift was gradual or took place in pulses. In a recent recompilation, Sundell et al. (2019) summarize existing and new uplift data for the Central Andes, showing that uplift started here around 20 Ma and attained an elevation of nearly 4 km around 10 Ma (Fig. 4b). Consequently, in the late Miocene, the Central

Fig. 4 Historical plant diversification patterns in the Andes in relation to global climatic changes ► and regional orogenic processes. **a** Global Cenozoic climate dynamics inferred from deep-sea benthic foraminiferal stable-isotope records (modified from Westerhold et al. 2020). **b** Variable surface uplift scenarios for different physiographic regions of the central Andes (modified from Sundell et al. 2019). Crosses indicate raw paleoaltimetry estimates as included in Sundell et al. (2019). Continuous grey lines are $\pm 1\sigma$ standard deviation of modern elevation and dashed lines represent simplified uplift scenarios. **c** Exemplary speciation rate through time for representative taxonomic groups with high species diversity in the Andes, Neotropical bellflowers (Campanulaceae, modified from Lagomarsino et al. 2016). Depicted: floral diversity of Andean bellflowers (Lagomarsino et al. 2016). **d** Abiotic and biotic drivers of diversification in Neotropical bellflowers, inferred using binary state-speciation and extinction (BiSSE) models. Left: Net diversification rates (speciation–extinction) Andean versus extra-Andean bellflowers. Middle: Net diversification rates of bellflowers bearing berries versus capsules. Right: Net diversification rates of invertebrate versus vertebrate-pollinated lineages. License for use was acquired for Westerhold et al. (2020), all other previously published materials are licensed under CC BY 4.0


A
Oligocene
Miocene
Plio.
Pleist.
Glaciation
Mean temperature difference to today (°C)
Eocene-Oligocene Climate Transition
Oligocene-Miocene Transition
Miocene Climate Optimum
B
Western Cordillera (15–15.5°S)
Elevation (km)
Altiplano
Eastern Cordillera
Pollen sum (%)
Modern elevation
Uplift
Trees
Grassland
C
Campanulaceae
Speciation events per Myr per lineage
Time (Ma)
D
Extra-Andean
Andean
Berries
Capsules
Invertebrate pollinated
Vertebrate pollinated
Posterior probability density
Net diversification rate (events per Myr per lineage)

Andes already could have accommodated alpine (puna) vegetation, more so considering the global cooling trend at this time (Fig. 4a). Nevertheless, recent paleobotanical evidence suggests that there was no alpine (puna) on the Altiplano (3800 m) prior to c. 5 Ma (Martínez et al. 2020) (Fig. 4b). Perhaps geological models overestimated past elevations, or the geographic distribution of the puna has varied a lot.

In the Northern Andes, the uplift of Eastern Cordillera was estimated to have started around 23 Ma (e.g. Ochoa et al. 2012; Restrepo-Moreno et al. 2019), and by 7.6 Ma the cordillera would have reached around 4500 m, i.e. 1000 m short of its present c. 5500 m elevation (Anderson et al. 2015). Although mountain building did not keep the same pace in the entire region, it is likely that by 7.6 Ma a proto-alpine vegetation (paramo) was in place. This is confirmed by the presence of Andean páramo taxa in marine records from the Pacific since 6 Ma (Grimmer et al. 2018) and the Atlantic and 5.4 Ma (Hoorn et al. 2017; Kirschner and Hoorn 2019; Fig. 4b), respectively. For contrast, the Venezuelan Andes is thought to have exhumed somewhat later, reaching an elevation of up to 3500–4000 m with indications of páramo presence around 5 ± 2 Ma (Bermúdez et al. 2017). Summarizing, in the Northern Andes, Humboldt's alpine vegetation or "pajonal" was first established no later than 7.6 Ma.

When comparing geological and molecular records, interesting parallels are observed. As expected, speciation ages of mid-elevation taxa from the Andean forest outdate the younger alpine vegetation (Luebert and Weigend 2014). Pérez-Escobar et al. (2017) generated a calibrated phylogeny for orchids that colonized the Andes both through immigration of pre-adapted taxa and through upslope migration from the Amazon lowlands between 20 and 15 Ma, coinciding with early uplift. A subsequent study of fern *Phlegmariurus* (Lycopodiaceae) showed increased diversification from 10 Ma onwards (Testo et al. 2019). Finally, a time-calibrated study on diversification of Neotropical bellflowers, a group typical for the Andean cloud forest (1900–3500 m), showed extremely fast speciation rates that coincided with mountain building from 5 Ma onwards (Lagomarsino et al. 2016) (Fig. 4c, d). Other examples of upslope migration from the Amazon lowlands exist for taxa belonging to the Rubiaceae (Antonelli et al. 2009), Chlorantaceae (Martínez et al. 2013), Iriarteeae (Bacon et al. 2018), and Malvaceae (Hoorn et al. 2019).

As shown above, the high mountains of the Tropical Andes have a diachronous history. In the Eastern Cordillera (Northern Andes), favourable conditions for the settlement of alpine vegetation (paramo) may have existed from 7.6 Ma, whereas in the Central Andes and Venezuelan Andes, puna/paramo was established since 5 Ma. Palynological evidence suggests that alpine taxa such as Espeletiinae (Hooghiemstra et al. 2006) populated the Northern Andes from 5 Ma and rapidly diversified after their arrival (Diazgranados and Barber 2017). Diversification rates substantially increased during the Quaternary under the regime of repetitive glacial–interglacial cycles (e.g. van der Hammen et al. 1973; Torres et al. 2013; Flantua and Hooghiemstra 2018; Flantua et al. 2019 and the video therein) and is likely still ongoing (Diazgranados and Barber 2017); this is also apparent from molecular evidence in *Lupinus* (Hughes and Eastwood 2006) and *Hypericum* (Meseguer et al. 2015; Nürk et al. 2018).

The ecological zones are dynamic, and their elevational position and surface area fluctuated over time while following the rhythm of orbitally driven Pleistocene ice ages (Flantua and Hooghiemstra 2018; Flantua et al. 2014, 2019). The fossil record suggests that during the Quaternary glaciations, the páramo and montane forest extended downslope, whereas during the interglacials, they were limited to the higher elevational zones (van der Hammen et al. 1973; Hooghiemstra and Van der Hammen 2004; Torres et al. 2013). These climate-driven changes in páramo fragmentation, and—in consequence—connectivity between the gene pools, are thought to form an important driver of speciation in the high Andes. Fittingly, Madriñán et al. (2013) coined the high Andes paramo vegetation the "fastest radiating vegetation since the Pliocene" (see also Flantua and Hooghiemstra 2018; Flantua et al. 2019).

Unsurprisingly, current climate change is already affecting the position of paramo plants. Expeditions by a Danish (Morueta-Holme et al. 2015) and a French team (Moret et al. 2019a), respectively, resampled plants on the slopes of the volcanoes that Humboldt visited previously. They found that between 1802 and the present, high elevation taxa suffered an upslope displacement of more than 250 m (equivalent to ~1.5 °C warming) (Moret et al. 2019a), suggesting a risk of extinction under future scenarios of accelerated global warming.

The Tibet-Himalaya-Hengduan Region

Often referred to as the "roof of the world", Tibet, or more specifically the Qinghai-Tibet Plateau (QTP), is one of the largest highlands on Earth and forms part of an extensive mountain region composed of the Kunlun and the Qilian Mountains to the north, the Karakorum range to the west, the Himalayas to the south, and the Hengduan Mountains to the east (Favre et al. 2015). Even though the entire region is often referred to as a biodiversity hotspot, it is in particular the mountains at its western, southern, and eastern fringe that are home to remarkable levels of biodiversity, with the Himalayas and the Hengduan Mountains both boasting more than 10,000 species of vascular plants with a high degree of endemism (Mittermeier et al. 2004). These Central Asian mountain ranges, in particular the Himalayas, with their fabled peaks (the exact elevations were unknown until 1855), were extremely intriguing to Humboldt as they promised the opportunity to expand his global comparisons of elevational gradients. He tried for decades to obtain permission to travel to India, but this was ultimately denied, likely due to the anti-colonialism stance that he has expressed in some of his works (Théodoridès 1966). Here, we pick up on his fascination and summarize our current knowledge of mountain evolution in the vast Tibeto-Himalayan-Hengduan (THH) region (Fig. 5).

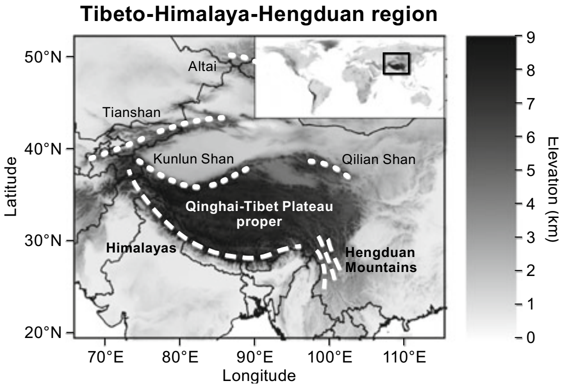


Fig. 5 Geographic locations of Tibet-Himalaya-Hengduan (THH) region and adjacent mountain regions. Dashed lines in the South represent stylized location of the Himalayas and the Hengduan Mountains, immediately adjacent to the Qinghai-Tibet Plateau (QTP; dark grey). Dotted lines show stylized location of mountains north and northwest of the QTP, and beyond

Similar to the Tropical Andes, our understanding of orogenesis in the THH region is constantly evolving. In contrast to the long-standing assumption that major uplift in this region was triggered by the collision of India and Asia (ca. 55–50 Ma), we now know that the Lhasa terrane (proto-Tibetan Plateau) was already at high elevation at that point in time and that surface elevation at the central plateau has likely been ca. 4000–5000 m since the mid or late Eocene (Molnar et al. 2010). Oxygen isotope ratios and the fossil record point to largely differing palaeo-elevations for several sedimentary basins throughout the QTP region, and these have been interpreted as evidence for a gradual outward extension of the plateau (e.g. Mulch and Chamberlain 2006; Taponnier et al. 2001). In contrast, uplift of the (now) species-rich mountain ranges surrounding the plateau occurred much more recently. For example, uplift of the Himalayas occurred only after the Eocene and current elevations were likely only reached by the late Miocene (Gébelin et al. 2013; Taponnier et al. 2001; Wang et al. 2008). The Hengduan Mountains were previously assumed to have uplifted even more recently, at the end of the Miocene and to have reached present elevations during the late Pliocene (Sun et al. 2011; Wang et al. 2014); however, newer fossil and tectonic evidence suggests that parts of these mountains might have been as high as 3000 m since the late Eocene and that near-modern elevations were established by the early Oligocene (Su et al. 2019).

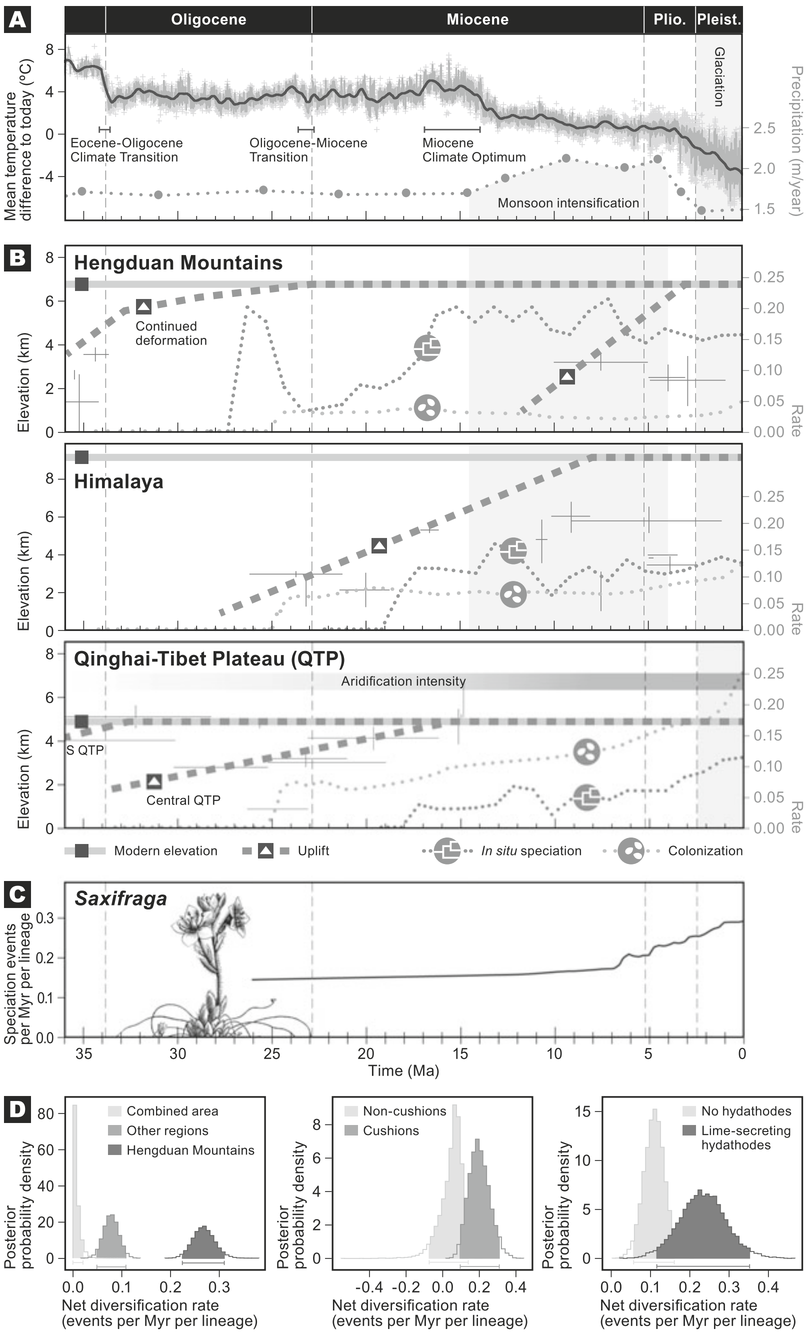
These complex continuously evolving uplift scenarios complicate our understanding of the evolutionary timeline of the formation of the characteristic, highly diverse species assemblages for which these mountain ranges are known today. For example, fossil evidence indicates that while the central plateau still housed humid subtropical vegetation during the Middle Eocene (Su et al. 2020), high elevation vegetation was likely already established in the northern parts of the QTP in the early Oligocene (Dupont-Nivet et al. 2008). However, several patterns are beginning to emerge following more than two decades of investigation into diversification of species-rich plant groups of the region, for example in *Saussurea* (Wang et al. 2009), *Meconopsis* (Xie et al. 2014), and *Saxifraga* (Ebersbach et al. 2017). Mountain uplift in the wider THH region was long used as a relatively undifferentiated explanation for past bursts of species diversification observed from time-calibrated phylogenies (Renner 2016). However, when investigated more closely, it appears that the Himalayas, the Hengduan Mountains, and the QTP itself differ widely in the timing of species diversification and colonization and that these events cannot always be directly related to reconstructed orogenic processes (Fig. 6b; Ding et al. 2020; Mosbrugger et al. 2018). For instance, many modern alpine plant lineages have been shown to have experienced bursts of diversification from the late Miocene onwards (Mosbrugger et al. 2018), but major uplift and deformation were likely already completed throughout the QTP itself and the Himalayas at that time (Fig. 6b, c).

In addition to geologic processes, climatic change has recently been highlighted as a driver for shaping the distribution and diversification of biota in the wider Tibetan region. For instance, beside global developments such as overall cooling during the Miocene (Fig. 6a), species assemblages were likely affected by regional events such as the intensification of the Asian summer monsoon. This provided seasonally increased moisture levels to biota in the Himalayas and Hengduan Mountains and led to pronounced erosion, thus shaping regional relief and impacting elevational gradients (Ding et al. 2020; Fig. 6a, b). In contrast, intensifying aridification, likely also triggered by uplift events, limited moisture availability on the QTP itself and throughout Central Asia, thus driving the establishment of high alpine, dry-adapted vegetation in these areas (Ding et al. 2020; Fig. 6b).

Intense climatic change was shown to have impacted diversification of lineages, likely via key opportunities provided by altered climatic conditions. For example, in the species-rich, alpine-arctic genus *Saxifraga* which is particularly diverse in the THH region, diversification rates were shown to have been faster in species characterized by two key traits: the cushion habit and lime-secreting hydathodes (Ebersbach et al. 2018; Fig. 6d). The evolution of these adaptations to the high alpine life zone likely allowed for colonization of novel, rock habitats and exploitation of that niche space. Similar patterns of elevational niche differentiation have been found in several other plant groups (Favre et al. 2016; Matuszak et al. 2016) throughout the THH region and in other mountain ranges, for example for the Andean bellflowers (Fig. 4d).

Pleistocene climate fluctuations had a significant impact on species richness patterns throughout the THH region (Muellner-Riehl 2019). In general, the exact timing and the extent of glaciations throughout the region are still under debate. However, it has become clear that many alpine lineages were able to survive episodes of adverse climate in situ or in peripheral glacial refugia, in particular in the Hengduan Mountains, and were likely driven towards differentiation by recurrent contraction and expansion of their distribution ranges as well as the resulting flickering connectivity of the elevational belts (Muellner-Riehl 2019). Recolonization patterns following deglaciation were likely an additional important factor leading to the current distribution of biodiversity in this region, with the Hengduan Mountains playing a crucial role as a source of alpine biota for both, the Himalayas and the QTP (Xing and Ree 2017; Ding et al. 2020).

Importantly, despite the progress that has been made towards our understanding of the manifold historical processes and factors contributing to the geographical


A
Oligocene
Miocene
Plio.
Pleist.
Glaciation
Mean temperature difference to today (°C)
Precipitation (m/year)
Eocene-Oligocene Climate Transition
Oligocene-Miocene Transition
Miocene Climate Optimum
Monsoon intensification
B
Hengduan Mountains
Continued deformation
Elevation (km)
Rate
Himalaya
Qinghai-Tibet Plateau (QTP)
Aridification intensity
S QTP
Central QTP
Modern elevation
Uplift
In situ speciation
Colonization
C
Saxifraga
Speciation events per Myr per lineage
Time (Ma)
D
Combined area
Other regions
Hengduan Mountains
Non-cushions
Cushions
No hydathodes
Lime-secreting hydathodes
Posterior probability density
Net diversification rate (events per Myr per lineage)

◂**Fig. 6** Historical plant diversification patterns in the Tibet-Himalaya-Hengduan (THH) region in relation to global climatic changes and regional orogenic processes. **a** Global Cenozoic climate dynamics inferred from deep-sea benthic foraminiferal stable-isotope records (modified from Westerhold et al. 2020) and monsoon conditions (modelled mean annual precipitation) (modified from Farnsworth et al. 2019; Ding et al. 2020). **b** Surface uplift scenarios and median rates of biotic assembly (in situ speciation and colonization) for the main mountain systems of the THH region (modified from Ding et al. 2020). Crosses indicate raw proxy paleoaltimetry data as reviewed by Ding et al. (2020). Continuous grey lines indicate approximate modern elevation and dashed lines represent simplified uplift scenarios. Note that competing uplift scenarios exist for the Hengduan Mountains. Shaded areas correspond to major climatic changes of relevance to the region as indicated in **a**. **c** Exemplary speciation rate through time for representative taxonomic groups with high species diversity in the THH region, *Saxifraga* sect. *Ciliatae* (modified from Ebersbach et al. 2017). Depicted: *S. brunonis* (Engler and Irmscher 1916). **d** Abiotic and biotic drivers of diversification in *Saxifraga*, inferred using Multiple State Speciation and Extinction (MuSSE) models. Left: Net diversification rates (speciation–extinction) of *Saxifraga* in the Hengduan Mountains versus other regions. Middle: Net diversification rates of cushion saxifrages versus other life forms. Right: Net diversification rates of lineages with lime-secreting hydathodes (glands) versus others. Licenses for use were acquired for Westerhold et al. (2020) and Ding et al. (2020), all other previously published materials are licensed under CC BY 4.0 or are no longer under copyright

patterns of biodiversity that we observe today, we are still far from having a complete picture on these patterns. For example, even though the Andes and the Hengduan Mountains share some important characteristics (deeply dissected physiognomies and steep elevational gradients, North–South orientation allowing for "escape routes" for climate-driven migration during periods of glaciation, rich lowland floras amenable to local recruitment following glaciation events), their relative importance in relation to historical processes in these wider mountain regions has remained unclear. Nevertheless, these two examples outlining our current knowledge of the evolution of two emblematic mountain regions illustrate strikingly that high levels of biodiversity and high levels of geodiversity (i.e. diversity of abiotic conditions) which commonly characterize mountain systems (e.g. habitat heterogeneity, elevational zonation) are linked and should be examined in a unified geobiodiversity framework, for example under the recently postulated mountain geobiodiversity hypothesis (Mosbrugger et al. 2018; Muellner-Riehl et al. 2019). Despite a lack of understanding of fundamental time-dependent processes such as orogeny, continental drift, and evolution, Humboldt had already mused about these interactions and memorably depicted their interdependencies in his *Naturgemälde*.

Conclusions and Outlook

Our review presents a perspective on the birth of the field of biogeography and pays tribute to Humboldt's farsightedness of bringing together animate and inanimate nature, which is still at the very core of modern historical biogeography. Following

Humboldt's conviction towards his final years of life, that one would have to take a "higher stand" ("einen höhern Standpunkt" einnehmen, Humboldt 1845) to fully understand nature, which reflected his insights when ascending the Chimborazo, our review here puts focus on two mountain systems, the Andes and the THH region, both of which also played an important role for Humboldt's insights. Building on Humboldt's idea of exploring the relationship between geodiversity and biodiversity on mountains in particular, a recent study provided a global comparison of mountain geodiversity and vascular plant diversity, looking both at short-term (ecological) as well as long-term (evolutionary) processes (Muellner-Riehl et al. 2019). These analyses indeed pointed towards an important role of historical factors on mountain plant species richness. This is just one example of many showing that drawing inspiration from Humboldt helps us to find explanations for global patterns of mountain vascular plant biodiversity, and more generally, to gain new insights into historical biogeography even in our modern times.

Acknowledgements We are very grateful to Gabriele Rada (iDiv, Halle-Jena-Leipzig) for her work on the figures. We also are deeply grateful to Gregor Falk, Simon Schneider, and Manfred Strecker for inviting us to contribute to this special volume dedicated to the memory of Alexander von Humboldt. We also acknowledge constructive comments from Kärin Nickelsen (LMU, Munich), Susanne Renner (WU, St. Louis), Henry Hooghiemstra (UvA, Amsterdam), Salomon Kroonenberg (TU, Delft), and an anonymous reviewer.

References

Anderson VJ, Saylor JE, Shanahan TM, Horton BK (2015) Paleoelevation records from lipid biomarkers: Application to the tropical Andes. GSA Bull 127:1604–1616

Antonelli A, Nylander JAA, Persson C, Sanmartin I (2009) Tracing the impact of the Andean uplift on Neotropical plant evolution. Proc Natl Acad Sci USA 106:9749–9754

Antonelli A, Zizka A, Carvalho FA, Scharn R, Bacon CD, Silvestro D, Condamine FL (2018) Amazonia is the primary source of Neotropical biodiversity. Proc Natl Acad Sci USA 115:6034–6039

Avise JC (2000) Phylogeography: the History and Formation of Species. Harvard University Press, Cambridge, Mass

Bacon CD, Velásquez-Puentes FJ, Hoorn C, Antonelli A (2018) Iriarteeae palms tracked the uplift of Andean Cordilleras. J Biogeogr 45:1653–1663

Bartholomew JG (1902) The philosophy of map-making and the evolution of the great german atlas. Scott Geogr Mag 18:34–39

Becquerel H (1896a) Sur les radiations invisibles émises par les corps phosphorescents. Comptes rendus de l'Academie des Sciences, Paris 122:501–503 [séance du 2 March 1896]

Becquerel H (1896b) Emission de radiations nouvelles par l'uranium metallique. Comptes rendus de l'Academie des Sciences, Paris [séance du 18 May 1896]

Bermúdez MA, Hoorn C, Bernet M, Carrillo E, Van Der Beek, PA, Garver JI, Mora JL, Mehrkian K (2017) The detrital record of late-Miocene to Pliocene surface uplift and exhumation of the Venezuelan Andes in the Maracaibo and Barinas foreland basins. Basin Res 29:370–395

Bicudo TC, Sacek V, de Almeida RP, Bates JM, Ribas CC (2019) Andean tectonics and mantle dynamics as a pervasive influence on Amazonian ecosystem. Sci Rep 9:1–11

Biermann KR (1985) Goethe in vertraulichen Briefen Alexanders von Humboldt. Goethe-Jahrbuch 102:16

Bijl PK, Schouten S, Sluijs A, Reichart GJ, Zachos JC, Brinkhuis H (2009) Early Palaeogene temperature evolution of the southwest Pacific Ocean. Nature 461:776–779

Böhme K, Müller-Wille S (2013) In der Jungfernheide hinterm Pulvermagazin frequens. NTM 21:93–106

Böttcher JC (2020) Beobachtung als Lebensart. Praktiken der Wissensproduktion bei Forschungsreisen im 18. Jahrhundert. Franz Steiner Verlag, Stuttgart

Braterman PS (2013) How science figured out the age of Earth. In: Determining the age of the Earth, Scientific American Geochronology

Browne J (1983) The secular ark: studies in the history of biogeography. Yale University Press

Brundin L (1966) Transantarctic relationships and their significance, as evidenced by chironomid midges: with a monograph of the subfamilies Podonominae and Aphroteniinae and the Austral Heptagyiae. Kungl Svens Vetenskapakad Handl 11:1–472

Buffon G (1749) Histoire Naturelle Générale et Particulière, Tome III. L'Imprimerie Royale, Paris

Buffon G (1756) Les animaux sauvages (de l'Histoire Naturelle Générale et Particulière, Tome VI). In: Œuvres. Gallimard, Paris, pp 703–707

Buffon G (1761) Histoire Naturelle Générale et Particulière, Tome IX. L'Imprimerie Royale, Paris

Buffon G (1766) Histoire Naturelle Générale et Particulière, Tome XIV. L'Imprimerie Royale, Paris

Buffon G (1778) Les époques de la nature. Muséum National de Histoire Naturelle, Paris

Buttimer A (2001) Beyond Humboldtian science and Goethe's way of science: Challenges of Alexander von Humboldt's geography (Jenseits Humboldtianischer Wissenschaft und Goethes Wissenschaftsverständnis: Herausforderungen der Geographie Alexander von Humboldts). Erdkunde 55:105–120

Camerini JR (1993) Evolution, biogeography, and maps: An early history of Wallace's Line. Isis 84:700–727

Cannon SF (1978) Science in culture: The early Victorian period. Dawson, New York [Pages 73–110 on Humboldtian Science (see also Nicolson M 1987)]

Chen YW, Wu J, Suppe J (2019) Southward propagation of Nazca subduction along the Andes. Nature 565:441–447

Christmann T & Oliveras I (2020). Nature of Alpine Ecosystems in Tropical Mountains of South America. Encyclopedia of World Biomes. Elsevier Inc.

Cleef AM (1979) The phytogeographical position of the neotropical vascular páramo flora with special reference to the Colombian Cordillera Oriental. In: Larsen K, Holm-Nielsen LB (eds) Tropical Botany, Academic Press, London, pp 175–184

Crame JA (2020) Early Cenozoic evolution of the latitudinal diversity gradient. Earth-Sci Rev 202:103090

Crick FH, Barnett L, Brenner S, Watts-Tobin RJ (1961) General nature of the genetic code for proteins. Nature 192:1227–1232. https://doi.org/10.1038/1921227a0. PMID 13882203

Crisci JV, Cigliano MM, Morrone JJ, Roig-Juñent S (1991) Historical biogeography of southern South America. Syst Zool 40:152–171

Cuatrecasas J (1958) *Aspectos de la vegetación natural de Colombia*. Colombia: Editorial Voluntad

Cutler AH (2009) Nicolaus Steno and the problem of deep time. In: Rosenberg GD (ed) The Revolution in Geology from the Renaissance to the Enlightenment, GSA Memoirs 203, 143–148. https://doi.org/10.1130/978-0-8137-1203-1-203.0.143

Darlington PJ (1957) Zoogeography: the Geographical Distribution of Animals. Wiley, New York

Darwin C (1859) On the Origin of Species by Means of Natural Selection, or the Preservation of Favoured Races in the Struggle for Life. John Murray, London

Darwin C, Wallace AR (1858) On the tendency of species to form varieties; and on the perpetuation of varieties and species by natural means of selection. Zool J Linn Soc 3:46–62. https://doi.org/10.1111/j.1096-3642.1858.tb02500.x

Daum AW (2019) Alexander von Humboldt. C. H. Beck, München, p 17–19

de Candolle AP (1820) Essai élémentaire de géographie botanique. Extrait du 18 volume du Dictionnaire des Sciences Naturelles. FG Levrault, Strasbourg 18:359–422
Dettelbach M (1996) 17 Humboldtian Science. In: Jardine N, Secord JA (eds) Cultures of Natural History. Cambridge University Press, Spary
Diazgranados M, Barber JC (2017) Geography shapes the phylogeny of frailejones (Espeletiinae Cuatrec. Asteraceae): a remarkable example of recent rapid radiation in sky islands. PeerJ 5: e2968
Ding W-N, Ree, RH, Spicer RA, Xing Y-W (2020) Ancient orogenic and monsoon-driven assembly of the world's richest temperate alpine flora. Science 369:578–581. https://doi.org/10.1126/science.abb4484
Dupont-Nivet G, Hoorn C, Konert M (2008) Tibetan uplift prior to the Eocene-Oligocene climate transition: evidence from pollen analysis of the Xining Basin. Geology 36:987–990
Eakin CM, Lithgow-Bertelloni C (2018) An overview of dynamic topography: The influence of mantle circulation on surface topography and landscape. In: Hoorn C, Perrigio A, Antonelli, A (eds) Mountains, Climate, and Biodiversity, Wiley-Blackwell, Chichester, pp 37–49
Ebach MC (2015) Origins of Biogeography. Springer, New York, New York, USA
Ebersbach J, Schnitzler J, Favre A, Muellner-Riehl AN (2017) Evolutionary radiations in the species-rich mountain genus *Saxifraga* L. BMC Evol Biol 17:1–13. https://doi.org/10.1186/s12862-017-0967-2
Ebersbach J, Muellner-Riehl AN, Favre A, Paule J, Winterfeld G, Schnitzler J (2018) Driving forces behind evolutionary radiations: *Saxifraga* section *Ciliatae* (Saxifragaceae) in the region of the Qinghai–Tibet Plateau. Bot J Linn Soc 186:304–320
Egerton FN (2009) A history of the ecological sciences, Part 32: Humboldt, nature's geographer. Bulletin Ecol Soc Am 90:253–282
England PC, Molnar P, Richer FM (2007) Kelvin, Perry and the Age of the Earth. Amer Sci 95:342. https://doi.org/10.1511/2007.66.342
Engler H, Irmscher E (1916) Saxifragaceae – *Saxifraga*. In: Engler H (ed) Das Pflanzenreich. Regni vegetabilis conspectus, vol. 1919. Engelmann, Leipzig, p 449–709
Escapa IH, Catalanot SA (2013) Phylogenetic analysis of Araucariaceae: integrating molecules, morphology, and fossils. Int J Plant Sci 174:1153–1170
Farnsworth A, Lunt, DJ, Robinson, SA, Valdes PJ, Roberts WHG, Clift, PD, Markwick P, Su, T, Wrobel, N, Bragg F, Kelland S-J, Pancost RD (2019) Past East Asian monsoon evolution controlled by paleogeography, not CO_2. Sci Adv 5:eaax1697. https://doi.org/10.1126/sciadv.aax1697
Favre A, Päckert M, Pauls SU, Jähnig SC, Uhl D, Michalak I, Muellner-Riehl AN (2015) The role of the uplift of the Qinghai-Tibetan Plateau for the evolution of Tibetan biotas. Biol Rev 90:236–253
Favre A, Michalak I, Chen CH, Wang, J-C, Pringle JS, Matuszak S, Sun H, Yuan Y-M, Struwe L, Muellner-Riehl A (2016) Out-of-Tibet: the spatio-temporal evolution of *Gentiana* (Gentianaceae). J Biogeogr 43:1967–1978
Fjeldså J (2018) Mountains and the diversity of birds. In: Hoorn C, Perrigio A, Antonelli, A (eds) Mountains, Climate, and Biodiversity, Wiley-Blackwell, Chichester, pp 245–256
Flantua SG, Hooghiemstra H (2018) Historical connectivity and mountain biodiversity. In: Hoorn C, Perrigio A, Antonelli A (eds) Mountains, Climate, and Biodiversity, Wiley-Blackwell, Chichester, pp 171–185
Flantua SGA, Hooghiemstra H, Van Boxel JH, Cabrera M, González-Carranza Z, González-Arango C, (2014) Connectivity dynamics since the Last Glacial Maximum in the northern Andes: a pollen-driven framework to assess potential migration. Monographs Systematic Botany Missouri Botanical Garden 128:98–123
Flantua SG, O'dea A, Onstein RE, Giraldo C, Hooghiemstra H (2019) The flickering connectivity system of the north Andean páramos. J Biogeogr 46:1808–1825
Forster JR (1778) Observations Made During a Voyage Round the World [in H.M.S. Resolution] on Physical Geography, Natural History, and Ethic Philosophy. G. Robinson, London

Forster G (1791–1794) Ansichten vom Niederrhein, von Brabant, Flandern, Holland, England und Frankreich, im April, Mai und Junius 1790. Voss; Unger, Berlin
Galli L (2020) Alfred Russel Wallace or Alexander von Humboldt: Who "invented" biogeography? BELS 2:37–39. https://doi.org/10.15167/2612-2960/BELS2020.2.1.1211
Gébelin A, Mulch A, Teyssier C, Jessup MJ, Law RD, Brunel M (2013) The Miocene elevation of Mount Everest. Geology 41:799–802
Gentry AH (1982) Neotropical floristic diversity: phytogeographical connections between Central and South America, Pleistocene climatic fluctuations, or an accident of the Andean orogeny? Ann Mo Bot Gard 69:557–593
Glaubrecht M (2019) Wer erklärt uns die Natur? Humboldt oder Darwin. GEO Magazin [in German] 11:30–51
Goethe JW v (1795) Letter to Alexander von Humboldt
Goethe JW v (1797) Letter to Duke Carl August
Gooley T (2012) The Natural Explorer. Hodder & Stoughton, London
Grimmer F, Dupont L, Lamy F, Jung G, González C, Wefer G (2018) Early Pliocene vegetation and hydrology changes in western equatorial South America. Clim Past 14:1739–1754
Guntau M (2009) The rise of geology as a science in Germany around 1800. Geolog Soc Lon Spec Pub 317:163. https://doi.org/10.1144/SP317.9
Güttler N (2014) Das Kosmokop. Karten und ihre Benutzer in der Pflanzengeographie des 19. Jahrhunderts. Wallstein Verlag, Göttingen
Hazzi NA, Moreno JS, Ortiz-Movliav C, Palacio RD (2018) Biogeographic regions and events of isolation and diversification of the endemic biota of the tropical Andes. Proc Natl Acad Sci USA 115:7985–7990
Hennig W (1966) Phylogenetic Systematics. University of Illinois Press, Chicago. Translated by D. Dwight Davis and Rainer Zangerl
Hess HH (1960) Evolution of ocean basins. Report to Office of Naval Research, contract no. 1858, 081–067:38
Hess HH (1962). History of ocean basins. Petrologic studies, 4, 599–620
Hesse V (2005) Goethe, die Gebrüder Humboldt und die Medizin – Festvortrag
Hesse V (2012) Alexander von Humboldt und der Botaniker Carl Ludwig Willdenow: Wissenschaft und Freundschaft. Publication of a lecture that was held in the context of the festivities for the 200th anniversary of the Berlin "Gesellschaft für Natur-und Heilkunde" on June 10, 2010 in the Blossom Hall of the Botanical Museum in Berlin-Dahlem, and on October 28, 2010 in the Berlin-Brandenburg Academy of Sciences and Humanities. https://www.avhumboldt.de/?p=8313
Higgins MA, Ruokolainen K, Tuomisto H, Llerena N, Cardenas G, Phillips OL, Vasquez R, Räsänen M (2011) Geological control of floristic composition in Amazonian forests. J Biogeogr 38:2136–2149
Holmes A (1913) The Age of the Earth. Harper, London and New York
Holmes, A (1946) An estimate of the age of the Earth. Nature 157: 680–684
Hooghiemstra H, Van der Hammen T (2004) Quaternary ice-age dynamics in the Colombian Andes: developing an understanding of our legacy. Philos Trans R Soc 359:173–181
Hooghiemstra H, Wijninga VM, Cleef AM (2006) The Paleobotanical record of Colombia: Implications for Biogeography and Biodiversity. Ann Mo Bot Gard 93:297–325
Hoorn C, Bogotá-A GR, Romero-Baez M, Lammertsma EI, Flantua SG, Dantas EL, Dino R, Dermeval A do Carmo, Chemale Jr F (2017) The Amazon at sea: Onset and stages of the Amazon River from a marine record, with special reference to Neogene plant turnover in the drainage basin. Glob Planet Change 153:51–65
Hoorn C, Perrigo A, Antonelli A (eds.) (2018) Mountains, Climate and Biodiversity. John Wiley & Sons
Hoorn C, van der Ham R, de la Parra F, Salamanca S, ter Steege H, Banks H, Star W, Heuven BJv, Langelaan R, Carvalho FA, Rodriguez-Forero G, Lagomarsino L (2019) Going north and south: The biogeographic history of two Malvaceae in the wake of Neogene Andean uplift and connectivity between the Americas. Rev Palaeobot Palynol 264:90–109

Hughes C, Eastwood R (2006) Island radiation on a continental scale: Exceptional rates of plant diversification after uplift of the Andes. Proc Natl Acad Sci USA 103:10334–10339
Humboldt Av (1793) Florae Fribergensis Specimen, Plantas Cryptogamicas Praesertim Subterraneas Exhibens. Berolini
Humboldt Av (1806) Letter to Karoline von Wolzogen
Humboldt Av (1845–1850). Kosmos. Entwurf einer physischen Weltbeschreibung. Cotta, Stuttgart und Tübingen
Humboldt Av, Bonpland A (1807) Ideen zu einer Geographie der Pflanzen nebst einem Naturgemälde der Tropenländer, auf Beobachtungen und Messungen gegründet, welche vom 10ten Grade nördlicher bis zum 10ten Grade südlicher Breite, in den Jahren 1799, 1800, 1801, 1802 und 1803 angestellt worden sind. Bearbeitet und herausgegeben von dem ersten. Cotta, Tübingen
Humphries CJ, Parenti L (1986) Cladistic Biogeography. Clarendon, Oxford
Humphries CJ, Parenti L (1999) Cladistic biogeography. 2nd ed. Oxford University Press, New York
Hutchinson GE (1957) Concluding remarks. Cold Spring Harbor Symp 22:415–427
Hutton J (1788) Theory of Earth; or an investigation of the laws observable in the composition, dissolution, and restoration of land upon the globe. Trans Royal Soc Edinburgh 1:209–304
Jackson ST (2009a) Humboldt, Ecology, and the Cosmos. Introduction to Essay on the Geography of Plants 1–52. University of Chicago Press, Chicago and London
Jackson ST (2009b) Alexander von Humboldt and the general physics of the Earth. Science 324:596–597
Jackson ST (2019) Humboldt for the Anthropocene. Science 365:1074–1076
Johnston AK (1848/1850) The Physical Atlas, A Series of Maps & Illustrations of the Geographical Distribution of Natural Phenomena Embracing I Geology. II Hydrography. III Meteorology. IV Natural History. The Geographical Society, Berlin. William Blackwood & Sons, Edinburgh, London
Jovanović L (2020) The Cosmopolitan Circumnavigator of the South Seas: A Biography of Georg Forster. In: Encyclopédie Internationale des Histoires de l'Anthropologie. Berose, Paris
Kimura M (1968) Evolutionary rate at the molecular level. Nature 217:624–626. https://doi.org/10.1038/217624a0
Kimura M (1983) The Neutral Theory of Molecular Evolution. Cambridge University Press
Kirschner JA, Hoorn C (2019) The onset of grasses in the Amazon drainage basin, evidence from the fossil record. Front Biogeogr 12:e44827. https://doi.org/10.21425/F5FBG44827
Klein U (2015) Humboldts Preußen. Wissenschaft und Technik im Aufbruch. Wissenschaftliche Buchgesellschaft, Darmstadt
Lagomarsino LP, Condamine, FL, Antonelli A, Mulch A, Davis CC (2016) The abiotic and biotic drivers of rapid diversification in Andean bellflowers (Campanulaceae). New Phytol 210:1430–1442. https://doi.org/10.1111/nph.13920
Larson JL (1968) The Species Concept of Linnaeus. Isis 59: 291–299
Lieberman BS (2000) Paleobiogeography. Plenum/Kluwer Academic, New York
Linder HP, Aspinall R, Bonaccorso E, Guayasamin JM, Hoorn C, Ortega-Andrade HM, (2019) Editorial. Humboldt Special Issue: The legacy of Alexander von Humboldt: Exploring the links between geo- and biodiversity. J Biogeogr 46:1625–1626
Linnaeus C (1741) Oratio de telleuris habitabilis incremento. Cornelius Haak, Leiden
Lomolino MV, Riddle BR, Whittaker RJ (2017) Biogeography: Biological Diversity Across Space and Time. Sinauer Associates, Sunderland, MA
Luebert F, Weigend M (2014) Phylogenetic insights into Andean plant diversification. Front Ecol Evol 2:27
Lyell C (1830) Principles of Geology, being an attempt to explain the former changes of the Earth's surface, by reference to causes now in operation. John Murray, London
MacArthur RH, Wilson EO (1963) An equilibrium theory of insular zoogeography. Evolution 17:373–387

MacArthur RH, Wilson EO (1967) The Theory of Island Biogeography. Princeton Univ. Press, Princeton, N.J.
Madriñán S, Cortés AJ, Richardson JE (2013) Páramo is the world's fastest evolving and coolest biodiversity hotspot. Front Genet 4:192
Mariss A (2015) A world of new things. Praktiken der Naturgeschichte bei Johann Reinhold Forster. Campus Historische Studien 72. Campus Verlag, Frankfurt am Main
Martínez C, Madrinan S, Zavada M, Alberto Jaramillo C (2013) Tracing the fossil pollen record of Hedyosmum (Chloranthaceae), an old lineage with recent Neotropical diversification. Grana 52 (3):161–180
Martínez C, Jaramillo C, Correa-Metrío A, Crepet W, Moreno JE, Aliaga A, Moreno F, Ibañez-Mejia M, Bush MB (2020) Neogene precipitation, vegetation, and elevation history of the Central Andean Plateau. Sci Adv 6:eaaz4724
Matthew WD (1915) Climate and evolution. Ann Acad Sci NY 24:171–318
Matuszak S, Favre A, Schnitzler J, Muellner-Riehl AN (2016) Key innovations and climatic niche divergence as drivers of diversification in subtropical Gentianinae in southeastern and eastern Asia. Am J Bot 103:1–13
Matzke NJ (2018) BioGeoBEARS: BioGeography with Bayesian (and likelihood) Evolutionary Analysis with R Scripts. version 1.1.1, published on GitHub on November 6, 2018. https://doi.org/10.5281/zenodo.1478250
Mayr G (2022) Paleogene fossil birds. Springer, Cham
Meseguer AS, Lobo, JM, Ree R, Beerling DJ, Sanmartín I (2015) Integrating fossils, phylogenies, and niche models into biogeography to reveal ancient evolutionary history: the case of *Hypericum* (Hypericaceae). Syst Biol 64:215–232
Mittermeier RA, Seligmann PA, Ford H (eds) (2004) Hotspots revisited. CEMEX, Mexico City
Molnar P, Boos WR, Battisti DS (2010) Orographic controls on climate and paleoclimate of Asia. Thermal and mechanical roles for the Tibetan Plateau. Annu Rev Earth Planet Sci 38:77–102
Moret P, Muriel P, Jaramillo R, Dangles O (2019a) Humboldt's Tableau Physique revisited. Proc Natl Acad Sci USA 116:12889–12894
Moret P, Muriel P, Jaramillo R, Dangles O (2019b) Humboldt's historical data are not messy, they just need expert examination. Proc Nat Acad Sci 116:21348–21349
Morrone JJ, Crisci JV (1995) Historical biogeography: introduction to methods. Annu Rev Ecol Syst 26:373–401. https://doi.org/10.1146/annurev.es.26.110195.002105
Morueta-Holme N, Engemann K, Sandoval-Acuña P, Jonas JD, Segnitz RM, Svenning JC (2015) Strong upslope shifts in Chimborazo's vegetation over two centuries since Humboldt. Proc Natl Acad Sci USA 112:12741–12745
Mosbrugger V, Favre A, Muellner-Riehl AN, Päckert M, Mulch A. (2018) Cenozoic evolution of geo-biodiversity in the Tibeto-Himalayan region. In: Hoorn C, Perrigio A, Antonelli A (eds) Mountains, Climate, and Biodiversity, Wiley-Blackwell, Chichester, pp 429–448
Muellner-Riehl A (2019) Mountains as Evolutionary Arenas: Patterns, Emerging Approaches, Paradigm Shifts, and Their Implications for Plant Phylogeographic Research in the Tibeto-Himalayan Region. Front Plant Sci 10:195. https://doi.org/10.3389/fpls.2019.00195
Muellner-Riehl AN, Schnitzler J, Kissling WD, Mosbrugger V, Rijsdijk KF, Seijmonsbergen AC, Versteegh H, Favre A (2019) Origins of global mountain plant biodiversity: testing the 'mountain-geobiodiversity hypothesis'. J Biogeo 46:2826–2838. https://doi.org/10.1111/jbi.13715
Mulch A, Chamberlain CP (2006) The rise and growth of Tibet. Nature 439:670–671
Müller-Wille S (1999) Botanik und weltweiter Handel. Zur Begründung eines natürlichen Systems der Pflanzen durch Carl von Linné (1707–1778) (= Studien zur Theorie der Biologie. Band 3). Verlag für Wissenschaft und Bildung, Berlin
Müller-Wille S, Böhme K (2020) „Jederzeit zu Diensten". Karl Ludwig Willdenows und Carl Sigismund Kunths Beiträge zur Pflanzengeographie Alexander von Humboldts. In: Päßler U, Ette O (eds): Geographie der Pflanzen. edition humboldt print, vol 1. J.B. Metzler, Stuttgart. https://doi.org/10.1007/978-3-476-04965-0_4

Myers N, Mittermeier RA, Mittermeier CG, Da Fonseca GA, Kent J (2000) Biodiversity hotspots for conservation priorities. Nature 403:853–858
Nelson G, Platnick NI (1981) Systematics and Biogeography: Cladistics and Vicariance. Columbia University Press, New York
Newton I (1675) Letter to Robert Hooke. https://digitallibrary.hsp.org/index.php/Detail/objects/9792
Nicolson M (1987) Alexander von Humboldt, Humboldtian science and the origins of the study of vegetation. Hist Sci 25:167–194
Nicolson M (1996) Humboldtian plant geography after Humboldt: The link to ecology. Br J H Sci 29:289–310
Nirenberg MW, Matthaei HJ (1961) The dependence of cell-free protein synthesis in *E. coli* upon naturally occurring or synthetic polyribonucleotides. Proc Natl Acad of Sci USA 47:1588–1602
Nirenberg MW, Caskey T, Marshall R, Brimacombe R, Kellogg D, Doctor B, Hatfield D, Levin J, Rottman F, Pestka S, Wilcox M, Anderson F (1966) The RNA code and protein synthesis. Cold Spring Harb Symp Quant Biol 31:11–24
Nürk NM, Michling F, Linder HP (2018) Are the radiations of temperate lineages in tropical alpine ecosystems pre-adapted? Global Ecol and Biogeogr 27:334–345
Ochoa D, Hoorn C, Jaramillo C, Bayona G, Parra M, De la Parra F (2012) The final phase of tropical lowland conditions in the axial zone of the Eastern Cordillera of Colombia: Evidence from three palynological records. J S Am Earth Sci 39:157–169
Oreskes N (1999) The Rejection of Continental Drift : Theory and Method in American Earth Science. Oxford University Press, New York
Ospovat D (1977) Lyell's theory of climate. J Hist Biol 10:317–339
Ott RF (2020) How lithology impacts global topography, vegetation, and animal biodiversity: A global-scale analysis of mountainous regions. Geophys Res Let e2020GL088649
Parenti L (2007) Common Cause and Historical Biogeography. In: Ebach MC, Tangney RS, (eds) Biogeography in a Changing World. CRC Press-Taylor and Francis Group, Boca Raton, California, pp 61–71
Patterson C (1956) Age of meteorites and the Earth. Geochim Cosmochim Acta 10:230–237
Pérez-Escobar OA, Chomicki G, Condamine FL, Karremans AP, Bogarín D, Matzke NJ, Silvestro D, Antonelli A (2017) Recent origin and rapid speciation of Neotropical orchids in the world's richest plant biodiversity hotspot. New Phytol 215:891–905
Perrigo A, Hoorn C, Antonelli A (2020) Why mountains matter for biodiversity. J Biogeogr 47:315–325. https://doi.org/10.1111/jbi.13731
Platnick NI, Nelson G (1978) A method of analysis for historical biogeography. Syst Zool 27:1–16
Rahbek C, Borregaard MK, Antonelli A, Colwell RK, Holt BG, Nogues-Bravo D, Rasmussen CMØ, Richardson K, Rosing MT, Whittaker RJ, Fjeldså J, (2019) Building mountain biodiversity: Geological and evolutionary processes. Science 365:1114–1119
Raven PH, Axelrod DI (1974) Angiosperm biogeography and past continental movements. Ann Mo Bot Garden 61:539–673
Renner SS (2005) Relaxed molecular clocks for dating historical plant dispersal events. Trends Plant Sci 10:550–558. https://doi.org/10.1016/j.tplants.2005.09.010
Renner SS (2016) Available data point to a 4-km-high Tibetan Plateau by 40 Ma, but 100 molecular-clock papers have linked supposed recent uplift to young node ages. J Biogeogr 43:1479–1487
Restrepo-Moreno SA, Foster DA, Bernet M, Min K, Noriega S (2019) Morphotectonic and orogenic development of the Northern Andes of Colombia: A low-temperature thermochronology perspective. In: Cediel F, Shaw RP (eds) *Geology and Tectonics of Northwestern South America,* Springer, Cham, pp 749–832
Ronquist F, Sanmartín I (2011) Phylogenetic methods in biogeography. Annu Rev Ecol Evol Syst. 42:441–464. https://doi.org/10.1146/annurev-ecolsys-102209-144710

Rosen DE (1978) Vicariant patterns and historical explanation in biogeography. Syst Zool 27:159–188
Rosenberg GD (2006) Nicholas Steno's Chaos and the shaping of evolutionary thought in the Scientific Revolution. Geology 34:793–796
Rosenberg GD (2009a) Introduction: The Revolution in Geology from the Renaissance to the Enlightenment. In: Rosenberg GD (ed) The Revolution in Geology from the Renaissance to the Enlightenment. GSA Memoir 203, USA. https://doi.org/10.1130/978-0-8137-1203-1-203.0.1
Rosenberg GD (2009b) The measure of man and landscape in the Renaissance and Scientific Revolution. In: Rosenberg GD (ed) The Revolution in Geology from the Renaissance to the Enlightenment. GSA Memoir 203, USA. https://doi.org/10.1130/978-0-8137-1203-1-203.0.1
Rudwick MJ (2005). Bursting the limits of time: the reconstruction of geohistory in the age of revolution. University of Chicago Press
Rupke NA (2008) Alexander von Humboldt: A Metabiography. University of Chicago Press, Chicago/London
Sanger F, Nicklen S, Coulson AR (1977) DNA sequencing with chain-terminating inhibitors. Proc Natl Acad Sci USA 74:5463–5467. https://doi.org/10.1073/pnas.74.12.5463
Sanmartín I (2012) Historical biogeography: Evolution in time and space. Evo Edu Outreach 5:555–568. https://doi.org/10.1007/s12052-012-0421-2
Sanmartín I, Ronquist F (2004) Southern Hemisphere biogeography inferred by event-based models: plant versus animal patterns. Syst Biol 53:216–243
Schouw JF (1823) Grundzüge einer allgemeinen Pflanzengeographie. Berlin: Reimer
Sclater PL (1858) On the general geographical distribution of the members of the class Aves. J Proc Linn Soc 2:130–145
Secord JA (1991) Darwin and Geology. BJHS 24:133–157
Simpson GC (1953) Evolution And Geography An Essay On Historical Biogeography With Special Reference To Mammals. Oregon State University of Higher Education, Eugene, OR
Stigall AL, Lieberman BS (2005) Using environmental niche modeling to study the Late Devonian biodiversity crisis. In: Over DJ, Morrow JR, Wignall PB (eds) Understanding the Late Devonian and Permian-Triassic biotic and climatic events: towards an integrated approach. Developments in paleontology and stratigraphy. Elsevier, Amsterdam, pp 93–180
Stockey RA (1982) The Araucariaceae: an evolutionary perspective. Rev Palaeobot Palynol 37(1–2):133–154
Su T, Spicer RA, Li S-H, Xu H, Huang J, Sherlock S, Huang Y-J, Li S-F, Wang L, Jia L-B, Deng W-Y-D, Liu J, Deng C-L, Zhang S-T, Valdes PJ, Zhou Z-K (2019) Uplift, climate and biotic changes at the Eocene–Oligocene transition in south-eastern Tibet. Natl Sci Rev 6:495–504. https://doi.org/10.1093/nsr/nwy062
Su T, Spicer RA, Wu F-X, Farnsworth A, Huang J, Del Rio C, Deng T, Ding L, Deng W-Y-D, Huang Y-J, Hughes A, Jia L-B, Jin J-H, Li S-F, Liang S-Q, Liu J, Liu X-Y, Sherlock S, Spicer T, Srivastava G, Tang H, Valdes P, Wang T-X, Widdowson M, Wu M-X, Xing Y-W, Xu C-L, Yang J, Zhang C, Zhang S-T, Zhang X-W, Zhao F, Zhou Z-K (2020) A Middle Eocene lowland humid subtropical "Shangri-La" ecosystem in central Tibet. Proc Natl Acad Sci USA 117:32989–32995
Sun B-N, Wu J-Y, Liu Y-S, Ding S-T, Li X-C, Xie S-P, Yan D-F, Lin Z-C (2011) Reconstructing Neogene vegetation and climates to infer tectonic uplift in western Yunnan, China. Palaeogeogr Palaeoclimatol Palaeoecol 304:328–336
Sundell KE, Saylor JE, Lapen, TJ, Horton, BK (2019) Implications of variable late Cenozoic surface uplift across the Peruvian central Andes. Sci Rep 9:4877. https://doi.org/10.1038/s41598-019-41257-3
Taponnier P, Zhiqin X, Roger F, Meyer B, Arnaud N, Wittlinger G, Jingsui Y (2001) Oblique stepwise rise and growth of the Tibet Plateau. Science 294:1671–1677
Testo WL, Sessa E, Barrington DS (2019) The rise of the Andes promoted rapid diversification in Neotropical *Phlegmariurus* (Lycopodiaceae). New Phytol 222:604–613
Théodoridès J (1966) Humboldt and England. Brit J Hist Sci 3:39–55

Torres V, Hooghiemstra H, Lourens L, Tzedakis PC (2013) Astronomical tuning of long pollen records reveals the dynamic history of montane biomes and lake levels in the tropical high Andes during the Quaternary. Quat Sci Rev 63:59–72

Trewick S (2016) Plate Tectonics in Biogeography. In: Richardson D, Castree N, Goodchild MF, Kobayashi A, Liu W, Marston RA (eds) International Encyclopedia of Geography: People, the Earth, Environment and Technology. Wiley-Blackwell

Troll C (1968) The cordilleras of the tropical Americas. Colloquium Gerographicum 9, 5–56, Dummler Verlag, Bonn, Proceedings of the UNESCO Mexico Symposium August 1–6, 1966

Unger F (1852) Versuch einer Geschichte der Pflanzenwelt. Wilhelm Braumüller, Vienna

van der Hammen T (1974) The Pleistocene changes of vegetation and climate in tropical South America. J Biogeogr 1:3–26

van der Hammen T, Cleef AM (1986) Development of the high Andean páramo flora and vegetation. In: Vuillemier F, Monasterio M (eds) High Altitude Tropical Biogeography. Oxford University Press

van der Hammen T, Werner JH, Van Dommelen H (1973) Palynological record of the upheaval of the Northern Andes: a study of the Pliocene and Lower Quaternary of the Colombian Eastern Cordillera and the early evolution of its High-Andean biota. Rev Palaeobot Palynol 16:1–122

Wallace AR (1863) On the physical geography of the Malay archipelago. J Roy Geogr Soc 33:217–234

Wang C, Zhao X, Liu Z, Lippert PC, Graham SA, Coe RS, Y H, Zhu L, Liu S, Li Y (2008) Constraints on the early uplift history of the Tibetan Plateau. Proc Natl Acad Sci USA 105:4987–4992

Wang Y-J, Susanna A, Raab-Straube E von, Milne R, Liu J-Q (2009) Islandlike radiation of *Saussurea* (Asteraceae: Cardueae) triggered by uplifts of the Qinghai–Tibetan Plateau. Bot J Linn Soc 97:893–903

Wang P, Scherler D, Liu-Zeng J, Mey J, Avouac JP, Zhang Y, Shi D (2014) Tectonic control of Yarlung Tsangpo Gorge revealed by a buried canyon in Southern Tibet. Science 346:978–981

Watson JD, Crick FHC (1953) Molecular structure of nucleic acids: A structure for deoxyribose nucleic acid. Nature 171:737–738. https://doi.org/10.1038/171737a0

Wegener A (1912) Die Entstehung der Kontinente. Geolog Rundschau [in German] 3:276–292

Westerhold T, Marwan N, Drury AJ, Liebrand D, Agnini C, Anagnostou E, Barnet JSK, Bohaty SM, De Vleeschouwer D, Florindo F, Frederichs T, Hodell DA, Holbourn AE, Kroon, D, Lauretano V, Littler K, Lourens LJ, Lyle M, Pälike H, Röhl U, Tian J, Wilkens RH, Wilson PA, Zachos JC (2020): An astronomically dated record of Earth's climate and its predictability over the last 66 million years. Science 369:1383–1387

Whittaker RJ, Riddle BR, Hawkins BA, Ladle RJ (2013) The geographical distribution of life and the problem of regionalization: 100 years after Alfred Russel Wallace. J Biogeogr 40:2209–2214

Wiley EO (1988) Phylogenetic systematics and vicariance biogeography. Syst Zool 37:271–290

Willdenow KL (1787) Florae Berolinensis Prodromus. – secundum systema Linneanum. Wilhelm Vieweg, Berlin

Willdenow KL (1798) Grundriss der Kräuterkunde zu Vorlesungen. Haude und Spener, Berlin. http://mdz-nbn-resolving.de/urn:nbn:de:bvb:12-bsb10707168-7

Wulf A (2016) Alexander von Humboldt und die Erfindung der Natur. C. Bertelsmann Verlag, München

Xie H, Ash JE, Linde CC, Cunningham S, Nicotra A (2014) Himalayan-Tibetan plateau uplift drives divergence of polyploid poppies: *Meconopsis* Viguier (Papaveraceae). PloS one 9: e99177

Xing Y, Ree RH (2017) Uplift-driven diversification in the Hengduan Mountains, a temperate biodiversity hotspot. Proc Natl Acad Sci USA 114:E3444–E3451

Ziggelaar A (translator) (1997) Chaos: Niels Stensen's chaos-manuscript, Copenhagen 1659, complete edition: Copenhagen, Danish National Library of Science and Medicine

Ziggelaar A (2009) The age of Earth in Niels Stensen's geology. In: Rosenberg GD (ed) The Revolution in Geology from the Renaissance to the Enlightenment. GSA Memoirs 203. https://doi.org/10.1130/978-0-8137-1203-1-203.0.135

Zuckerkandl E, Pauling L (1965) Molecules as documents of evolutionary history. J Theor Biol 8:357–366

Carina Hoorn is a geologist/paleoecologist and Associate Professor at the Institute for Biodiversity and Ecosystem Dynamics (IBED) of the University of Amsterdam, The Netherlands. She is interested in Cenozoic plant evolution, climate, and paleoenvironments, particularly in the Andes-Amazonian system, the Tibeto-Himalayan region and Myanmar. She also was the principal editor of *Amazonia, Landscape and Species Evolution* (2010) and *Mountains, Climate and Biodiversity* (2018) published by Wiley.

Jana Ebersbach is Assistant Professor at the Institute of Biology at Leipzig University, with a keen interest in the processes and circumstances that lead to intra- and interspecific diversity in plants.

Alexandra Muellner-Riehl is Professor of Molecular Evolution and Plant Systematics and Director of Herbarium (LZ) at Leipzig University, Germany, and full member of the German Centre for Integrative Biodiversity Research (iDiv). She is a plant systematist with a focus on historical biogeography. Her work centers on describing biodiversity in species-rich areas of high global conservation priority and elucidating the processes that gave rise to this biodiversity.

Understanding the Composition and Functionality of the New World

Fig. 1 Le Chimborazo, vu depuis le plateau de Tapia. Voyage de Humboldt et Bonpland. Premiere Partie. Relation Historique. Atlas Pittoresque. Paris. F. Schoell. 1810. Vues des Cordillères, et monumens des peoples indigènes de l'Amérique (Courtesy of David Rumsey Collection)

Revisiting the Chimborazo Volcano—Cradle of Plant Geography

Naia Morueta-Holme

Abstract In 1806, Alexander von Humboldt and his team visited Chimborazo, a 6263 m colossal volcano in Ecuador. The extensive plant observations the team collected here and in the surrounding Andes Mountains, along with measurements of the environment, served Humboldt to define the new field of plant geography, the science of "what grows where and why". Humboldt synthesized the main drivers of the distribution of life on Earth, spread the notion of the importance of climate on geographical patterns in nature, and recognized the role of humans in destroying nature through environmental change. Yet Humboldt's legacy did not only provide the beginning of this new scientific field. His plant observations and collections give us a unique glimpse of what the distribution of vegetation along elevation gradients was in his time. In this chapter, we travel to the place where the field was born in the literal and figurative sense. We explore the changes that the vegetation of Chimborazo has undergone, and we look into Humboldt's influence on plant geography and see how, generations later, plant geography—and biogeography in general—have gained prominence as fields for understanding, predicting, and addressing the impact of human-driven global change on biodiversity.

Keywords Biotic change · Anthropocene · Historical resurveys · Biogeography · Climate change · Land use change · Biodiversity crisis

Footsteps—Tracking von Humboldt

> Three steps. Stop. Catching breadth in the thin air. Repeat. I focus on stepping in the footsteps of our guide in the snow, slowly making my way up the volcano. I try to hurry to keep pace with the group, to keep focusing on the footsteps (they remind me of why we are here). I try to ignore the merciless wind, ignore that it is pitch dark (it is 4 am). I try to ignore the sheer drop to each side of the icy ridge we cross at one point (the dense fog

N. Morueta-Holme (✉)
Center for Macroecology, Evolution and Climate, GLOBE Institute, University of Copenhagen, Copenhagen, Denmark
e-mail: morueta-holme@sund.ku.dk

G. C. Falk et al. (eds.), *Alexander von Humboldt*,
https://doi.org/10.1007/978-3-030-94008-9_4

> helps). I try to ignore yesterday's warning from our guide that we should be back on solid ground before the morning sun starts loosening the ice ("then it might get a little dangerous"). We must find the last plant, find the upper limit for plant growth on this side of the mountain. Today. The scientist in me should feel excitement every time we find a new individual. It means the growth limit has shifted upwards even more. Instead, I sigh at each plant that peeks teasingly through the snow. It means we must continue hiking. Usually, I am very fond of hikes and adventures, but right now I cannot help but wonder how I ended up here.
>
> At long last. We find the last individuals of the mustard *Draba aretioides* and the aster *Pentacalia chimborazensis* – in full bloom. We fight our way up to 5,200 meters and declare this to be the upmost sample of our study. The peak of the volcano towers more than 1,000 meters above our heads, at 6,263 meters. At least the fog shields us from the view, even though morning has broken (it is now 6 am). Just like our predecessor 210 years ago, we must accept that any pretension of reaching the peak from this side of the mountain is hopeless for us. While he was disappointed to turn around, I am mostly relieved that we can now go back to safe ground. We have achieved our goal: we have acquired the necessary plant collections and have made it above the limit of plant growth on the Chimborazo volcano in Ecuador – a limit he originally defined. He, the father of plant geography, Alexander von Humboldt.

In the summer of 1802, Humboldt was on his third year in the Americas, on a five year exploration of this major addition to European maps. Together with his companion, the botanist Aimé Bonpland (1773–1858), and their team, he had been traveling through the Amazon rainforest along the Orinoco River, visited Cuba, Venezuela, Colombia, and Ecuador. Tirelessly, they noted, described, and collected the species—plants in particular—that they found on their way. With the finest instruments of the time, they would measure anything in the environment that Humboldt thought might influence the occurrence of species: the temperature, the elevation, the air pressure, the gravity, and even the blueness of the sky. The motivation was curiosity, awakened back in his home country Germany by the objects that explorers of the time brought back to Europe. Humboldt himself wrote later, in 1806 (von Humboldt 1806, in Buttimer 2012) that

> the sight of exotic plants, even of dried specimens in a herbarium, fired my imagination and I longed to see the tropical vegetation in southern countries with my own eyes.

The five years of data collection set the foundation for a long and productive research and writing career until Humboldt's death in 1859. The plant collections were described upon their return to Europe by C. S. Kunth (1788–1850) in *Nova Genera et Species Plantarum*—a work of no fewer than seven volumes. Most of the species were new to science and documented some of the prominent patterns of the geography of plants. Humboldt's observations of the patterns of nature were not unique—the early history of the field of biogeography was impacted by several great naturalists. Even in the Americas, he would exchange ideas with the botanist José Celestino Mutis (1732–1808) and naturalist Francisco José de Caldas (1768–1816) among others. However, Humboldt's ability to synthesize the cutting-edge knowledge of the time within the physical, geological, and biological sciences represented a new holistic and quantitative approach to the understanding of nature. His synthesis set the foundation of plant geography, which he described (Humboldt and Bonpland [1807] 2009: 64) as the

> science that concerns itself with plants in their local association in the various climates. This science, vast as its object, paints with a broad brush the immense space occupied by plants.

The culmination of Humboldt's ability to synthesize knowledge is represented in the "Tableau Physique des Andes et Pays Voisins", one of his foremost contributions to science. The "Tableau Physique" consists of an exquisite illustration of the profile of Chimborazo, flanked by tables detailing measurements in the physical environment as they change with increasing elevation. On the central part, the cross section of Chimborazo, names were written for the vegetation zones and select plants, summarizing their distribution along the elevation gradient of the Andes Mountains. The choice of Chimborazo to summarize the vegetation and environment of the Andes was far from random. Until the Himalayas were measured in the 1840s, Chimborazo was thought to be the tallest mountain on Earth. What better place on Earth to use as a symbol and illustration of one of the core patterns of plant geography, the replacement of species along elevation?[1]

What Grows Where and Why?

> Large, thick grass tussocks cover the landscape here at 3,800 meters of elevation. It is impossible to set up tents, so we have to spend the night at a spot where the trail widens a little. There is no doubt that Humboldt's description of this vegetation type, "Pajonal" ("the straw region") is fitting. We are above the tree line in the paramo, but the tussocks are interrupted here and there by bushes: *Calceolaria ericoides* (Calceolariaceae) with the golden shoe shaped flowers and rosemary looking leaves, the blue flowered Monninas, and the yellow flowered asters *Gynoxis buxifolia*. Hidden between the tussocks, we find a treasure trove of small flowering herbs. The grass tussocks dominate all the way up to 4,400 meters, but as we hike up Chimborazo, we find more and more rosette plants (e.g. the aster genera *Hypochaeris* and *Werneria*) and cushion plants like *Azorella* (Apiaceae), *Pernettya* (Ericaceae) and *Geranium* (Geraniaceae). The cushions form increasingly large green tapestries along the mountain side, sprinkled by delicate white and yellow flowers. Here and there, the soft and white fuzzy leaves of the asters *Senecio nivalis* and *Culcitium canescens* stick out like little rabbit ears. As a child, whenever I thought of tropical plants, I used to think of lianas, palms, large leaves, and oversized, bright colored flowers. Yet the top of the tropical world could not be more different.
>
> We hike for several days in this fascinating landscape and collect information on where the plants grow. For every 100 meters that we move up in elevation, we lay out a transect, a line along the elevation curve of the mountain, and count, note, photograph, and collect individuals of plants within five by five meter squares marked with plastic poles at the

[1] Humboldt later embarked on a trip to the Himalayas, but did not reach his goal. Still, because of the shape of the Earth not being a perfect sphere, the peak of Chimborazo is the point on Earth closest to the sun and would thus have remained a fine choice for the representation of elevation gradients in nature.

> beginning, the center and end of the transect. We press and dry the plants in newspapers and carry them down the mountain in big piles when the field work is over.

The dramatic change in vegetation that takes place along elevation gradients was one of the key patterns that Humboldt pondered about—not just as he observed them on the slopes of Chimborazo, but all the way from the lowlands of the Amazon basin to the peaks of the Andes. Through their extensive travels in the Americas and other parts of the world, Humboldt and his peers noticed other large-scale patterns in nature, which they documented for the first time ever with their observations and collections. For every pattern of what grows where that they discovered, the question "why" begged to be answered. Why do the numbers of species increase as we approach the equator from the poles? Why are so many species rare, occurring in very few places, while other species are found across vast areas or even on multiple continents? Why are species communities of distant places completely different, even when they have similar climates? Why do places like the Andes harbor many more rare species than temperate regions or even than other parts of the tropics? Thus, even if science in the time of Humboldt was mostly descriptive, his eagerness—one could almost say obsessiveness—to collect and describe data was not for the sake of collection. As he explained (von Humboldt 1799, in Knobloch 2007):

> I shall collect plants and fossils, I shall be able to make useful astronomic observations […], I shall conduct chemical analyses of the air,—but all that is not the main purpose of my expedition. Above all, I will observe the interactions of forces, the influence of the inanimate environment on plant and animal life.

In order to answer the question of "what grows where and why", Humboldt thus collected information not only on the occurrence of species but also on the environmental factors that could affect them. He summarized his findings in tables and figures, with the "Tableau Physique" as the ultimate synthesis of how different factors and species distributions are coupled along elevation gradients. Using this approach, Humboldt was able to derive that climate, and in particular temperature, plays a key role in driving the distribution of vegetation zones and individual plant species.

Today, climate is still recognized as one of the most important drivers of the distribution of species. We know that each individual species is adapted to a specific range of environmental conditions, or abiotic factors. On Chimborazo, the tussocks, rosettes, and cushion growth forms are some of the ways plants have adapted to this harsh environment to tolerate the relatively dry and cold climate. The plant cushions, for instance, work as sponges to keep moisture, and several other plant species can grow on them and take advantage of the nutrients that are released as the center of the cushion decomposes (Luteyn 1999). The white hairs that cover many of the plant species here—as opposed to "naked" sister species growing at lower elevations—provide insulation against the cold and reflect the sun rays, protecting the plant tissue from the high radiation levels found at high elevation. Plants may not care so much about the blueness of the sky, but they do care about getting sunburnt because of the thinner atmosphere at this elevation.

Along the elevation gradients, the changing environmental conditions allow for different species to thrive. Indeed, a big part of the explanation of why mountains around the world are so diverse compared to other parts of the world is found in precisely their climate. Not in a particular set of temperatures or precipitation, but in the fact that the topography creates many different combinations of climate conditions within a limited amount of space. Thus, the Northern Andes alone captures around half of the mean temperature and precipitation conditions of the entire planet, more than the 12 times larger area of the Amazon region (Rahbek et al. 2019). The tightly packed climate habitats—often unique worldwide—can thus support a mesmerizing number of species with different requirements.

Humboldt's studies led him to conclude that climate was of big importance for explaining the distribution of species. However, he neither believed in simple answers nor sought them. Rather, he wanted to understand the big picture of how different factors depended on and influenced each other, to obtain "insight into the hidden connections of the different powers and forces of nature" (von Humboldt 1849: vi). Humboldt was convinced that everything was interconnected (von Humboldt and Bonpland [1807] 2009: 79):

> In this great chain of causes and effects, no single fact can be considered in isolation

No factor could be studied separately from everything else, and all areas of science had to be used to understand the world—geology, geography, botany, climatology, and so on. It was indeed this holistic approach that made von Humboldt such an innovative scientist. Later, the tendency was for science to become increasingly specialized, splitting into different disciplines with a focus on a reductionist search for universal laws. However, today we see a renewed recognition of the complexity of the natural world and have gone back to Humboldt's interdisciplinary study approach. The same applies to the explanation of geographic patterns in nature. After some time of searches for simple explanations in ecology (especially in the 1970s), we are back to Humboldt's holism and search for "the big picture". Besides climate, we know that other factors such as the interaction with other organisms and the dispersal ability of species play important roles in explaining patterns of the distribution of species and ecosystems. All these factors interact with one another, and their relative importance changes across spatial scales from local to global, across temporal scales, across regions, and across organism groups. Importantly, since Humboldt, our improved knowledge of the formation of continents and mountains, and changes in the climate system over millions of years have led us to a much better understanding of how dynamic Earth and ecological processes in nature can be. While Humboldt did recognize that events in the history of Earth could influence the distribution of species, he described the occurrence of marine fossils and shells on mountain tops as mysterious. Thus, our view today of the world is as something much more dynamic than Humboldt and his peers could grasp, and we have found that geologic and climatic changes offer many answers to the movement, speciation, and extinction of species.

If we want to preserve the diversity of life on Earth, knowledge on its distribution and of what places harbor most species, can help us prioritize conservation efforts. Understanding the underlying drivers not only allows us to comprehend the complex forces that shape nature—it is also paramount for predicting how it may respond when the environment changes. The science of plant geography is still very much driven by curiosity like Humboldt was, yet with the added layer of urgency for meeting the needs of society to understand how the ecosystems we ourselves depend on might change into the future, and how they are best preserved. All the accumulated knowledge notwithstanding, the question of "what determines biodiversity", with its deep roots in the thoughts of Humboldt and his peers (Morueta-Holme and Svenning 2018), still remains one of the biggest unanswered questions of science in the twenty-first century (Pennisi 2005). Plant geography and biogeography in general have mainly searched for natural explanations to the large-scale patterns of nature. However, there is one piece of the puzzle of interconnections in nature that is only beginning to be incorporated into the answers, namely humans.

A New Player Driving Changes in Patterns

Very first day of field work. We are doing a preliminary survey to familiarize ourselves with the vegetation, and search for the lowest areas on Chimborazo to include in our study. I look down at the GPS in my hand. It is startling when I realize that were are already at 3,800 meters above sea level. Can we really not cover a broader elevation gradient? We look across the landscape. Further down, fields, scattered houses and larger villages are visible. If we want to study the possible impact of climate change on the distribution of plants, we will have to do with a comparison of the upper part of Chimborazo, which is protected by the nature reserve and not converted to agriculture.

A day in the middle of the field work. We are collecting plants in the lowest transect of the elevation gradient, at 3,800 meters. Halfway through the work, we see a four-wheeler pulling up by the trail at some distance. Five people get out with machetes. They cut at the grass tussocks, carry the straw to the car. They will be using it for their domestic animals, explains my colleague Pablo Sandoval-Acuña. Reserve or no reserve, Chimborazo does not escape the direct influence of human land use. In these lower transects, we also find non-native species like white clover (*Trifolium repens*) and red sorrel (*Rumex acetosella*). Both are native to Eurasia, but have been spread by humans to other continents either by accident or on purpose to grow as fodder. There are more along the sides of the trail, wide enough down here for cars to drive up, likely with seeds stuck in the wheels from lower fields. The impact of humans on species' distributions is pervasive.

Humboldt lived in the middle of the Industrial Revolution. The transformation to industrialized societies brought many benefits to the average person, with increases in wealth and quality of life, and spurring the growth of the world's human population from ~ 1 billion in 1800 to the over 7.7 billion people that today inhabit the planet. While the impacts of humans on the biosphere were already marked in earlier phases of human history through hunting and the spread of agriculture and trade, industrialization started spinning the wheels of massive environmental changes. By the end of Second World War, an explosion in the human enterprise and its global environmental footprint mark the so-called Great Acceleration (Steffen et al. 2007; Waters et al. 2016). Exponential growth in industrial production, motorized transportation, and water consumption are just a few of the indicators of the Great Acceleration. The consequent increases in CO_2 and other greenhouse gas emissions have led to the ongoing change of the global climate, with an increase in global mean temperatures of 1.1 °C since pre-industrial levels. The sum of these pervasive, lasting impacts of human activities on the planet has led to the denomination of an entirely new geologic epoch: the Anthropocene (Waters et al. 2016).

Humboldt worried about the destruction and pollution of some of the natural places he visited, and raised awareness about the negative impacts of humans on nature. For instance, he argued that reduced numbers of trees in Spain and Italy were not because the climates here were too hot for trees to exist, but because ancient civilizations had cut down the forests, and warned (von Humboldt 1849: 232):

> The wants and restless activity of large communities of men gradually despoil the face of the earth

Could Humboldt have imagined the magnitude of human imprint on Earth two centuries later? Any guess is speculation. As of today, we have altered around three quarters of the lands on Earth (IPBES 2019). What used to be wild habitats are now fields, cities, roads, and cattle ranches. The destruction of habitats, together with direct exploitation, climate change, pollution and the movement by humans of non-native species have brought us to the midst of a global biodiversity crisis, the 6th mass extinction. We are losing species and ecosystems at a rate unprecedented in human history, and only known from five previous mass extinction events, the last one being the extinction of the dinosaurs.

The climate crisis is a defining feature of our time. But how will nature react to ongoing climate change into the future? Will species adapt to the changes/move to track suitable environments? Or will they simply go extinct? In order to predict the trajectories that biodiversity patterns will follow under continued human-driven environmental change, we need to understand how species have responded in the past. Humboldt may not have been able to answer these questions, yet his legacy data may. His observations on the distribution of species along elevation gradients provide us with a unique window to what nature looked like in the Andes two centuries ago. Revisiting some of the places Humboldt described can thus shed light onto the biotic changes that may have taken place since he wandered in these landscapes.

Resurveys Unveil Biotic Shifts in the Anthropocene

> The changes in vegetation are dramatic. 5,185 meters above sea level. That is the elevation at which we find the last plants on Chimborazo. Humboldt had reported 4,600 meters as the upper limit of vascular plant growth, with his last observation of a moss at around 4,700 meters during his climb of the volcano. The data we have collected every 100 meters from 3,800 to 5,200 meters along the slopes of the volcano allow us to compare the current distribution of plants and vegetation belts with Humboldt's observations. Two years after our expedition to the tallest mountain in Ecuador, my colleague Max Segnitz and I are making the last adjustments to the main figure of our publication. Inspired by Humboldt's insistence on using art to communicate science, Max has done digital refinements to a new painting illustrating the results of our study on the profile of Chimborazo. The painting represents an update of Humboldt's original "Tableau Physique" (though "slightly" coarser in artistic style). The vegetation and glacier limits in 1802 are on the left side, the 2012 update on the right.

Alexander von Humboldt's observations and collections of the vegetation and plants of Chimborazo and the surrounding mountains presented a unique opportunity to study biotic changes over a long time scale in the tropics—a region remarkable for its sparsity of historical species records. By following in Humboldt's footsteps on the southeastern side of Chimborazo, our resurvey in 2012 (Morueta-Holme et al. 2015) showed that the vegetation zones defined by Humboldt, individual species and genera, and the overall limit of plant growth appear to have shifted hundreds of meters upward, with a rough estimate of >500 m of average change. The responses in the upper range limit of individual species and genera were variable, with some found much higher in 2012 than Humboldt reported for 1802, while others were found at lower elevations. We cannot conclude how much individual species have in fact shifted up or down, as uncertainties grow when zooming into the details (an individual may have gone undetected at a given elevation in either survey). Yet the overall trend is clear: Even in the species-rich tropics, where climate change has been less pronounced than in temperate regions since the Industrial Revolution, nature is changing. The lower limit of Chimborazo's glaciers has melted back. Plants have followed upward, likely because of the newly exposed bare ground as well as the warmer growing conditions throughout the elevation range of the mountain.

Changes in geographic distributions are the most commonly observed responses of species to climate change (Scheffers et al. 2016). The upward shifts that the 2012 Chimborazo resurvey unveiled are consistent with findings from other mountains that have experienced warming. In Europe, resurveys of over a century of historical data from mountain summits have found that plant richness has been increasing as plants have been shifting upward tracking the increasingly warmer conditions (Steinbauer et al. 2018). It is not only plants that are shifting their distribution, but also animals. For instance, evidence for upslope shifts has been found in mammals of California (Moritz et al. 2008) and birds of Peru (Freeman et al. 2018). The variability in individual responses of plants of Chimborazo is also not unique. Most resurveys find that some species do not move upward, or even shift down. Only half of the mammal species in the California resurvey were found to shift upslope (Moritz et al. 2008), and when looking at the optimum elevation of plants in another California resurvey, the majority of plants had actually been shifting downward (Crimmins et al. 2011). While some of the variation may be due to uncertainties in the resurveys, it appears that responses to factors other than average temperature are driving these differences, e.g., downward shifts in water availability (Crimmins et al. 2011) or possibly habitat modifications, or release from competitors that have shifted up and now allow other species to spread to lower elevations (Lenoir et al. 2010). Just like Humboldt observed, multiple factors influence the distribution of species and add complexity to the responses in nature to environmental change.

Resurveys of historical datasets are challenging. There are many sources of uncertainty that introduce noise to the signal of how nature has or has not changed in response to anthropogenic environmental change. How reliable were Humboldt's elevation measurements? Where exactly did he and Bonpland collect and observe individual plant species? Why are there sometimes inconsistencies in the elevation limits that Humboldt describes in different publications? There is no doubt that historical data are messy, and require very careful examination. Historical accounts are often open to interpretation with today's eyes, and researchers may disagree on such interpretations. Humboldt's data are particularly challenging, as they were collected in a time before systematic sampling protocols became the norm in ecology. Behind the scenes of what may seem a simple subtraction of historical and current values of elevation to calculate distribution changes along an elevation gradient, lie a myriad of analyses, readings of handwritten historical documents in multiple languages, endless discussions with colleagues about minute details. In the case of the resurvey of Chimborazo, mere weeks of fieldwork required over two years of data analysis, compiling elevation ranges from different publications, checking for the sensitivity of results to methodological choices, confirming species identifications with some of the foremost botanists of the world, tracking down species names that have changed since Humboldt's time, lumping data for species recognized as more than one today, confirming that there were no systematic errors in Humboldt's elevation measurements by using Google Earth to locate the town squares or prominent houses (sometimes now converted into museums) from which he measured elevation throughout his travels in the Americas. Our best bet to alleviate the errors introduced by the many sources of uncertainty is to lean on multiple lines of evidence to discern robust trends of change. On Chimborazo, three parameters of biotic change—plant growth limit, average shifts across individual species and genera, and shifts in upper limits of vegetation belts all showed over 500 m upward shifts. A later, independent resurvey of Humboldt and Bonpland's preserved plant collections on another volcano, Antisana, documented similar upward shifts: The growth limit of plants had shifted 215–266 m (Moret et al. 2019), and the average shift across individual plant species was 458–563 m (Morueta-Holme et al. 2019). While exact shift estimates may be impossible to derive from resurveys of historical data, substantial upward shifts have been taking place on the upper slopes of the Ecuadorian Andes. There is no doubt that these fragile ecosystems are changing dramatically.

Species in mountains are on the move, but is it problematic? On the one hand, the elevation gradient in temperature allows species to better track climate changes compared to lowland species, which may have to shift hundreds of kilometers to track shifting suitable habitat conditions. The strong heterogeneity of mountain landscapes means that in some cases, species may simply need to move "sideways" to find suitable microclimatic conditions (Rahbek et al. 2019). Species inhabiting foothills have been found to expand their ranges, thus benefitting from climate change (Freeman et al. 2018). On the other hand, species that live at high elevations are more prone to running out of suitable habitat as they reach the mountaintop. Especially in tropical regions, where the latitudinal temperature gradient is weak, species may not have any suitable habitat left in the region, leading to extinction of species (Freeman et al. 2018). Differences in the individual responses of species to climate change mean there are winners and losers. Losses due to local extinctions or distributions shifts may lead to cascading effects through the food web, spreading the negative consequences of environmental change on biodiversity.

Climate has changed many times before. Fossils and the pollen record provide evidence that species have moved in the past as well, even the vegetation of the Andes. However, the rate at which climate is changing is unprecedented in human history, and its effects are exacerbating the negative impacts of other human-driven threats to biodiversity, in particular land transformations. Habitat loss dramatically reduces the population sizes of species, leading to less resilience to, e.g., extreme weather events. Fragmented landscapes are making migrations to track climate change much harder. In Europe and North America, many tree species are still moving toward equilibrium with climate since the Last Glacial Maximum 21,000 years ago. Yet the rates of migration required to keep the pace of anthropogenic climate change are much higher than those previously observed.

Humboldtian Approaches to Understand and Solve the Biodiversity Crisis

A day at home in front of the computer. The data has been analyzed with all sorts of approaches, possible explanations checked and rechecked. The changes we have found of the vegetation are stronger than we could expect only from the average temperature increases in Ecuador since Humboldt's time. There seems to never be a simple explanation for the patterns of nature. Even if most of the changes on Chimborazo are in line with an impact of warmer temperatures and decreasing rainfall along the full elevation gradient, humans have impacted the vegetation in other ways in the lower areas, despite the fact that they are within the protected reserve. Burning and harvesting of grass tussocks, which the locals use for their livestock, promotes the growth of this vegetation zone and outcompetes other species. It is also here that we find non-native species arrived with humans. The intensification of human land use in the region since to the time of Humboldt, thus appears to also play a role together with climate change.

Nature's responses to global environmental change are complex, and now more than ever there is an urgent need to understand how nature has been changing during the Anthropocene. Studies of biodiversity along spatial gradients on climate or land use intensity can help, yet face the challenge of a shifting baseline in biodiversity patterns as even the wildest places on the planet are affected by climate change. Resurveys of historical datasets involve tremendous, at times tedious, detective work for finding the datasets, digitizing them, assessing their reliability, and performing fieldwork with methodologies adjusted to both be comparable to the original survey and live up to modern standards. All of this is expensive in terms of time and money. Yet many of those historical datasets are the only window we have to gaze into the past and reconstruct the ecosystems visited by explorers of the world. While the window may be somewhat murky, the trends of biotic change we can extract are a powerful supplement to other approaches, such as standardized monitoring schemes covering shorter time spans, space-for-time modeling, and experiments. With the technological advances of the Anthropocene and the advent of image and text recognition tools, and the possibilities within crowdsourcing, we can accelerate the digitization of historical datasets hidden in museums and researchers' offices. We thus now stand a much better chance of taking advantage of this relatively untapped resource in our quest for understanding how nature has already been changing during the Anthropocene, disentangle the individual drivers of change and their interactions, and improve our predictions of responses to future scenarios of environmental change.

Humboldt argued that humans in some cases could drive deviations to the general relationship between climate and species diversity gradients (von Humboldt 1849: 232). Today, we know that we are changing the global and local climate, disrupting food webs, moving species, creating new barriers for dispersal. As a consequence, the evidence is mounting that humans can have a marked footprint even on fundamental, large-scale biogeographic patterns. While climate sets the scene for mammal food webs across the world, humans are making them more depauperate (Mendoza and Araújo 2019). Trees are being confined to steep terrains unsuitable for agriculture, leaving a human-driven worldwide topographic signal on the distribution of forest patches (Sandel and Svenning 2013). Even in the "pristine" Amazon, pre-Columbian settlements, with their spreading of edible fruit trees, have left a signature on the composition of current wild tree assemblages (Levis et al. 2017).

Undoubtedly, humans are as much a part of the interconnected web of life as plants, animals, and the physical environment. We are exerting a massive impact on nature, yet the interconnection goes both ways. Mankind completely depends on nature. Our quality of life hinges on the contributions of nature to people: materials, food production, medicine, clean water, climate control—and not the least cultural, spiritual, and inspirational values. As we deteriorate landscapes and change the global climate, the consequences for humans become obvious. If climate change continues unabated, the home regions of up to 3 billion people stand to experience temperatures now occurring in the Sahara—outside the climatic niche within which human civilizations have thrived for 6000 years (Xu et al. 2020). Species are moving in response to climate change, and the impacts of this on human livelihoods have already been documented all over the world (Pecl et al. 2017). On Chimborazo, the glaciers have diminished by ~20% since the 1980s (Appenzeller 2019). As a consequence, the water supplies that the people living in the region are so dependent on, are diminishing. In some cases, water flows have gone down by 80% over 40 years. And the conflicts between upstream and downstream settlements are growing (Appenzeller 2019). The story repeats itself across mountain glaciers throughout the tropics.

The climate change and biodiversity crises are both “wicked problems”—extremely complex to address because of the very interconnections between drivers and responses that Humboldt was trying to disentangle. Humboldt’s holistic approach is thus not only needed for understanding, but also for solving these global challenges. The transformative changes that societies all over the world need to undergo require strong international collaborations, and the mobilization of all disciplines in the natural, social sciences and humanities. The 17 Sustainable Development Goals of the United Nations are the first step, a joint vision for the world in which we wish to live. As all 17 goals are interlinked, it is paramount that the solutions we design for solving one issue do not worsen another. Massive monocultures of crops for biofuel production may attenuate the challenge of moving away from fossil fuels, yet feed the fire of biodiversity loss through increases in land transformation.

We need to find ways to give space back to wild nature, to allow natural dynamics to blossom, and to let species move to track climate change. Protection of remnants, rewilding, and mitigation of threats including climate change all go hand in hand. Thus, changes are needed through all levels of societies, through international treaties, national commitments, grass root movements, and individual choices. It is imperative that the solutions we choose are based on the best available knowledge. Thus, scientists have a big responsibility in communicating research findings. At the global level, the International Panel on Climate Change (IPCC) and the International Panel on Biodiversity and Ecosystem Services (IPBES) provide much needed syntheses of the state-of-the-art knowledge on climate change and biodiversity loss. Such “Humboldtian” efforts are key for informing political actions. Yet even at the individual level, scientists need to follow Humboldt’s continuous effort to communicate research to the public, to open the eyes of all to the wonders of nature. We only protect what we care about. We can only care for what we know.

Concluding Remarks: Plant Geography for the Future of Nature

Humboldt painted for us the first big picture of the geography of plants in the Americas. His influence on the field of plant geography is still discernible—in the methods used to derive relationships between patterns, in the renewed appreciation of the complexity of nature and value of holistic approaches to understand it, in the recognition of the importance of nature for humans. Today, we have a much more dynamic view of the world than Humboldt, but this is to a large extent thanks to scientific disciplines collaborating in the vein of Humboldt.

Our understanding of how fast the world can change and that we humans have an enormous impact on the patterns of nature means that the societal need for the field of biogeography has never been stronger. Nature as we have known it has already changed dramatically since the time of Humboldt and the Industrial Revolution. Because of human activities, species are disappearing at a pace only seen a handful of times in Earth's history—and never before experienced by humans. Once they are gone, these species are lost forever. While plant geography in its early days was mostly focused on the description and understanding of patterns in nature, today there is an increasing interest in using the tools and theories of the field to predict how global change will influence nature into the future, and how such predictions can be used to plan conservation efforts. Key to such predictions is that we understand the processes underlying patterns in nature. Our understanding has been much improved, but we biogeographers still have a colossal job ahead of us—in the field, in herbaria, in museums, and behind the computer. Hopefully, Humboldt can keep inspiring us in continuing this work.

> The wind has dwindled to a merciful breeze that makes the grass tussocks sway lightly. For once, the sun peeks through the clouds and warms up the *Azorella* cushion on which I am sitting. In the distance, the agricultural fields seem to creep closer. Every year, these fields need to feed more human mouths – just like everywhere else in the world. What will this place look like in 30 years? Extrapolating a model based on the observations of the past two centuries may give me an idea. Business as usual makes for gloomy predictions. Right now, however, I will simply enjoy the sight of the Ecuadorian Hillstar hummingbird – also known as Star of Chimborazo (*Oreotrochilus chimborazo*) – that has perched itself on the bright orange blossoms of the "flower of the Andes", *Chuquiraga jussieui*. As long as they are still here, there is a chance I will be able to show the treasure trove of species to my young children. Only time will tell if the model is wrong, and if we thus will be able to pass the torch of stewardship on to the next generation.

Acknowledgements I would like to thank all the colleagues that were involved in the resurvey of Chimborazo and those participating in discussions that shaped many of the ideas presented here. The chapter is based on Morueta-Holme and Svenning (2018) and the article in Danish Morueta-Holme, N. (2018) "Chimborazovulkanen". *URT* 42(2): 12–17. This work could not have been possible without the financial support from an EliteForsk Award, Ingeniør Fiedler og Hustrus Grant, and the Carlsberg Foundation.

References

Appenzeller, Tm. 2019. "Global Warming Has Made Iconic Andean Peak Unrecognizable." *Science*, September. https://doi.org/10.1126/science.aaz4542.

Buttimer, Anne. 2012. "Alexander von Humboldt and Planet Earth's Green Mantle." *Cybergeo: European Journal of Geography*, 616. https://doi.org/10.4000/cybergeo.25478.

Crimmins, Shawn M., Solomon Z. Dobrowski, Jonathan A. Greenberg, John T. Abatzoglou, and Alison R. Mynsberge. 2011. "Changes in Climatic Water Balance Drive Downhill Shifts in Plant Species' Optimum Elevations." *Science* 331 (6015): 324–327. https://doi.org/10.1126/science.1199040.

Freeman, Benjamin G., Micah N. Scholer, Viviana Ruiz-Gutierrez, and John W. Fitzpatrick. 2018. "Climate Change Causes Upslope Shifts and Mountaintop Extirpations in a Tropical Bird Community." *Proceedings of the National Academy of Sciences* 115 (47): 11982–11987. https://doi.org/10.1073/pnas.1804224115.

IPBES. 2019. *Summary for Policymakers of the Global Assessment Report on Biodiversity and Ecosystem Services of the Intergovernmental Science-Policy Platform on Biodiversity and Ecosystem Services*. Edited by Sandra Díaz, J. Settele, E. S. Brondízio, H. T. Ngo, M. Guèze, J. Agard, A. Arneth, et al. Bonn, Germany: IPBES secretariat. www.ipbes.net.

IPCC, 2021. "Summary for Policymakers". In: *Climate Change 2021: The Physical Science Basis. Contribution of Working Group I to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change*, edited by V. Masson-Delmotte, P. Zhai, A. Pirani, S.L. Connors, C. Péan, S. Berger, N. Caud, Y. Chen, L. Goldfarb, M.I. Gomis, M. Huang, K. Leitzell, E. Lonnoy, J.B.R. Matthews, T.K. Maycock, T. Waterfield, O. Yelekçi, R. Yu, and B. Zhou. Cambridge University Press. In Press

Knobloch, Eberhard. 2007. "Alexander von Humboldt - the Explorer and the Scientist." *Centaurus* 49 (1): 3–14. https://doi.org/10.1111/j.1600-0498.2007.00058.x.

Lenoir, Jonathan, Jean-Claude Gégout, Antoine Guisan, Pascal Vittoz, Thomas Wohlgemuth, Niklaus E. Zimmermann, Stefan Dullinger, Harald Pauli, Wolfgang Willner, and Jens-Christian Svenning. 2010. "Going against the Flow: Potential Mechanisms for Unexpected Downslope Range Shifts in a Warming Climate." *Ecography* 33 (2): 295–303. https://doi.org/10.1111/j.1600-0587.2010.06279.x.

Levis, C., F. R. C. Costa, F. Bongers, M. Peña-Claros, C. R. Clement, A. B. Junqueira, E. G. Neves, et al. 2017. "Persistent Effects of Pre-Columbian Plant Domestication on Amazonian Forest Composition." *Science* 355 (6328): 925–931. https://doi.org/10.1126/science.aal0157.

Luteyn, J.L. 1999. "Introduction to the Páramo Ecosystem." In *Páramos: A Checklist of Plant Diversity, Geographical Distribution, and Botanical Literature*, edited by J. L. Luteyn, 1–39. New York: The New York Botanical Garden Press.

Mendoza, Manuel, and Miguel B Araújo. 2019. "Climate Shapes Mammal Community Trophic Structures and Humans Simplify Them." *Nature Communications* 10 (5197): 1–9. https://doi.org/10.1038/s41467-019-12995-9.

Moret, Pierre, Priscilla Muriel, Ricardo Jaramillo, and Olivier Dangles. 2019. "Humboldt's Tableau Physique Revisited." *Proceedings of the National Academy of Sciences USA* 116 (26): 12889–12894. https://doi.org/10.1073/pnas.1904585116.

Moritz, Craig, James L Patton, Chris J Conroy, Juan L Parra, Gary C White, and Steven R Beissinger. 2008. "Impact of a Century of Climate Change on Small-Mammal Communities in Yosemite National Park, USA." *Science* 322 (5899): 261–264. https://doi.org/10.1126/science.1163428.

Morueta-Holme, Naia, and Jens-Christian Svenning. 2018. "Geography of Plants in the New World: Humboldt's Relevance in the Age of Big Data." *Annals of the Missouri Botanical Garden* 103: 315–329. https://doi.org/10.3417/2018110.

Morueta-Holme, Naia, Kristine Engemann, Pablo Sandoval-Acuña, Jeremy D Jonas, R Max Segnitz, and Jens-Christian Svenning. 2015. "Strong Upslope Shifts in Chimborazo's

Vegetation over Two Centuries since Humboldt." *Proceedings of the National Academy of Sciences USA* 112 (41): 12741–127445. https://doi.org/10.1073/pnas.1509938112.

Morueta-Holme, Naia, Kristine Engemann, Pablo Sandoval-Acuña, Jeremy D Jonas, R Max Segnitz, and Jens-Christian Svenning. 2019. "Resurvey of Antisana Supports Overall Conclusions of Chimborazo Study." *Proceedings of the National Academy of Sciences USA* 116 (43) 21346–21347. https://doi.org/10.1073/pnas.1911597116.

Pecl, Gretta T., Miguel B. Araújo, Johann D. Bell, Julia Blanchard, Timothy C. Bonebrake, I-Ching Chen, Timothy D. Clark, et al. 2017. "Biodiversity Redistribution under Climate Change: Impacts on Ecosystems and Human Well-Being." *Science* 355 (6332): 1–9. http://science.sciencemag.org/content/355/6332/eaai9214.

Pennisi, Elizabeth. 2005. "What Determines Species Diversity?" *Science* 309 (5731): 90. http://www.sciencemag.org/content/309/5731/90.short.

Rahbek, Carsten, Michael K Borregaard, Robert K Colwell, Bo Dalsgaard, Ben G Holt, Naia Morueta-Holme, David Nogues-Bravo, Robert J Whittaker, and Jon Fjeldså. 2019. "Humboldt's Enigma: What Causes Global Patterns of Mountain Biodiversity?" *Science* 365 (6458): 1108–1113. https://doi.org/10.1126/science.aax0149.

Sandel, Brody, and Jens-Christian Svenning. 2013. "Human Impacts Drive a Global Topographic Signature in Tree Cover." *Nature Communications* 4 (1): 2474. https://doi.org/10.1038/ncomms3474.

Scheffers, Brett R., Luc De Meester, Tom C. L. Bridge, Ary A. Hoffmann, John M. Pandolfi, Richard T. Corlett, Stuart H. M. Butchart, et al. 2016. "The Broad Footprint of Climate Change from Genes to Biomes to People." *Science* 354 (6313): aaf7671. https://doi.org/10.1126/science.aaf7671.

Steffen, Will, J Crutzen, and John R McNeill. 2007. "The Anthropocene: Are Humans Now Overwhelming the Great Forces of Nature?" *AMBIO: A Journal of the Human Environment* 36 (8): 614–21. https://doi.org/10.1579/0044-7447(2007)36[614:TAAHNO]2.0.CO.

Steinbauer, Manuel J., John Arvid Grytnes, Gerald Jurasinski, Aino Kulonen, Jonathan Lenoir, Harald Pauli, Christian Rixen, et al. 2018. "Accelerated Increase in Plant Species Richness on Mountain Summits Is Linked to Warming." *Nature* 556 (7700): 231–234. https://doi.org/10.1038/s41586-018-0005-6.

von Humboldt, Alexander. 1849. *Aspects of Nature, in Different Lands and Different Climates: With Scientific Elucidations*. 3rd ed. Philadelphia: Lea and Blanchard.

von Humboldt, Alexander, and Aimé Bonpland. 2009. "Essay on the Geography of Plants - with a Physical Tableau of the Equinoctial Regions (1807)." In *Essay on the Geography of Plants*, edited by Stephen T Jackson, 61–155. Chicago: The University of Chicago Press.

Waters, Colin N., Jan Zalasiewicz, Colin Summerhayes, Anthony D. Barnosky, Clément Poirier, Agnieszka Gałuszka, Alejandro Cearreta, et al. 2016. "The Anthropocene Is Functionally and Stratigraphically Distinct from the Holocene." *Science* 351 (6269): aad2622–aad2622. https://doi.org/10.1126/science.aad2622.

Xu, Chi, Timothy A. Kohler, Timothy M. Lenton, Jens-Christian Svenning, and Marten Scheffer. 2020. "Future of the Human Climate Niche." *Proceedings of the National Academy of Sciences USA* 117 (21) 11350–11355. https://doi.org/10.1073/pnas.1910114117.

Naia Morueta-Holme seeks to understand the synergistic effects of broad scale climate and regional land use change on the distribution of species to inform conservation practices under global environmental change. Her academic background is in plant biogeography. Currently, she is an Assistant Professor at the Center for Macroecology, Evolution and Climate at the University of Copenhagen, Denmark.

Humboldt, the Earth Scientist

Fig. 1 Volcan de Jorullo. Voyage de Humboldt et Bonpland. Premiere Partie. Relation Historique. Atlas Pittoresque. Paris. F. Schoell. 1810. Vues des Cordillères, et monumens des peuples indigènes de l'Amérique. (Courtesy of David Rumsey Collection)

Humboldt's Interpretation of the Andean Geology

Victor A. Ramos

Abstract Humboldt's output in a variety of scientific disciplines was phenomenal and quite extraordinary for his time, but the subsequent output of analyses, essays, biographies, and discussions on different aspects of his work has possibly been even greater. This paper concentrates on just one small aspect of his contributions, focusing on his understanding of the Andean mountains. The observations that he made during his two years in this mountain range are analyzed, as well as how his interpretations conflicted with the accepted theories of the time, despite his having had a conventional training at what was then one of most respected geological institutions in Europe, the *Freiberg Bergakademie*. One of his main legacies derives from his recognition of chains of volcanoes hundreds of kilometers in length within the Andes, parallel to their axial region, and of their relationship to major earthquakes. His meticulous description of these volcanoes led to him being acknowledged as the first Andean volcanologist. His passion for measuring and for quantifying his observations using the wide range of instruments that he carried with him on his travels enabled him to produce the first geological cross-sections of the Andes to include lithology and stratigraphy. The rock samples that he collected led to a new type of volcanic rock, known as andesite, being defined some years later. Andesite is one of the dominant types of volcanic rock in the Andes and has since been identified in many other parts of the world. Humboldt's interpretations were instrumental in resolving an old controversy between the Neptunists (led by his former teacher, Abraham Gottlob Werner) and the Plutonists (led by James Hutton), although he waited until a few years after Werner's death to release them. To fully appreciate Humboldt's work, however, it is important to view his geological legacy in the context of the depth and breadth of his knowledge of nature as is clear and evident from his Cosmos treatise.

Keywords Volcanoes · Earthquakes · Andes · Cross-sections · Andesite

V. A. Ramos (✉)
Instituto de Estudios Andinos don Pablo Groeber, Universidad de Buenos Aires-CONICET, Buenos Aires, Argentina
e-mail: andes@gl.fcen.uba.ar

G. C. Falk et al. (eds.), *Alexander von Humboldt*,
https://doi.org/10.1007/978-3-030-94008-9_5

Introduction

There have been a remarkable number of publications dedicated to Alexander von Humboldt, focusing on different aspects of his life, his scientific contributions, the significance of his observations, and the legacy that he has left behind in a variety of scientific disciplines. This paper will consider just one small aspect of his work and attempt to analyze his interpretation of the geology of the Andes following his extensive travels through this mountain range (see Fig. 1). It is important to note that the interpretations that he put forward were against the mainstream opinions of the time, including those that he had learned from his eminent teachers during his training at some of the best institutions of the eighteenth century, such as the *Bergakademie Freiberg*, which was the first School of Mines in Europe and considered to have been one of the cradles of geology at that time. This presentation aims to be as objective as possible regarding Humboldt's observations and interpretations and to avoid falling back on the sort of laudatory story that his work commonly seems to attract. However, the accuracy of his observations and his perhaps simplistic way of viewing nature allowed him to arrive at such unique explanations for a world about which so little was known at the time, that their validity never ceases to amaze.

Fig. 1 Humboldt's journeys in the Central and Northern Andes

An important aspect of the success of his expedition was the support provided by Aimé Bonpland, who Humboldt was able to rely on throughout his voyages. As Humboldt recognized in his narratives:

> I was aided by a courageous and enlightened friend, and it was singularly propitious to the success of our participated labor, that the zeal and equanimity of that friend never failed, amidst the fatigues and dangers to which we were sometimes exposed.[1]

A brief description of Humboldt's experience and studies prior to his arrival in South America is presented below, followed by an analysis of his observations in the Andes. This will allow his academic training to be considered when evaluating his work.

Academic Training

Alexander von Humboldt, together with his brother Wilhelm, received their early education from select tutors at the family's chateau until the time came for them to enter university. Following a frustrating experience at Frankfurt, they studied at the *Universität Göttingen*, which was one of the most renowned scientific centers in Europe at the time, especially in the field of natural sciences. In Göttingen Alexander von Humboldt had excellent teachers such as Georg Christoph Lichtenberg, one of the founders of experimental physics (Baran 2017), from whom he learned the value of experiments and measurements, as well as the value of quantifying precise observations. One of the most important and interesting people that Humboldt associated with in Göttingen was Georg Forster, who was undoubtedly the most prominent of the Germany-based scientific travelers at the time and, together with his father, had accompanied James Cook on one of his trips around the world. Forster encouraged Humboldt to make his first exploration trip, which was to investigate the basalts in the Rhine Valley. After a month-long trip, he wrote and published his first geological contribution: *Mineralogische Beobachtungen über einige Basalte am Rhein* (Mineralogical observations on some Rhine basalts). His one-year stay at Göttingen provided him with a solid basis in the natural sciences, including physics, chemistry, and botany, as well as other disciplines.

Humboldt's work on basalts enabled him to be quickly accepted at the *Bergakademie Freiberg*, where he studied in 1791 and 1792. The *Bergakademie Freiberg* which was the oldest university of mining and metallurgy in the world, was at that time directed by Abraham Werner (1726–1817) who was considered the "father of German geology". Werner was the founder of the Neptunist school which interpreted all rocks, including igneous rocks, as having formed by precipitation in an aqueous environment. Upon learning of this work on the Rhine basalts, whose

[1] Narratives, vol. 1, von Humboldt and Bonpland (1807).

origin Humboldt had also interpreted in this way, they were in complete agreement and he was quickly accepted into the academy.

During his two years in Freiberg, Humboldt learned to recognize minerals and rocks and studied the exploitation methods used in the mines that were common in the surrounding areas. While at the Academy he formed friendships with two of his classmates that would last for the rest of his days and have an important influence on his life: a Spanish student called Andrés Manuel del Río and a fellow countryman called Leopold von Buch.

This training in Freiberg and subsequent experience gained over three years as a mining inspector in Prussia allowed Humboldt to mature and to consolidate the knowledge that he had acquired, to the extent that he now felt ready to embark on his first great expedition and travel to the Americas.

Preparations for the Expedition

The preparations for this expedition involved two major concerns. The first was to obtain a permit from the King of Spain to carry out a scientific expedition to his American colonies, a task that would not have been easy at that time as the colonies were generally closed to such initiatives. Several months of planning were involved during which time contacts were cultivated with some of the participants in the Malaspina Expedition a few years earlier, which allowed Humboldt to obtain relevant maps, documents, and even a passport for free movement within the American territories. During these months, Humboldt also developed a friendship with the botanist Aimé Bonpland, who subsequently accompanied him on the expedition (see von Humboldt and Bonpland 1807).

The second major concern was to obtain all the instruments that would be required to take the measurements that his former teacher Lichtenberg had taught him would be essential to quantify his observations. These instruments were purchased from the best suppliers and instrument makers in Paris.

As Humboldt stated in his narratives, following months of preparation

> I was provided with instruments of easy and convenient use, constructed by the ablest makers, and I enjoyed the special protection of a government which, far from presenting obstacles to my investigations, constantly honored me with every mark of regard and confidence.

The main instruments that Humboldt used for his surveying and for making a wide range of observations were his sextants: one large one and one pocket sized. These he used to measure the sun's elevation and work out the time of day, and to obtain the latitude. He also used a Berthoud chronometer (a precision clock) to measure the time difference from Paris at noon, which he then used to calculate the longitude. These measurements, together with the barometric pressure, allowed him to calculate the altitude, latitude, and longitude. This information was crucial as there were no maps available for his trip across the Andes on which to accurately plot his route and his observations. Having these instruments with him meant that he was able to make accurate surveys of the main volcanoes that he came across, their lava flows, and a variety of other features.

Humboldt also had other instruments with which to measure the magnetic field, ambient humidity, atmospheric transparency, temperature variations, etc. Together with information acquired from intense correspondence with scientists from other parts of the world, these measurements allowed Humboldt to produce a series of maps of isotherms, magnetic declination, etc., that were subsequently published in his Cosmos treatise and gave rise to a new scientific discipline, which we now know as physical geography (von Humboldt 1849).

Transporting of all these instruments through the Andean valleys and up the mountains was certainly not easy: They were carried in a large box, almost two meters long, between two horses or mules. This was only feasible for the first part of the trip and when they came to the Nudo de Pastos pass between southern Colombia and northern Ecuador they had to leave some of the instruments behind. The large box and the heavier instruments were left in Popayán, where they are now exhibited in a private Natural History Museum.

Humboldt's Main Andean Observations

Soon after Humboldt and Bonpland set foot in South America and within their first few weeks in Cumaná, Venezuela, they experienced their first earthquake and were most impressed by two strong seismic shocks that occurred within 15 s of each other (von Humboldt and Bonpland 1822). They soon learnt that earthquakes were very frequent in this part of South America, but the biggest surprise for Humboldt must have been when he realized the important influence of volcanoes in the Andean Mountain chain (Hall 2001). His former mentor Werner taught that volcanoes were only of secondary importance in the formation of mountains, which contrasted with Hutton's ideas. For Hutton, igneous activity was one of the main driving forces behind the formation of mountains. When Humboldt traveled through the Magdalena River valley in Colombia, mapping in detail all the features that he came across and using his instruments, from the sextant to the barometer, to compile a detailed map of the region,[2] he became aware of the line of volcanoes over to the west, within the Central Cordillera.

Humboldt and Bonpland arrived in Bogotá where they stayed for two months and had the opportunity to exchange experiences and botanical specimens with José Celestino Mutis (1732–1808), a Colombian sage and botanist who was a well-known authority on South American flora (Von Humboldt and Bonpland 1805).

[2] Carta del Río Magdalena de 1801, Biblioteca Luis A. Arango, Bogotá.

(a) Mountain chains and volcanic activity

The expedition left Bogotá and progressed slowly up the Magdalena valley before then passing through the Paso del Quindio and crossing the Central Cordillera to the Cauca valley. One of the first volcanoes that Humboldt examined on the way from the Magdalena valley to the Cauca valley was the Puracé volcano. This volcano, which reaches 4.646 m a.s.l., is located within the Central Cordillera and is one of the most active volcanoes in Colombia: It is surrounded by hydrothermal springs and has a long history of eruptions (Monsalve et al. 2014). Humboldt had the opportunity to collect samples of a new class of volcanic rock, which was subsequently named andesite after the Andes where it was first sampled by him. These first volcanic rock samples collected by the expedition are now displayed in Madrid's *Museo de Ciencias Naturales*.

The difficult path through the Paso del Quindio (Dassow Walls 2009) made it clear that it was no longer going to be possible to continue transporting all the instruments. The Nudo de Waka and Nudo de Los Pastos gorges, on the border between Colombia and Ecuador, were too narrow to allow the passage of two mules or horses carrying the main box of instruments between them. The large sextant and some of the other instruments, as well as the large wooden box that they were carried in, were therefore left in Popayán. Humboldt was also very concerned about the safety of his fragile instruments, especially that of the last remaining barometer after two had been damaged on the trip between Cartagena and Bogotá. This last barometer was subsequently always transported on foot by an assistant whose sole mission was to ensure that it reached its destination safely. Humboldt well understood that without a barometer he would not be able to ascertain the height of the volcanoes and mountains that he was so interested in.

Near San José de Pasto he described an active volcano (Hall 2001) which he referred to as Pasto, and which possibly corresponds to the Galeras volcano. From the heights of the Waka massif, Humboldt was greatly impressed by the extraordinary sight of such a large number of imposing volcanoes surrounding them.

These volcanoes aroused Humboldt's curiosity, since the rudimentary geological knowledge that he had acquired at the *Bergakademie Freiberg*, was not able to explain their existence. In this context, it is important to bear in mind that there were only two active volcanoes in the whole of Europe: Etna and Vesuvius. During the next five months, from a base in either Quito or the rural Hacienda La Ciénega, he was therefore motivated to organize a series of short expeditions to examine, measure and survey these volcanoes and to collect numerous samples of these unusual volcanic rocks.

Once Humboldt had established himself in Quito, he devoted his time to examining the nearby volcanoes. These were months of amazing activity during which time he seemed to find new evidence of the importance of these volcanoes and their lavas with every step that he took.

The Pichincha volcano was the first to be examined and surveyed (Fig. 2). Comparing Humboldt's map with those produced by recent surveys (e.g., Monzier

Fig. 2 Detailed map of the Pichincha volcano, surveyed by Humboldt in 1802 (Plan hypsometrique du volcan de Pichincha. Atlas Geographique et Physique, pour Accompagner la Relation Historique. Sixieme livraison. Paris, J. Smith, Rue Montmorency, No. 16; Londres, Dulau et Compie., Soho-Square. 1831. Imprimerie de J. Smith.)

et al. 2002) reveals the accuracy of his depictions of the complex eruptions. In his travel diary, he also drew up an excellent cross-section of the volcano and its main crater (Hall 2001, p. 130). Humboldt highlighted in his conclusions that Quito was on the opposite side to the outlet from the main crater, from where the lava flows were toward the west. Hall (2001) considered this to be the first example of volcanic risk assessment in the Andes. Humboldt climbed this volcano three times; he was impressed by the seismic shocks that occurred on his first visit, when he recorded 15 tremors within 35 min.

Humboldt also described an eruption of the Pasto Volcano in 1797, from which a high column of smoke was emitted continuously over a three-month period, stopping at the same moment that the great earthquake of Riobamba occurred some sixty miles away, causing extensive damage and killing between thirty and forty thousand Indians (von Humboldt 1823). It was not until some years later that Darwin confirmed this relationship between earthquakes and volcanoes, a relationship that he associated with the formation of the Andes mountains (Darwin 1838).

Another volcano that caught Humboldt's attention and to which he directed considerable attention was the Antisana volcano. The precision of his surveys can be seen from the resulting map (Fig. 3), in which he identified the various and different basaltic volcanic flows and that they derived not only from the main crater but also from fissures.

Humboldt's comparative analysis of the Cotopaxi and Tungurahua volcanoes told him that the latter had been largely destroyed by earthquakes, while the former remained intact. From the perfect cone of the Cotopaxi volcano compared to those of other volcanoes, he concluded that it was likely to collapse at some stage in the future and produce extensive lava flows.

Humboldt later focused his attention on the Chimborazo volcano and the impact that its elevation had on the vegetation but did not present much in the way of specific data on its geology. He climbed the Chimborazo volcano to almost 5900 m, which at that time was considered to be the highest mountain in the world. However, few people are aware that the German naturalist Tadeo Haenke had reached in 1794 the summit of the Misti volcano in Peru, which is of a similar height (5850 m a.s.l., Ramos and Alonso 2019).

Humboldt's journey through the Central Andes took him to Lima, the important capital of the Viceroyalty of Peru, where his party arrived in October 1802. They spent a couple of months in Lima, where he took the opportunity to visit the important Huancavélica Mine. This mine, which was located about 250 km southeast of Lima, had been the main source of *azogue* (quicksilver) in the Spanish colonies since 1563. The mercury extracted was highly valued for the beneficiation of gold and silver. This mining center was by this time in full decline, since after more than two hundred years of supplying mercury to the gold and silver mines of the Spanish colonies, from Mexico to Peru, its reserves were slowly running out. When the naturalist Tadeo Haenke visited Lima in 1794 as part of the Malaspina Expedition, the viceroy asked him to examine the Huancavélica Mine; he subsequently verified that the at times quite irrational methods of exploitation used had resulted in premature depletion of the reserves (Ramos and Alonso 2019). It is not known whether Humboldt's visit to the mine was at the request of the viceroy or just for his own interest, but he collected samples of cinnabar that are currently stored in the *Museum für Naturkunde* in Berlin (Fig. 4).

From Lima, Humboldt and Bonpland headed back north by sea to Guayaquil in Ecuador, where they arrive in 1803. Humboldt was excited to learn that the Cotopaxi volcano was erupting and wanted to cross the Andes again but had to abandon that idea or risk losing his passage on the ship that was to take them to Mexico. That was his last experience with the Ecuadorian volcanoes in which he had such a strong interest and that had awakened in him a new understanding.

(b) Humboldt's interpretation of volcanic activity

During his time in the Andes, Humboldt tried to find an explanation for the things that he observed. He had been particularly struck by how unstable the region was, as evidenced by the strong earthquakes (such as the Riobamba earthquake of 1797), and by the presence of so many volcanoes aligned parallel to the main trend of the

a

b

Fig. 3 **a** The Antisana volcano map produced by Humboldt in 1802 (von Humboldt in Berghaus 1845). **b** Aerial view showing the complex nature of the lava flows in the western foothills of the Antisana Volcano, presently known as Flujos de Antisanilla (courtesy of Benjamin Bernard, Volcanes de Ecuador)

Fig. 4 Cinnabar sample from the Huancavélica Mine, collected by Humboldt and deposited in Berlin's Museum für Naturkunde (courtesy of Stephen Jackson, University of Wyoming)

Cordillera, and he tried to understand the reason for these features. The tremors that he had felt on the Pichincha volcano, and the associated loud noises, led him to speculate on "the existence of large cavities that form at the base of the volcano" and the possibility that the volcanic centers that he observed on both sides of the inter-Andean valley that runs northeast from Quito might be connected at depth. He suggested that the molten material could break through to the surface through fissures, not only in the current volcanic centers but also forcing its way through into new areas, a possibility that appeared to be supported by the presence of hot sulfurous springs in certain areas at some distance from existing volcanoes.

However, the main effect of Humboldt's descriptions was to provide strong support for changing the current European paradigm for volcanism, in which volcanism was thought to occur at isolated locations with a random distribution. Finding volcanoes concentrated along structures that were hundreds of kilometers long in the central part of the Andes mountain range suggested the possibility of there being some sort of tectonic control for the volcanism. On his arrival back in Europe Humboldt invited Leopold von Buch, his friend and former fellow student at the *Freiberg Bergakademie*, to join him on a visit to Vesuvius where, in 1805, they examined that European volcano together.

It was, however, not until 1823, a few years after the death of his former teacher Abraham Werner, that Humboldt published his ideas concerning how volcanoes formed in different parts of the world (Sengör 2020; von Humboldt 1823). He described lavas that flowed from fissures and lines of volcanoes "*many hundreds of miles long, sometimes parallel to the main direction of the mountains, and as in the Andes, sometimes cutting vertically through the axis of the mountains, as in Mexico, where fire-breathing trachyte mountains alone reach the high snow line, and have probably broken out on a chasm, a length of ten geographic miles across the whole continent, from the Pacific to the Atlantic Ocean*" (von Humboldt 1823). His novel ideas on how volcanoes formed were far removed from his earlier ideas on the origins of the Rhine basalts (Krafft 1993). While this could be considered to indicate conversion to Hutton's Plutonist ideas, that clearly had not occurred as several decades later Humboldt presented Wernerian (i.e., Neptunist) interpretations for the origin of granites that he had seen in Russia.

Perhaps one of Humboldt's most important legacies was his recognition that volcanism was not continuous along the entire length of the Andes but was concentrated in three sectors (Fig. 5), as reported in his Cosmos treatise (von Humboldt 1849).

Humboldt's description of the distribution of volcanoes along the Andes was especially extraordinary as he had only directly observed the northern zone in the field. The central and southern zones were reconstructed through his correspondence with Chilean naturalists such as Rudolph Philippi and Ignacy Domeyko. Humboldt was the first to identify this peculiar distribution of volcanism in the Andes. It was not until well over a century later that a plausible explanation for this distribution was arrived at, when Barazangi and Isacks (1976) were able to relate the distribution of volcanoes to variations in the dip of the subducting oceanic slab.

(c) A new rock type: andesite

Humboldt collected as many samples as he could from the various volcanoes that he visited and his attention was particularly drawn to a certain albite and hornblende bearing volcanic rock. His collection of Andean samples had a long and interesting

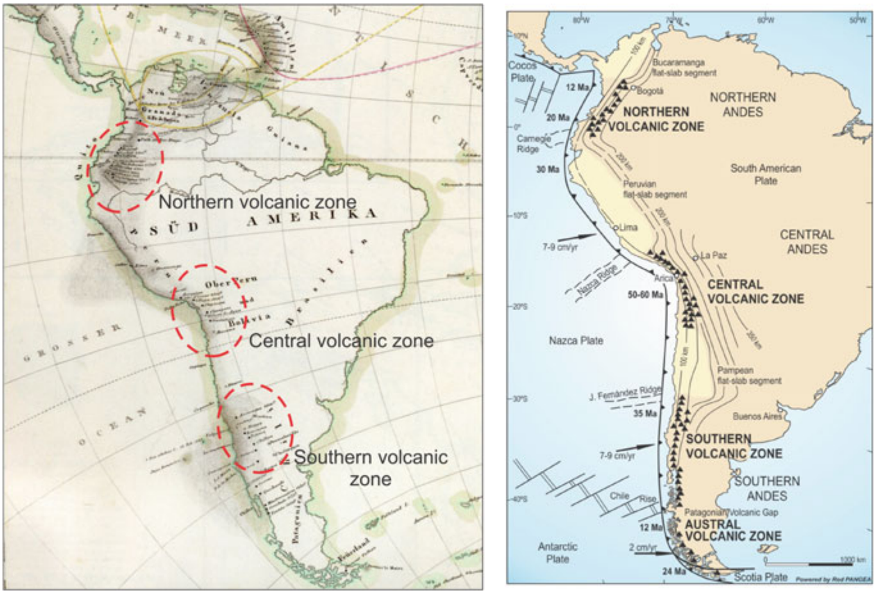


Fig. 5 Humboldt's understanding of the distribution of Andean volcanoes (from von Humboldt in Berghaus 1845) compared with the known present-day Andean volcanic zones (Ramos 2009)

journey back to Europe. For example, a box containing some of these samples was being transported on a French ship when the vessel was captured by an English captain, but Humboldt had left written instructions with the shipment which the English captain fortunately followed, and the box was duly delivered to Joseph Banks in London (see Banks 2000). Thanks to the written instructions and the action of the English captain, these Andean volcanic samples thus eventually reached the hands of Humboldt's friend Leopold von Buch, who examined them some years later. Most of these samples ended up at the *Museo de Historia Natural* in Madrid or the *Museum für Naturkunde* in Berlin.

Von Buch examined the rock samples and was the first to identify the albite and hornblende bearing rock as a new rock type, for which he coined the name andesite in 1836. This new rock type turned out to be one of the most common rock types in the Andes.

(d) The orogenic volume of the mountain chain

Humboldt always had in the back of his mind his Göttingen professor's advice to quantify his observations as far as possible. He had learned the value of recording measurements and, following Professor Lichtenberg's recommendations, made use of all his instruments to obtain the most accurate picture possible of the Andes. He applied the same concepts in the Andes as when he was in Madrid for a few months, during which time he made a longitudinal topographic profile of Spain that identified for the first time the *Meseta Española*. Humboldt's topographic cross-sections of the Andes revealed that the volumes involved varied considerably at different latitudes, as can be seen in Fig. 6.

The comprehensive set of instruments that Humboldt took with him on his long journeys allowed him to obtain precise figures for latitude, longitude, elevation, and magnetic field, as well as many other measurements (von Humboldt in Berghaus 1845). The topographic profiles based on his barometric measurements, together with information obtained on other sectors of the Andes through correspondence with other scientists, enabled him to put together the sections illustrated in Fig. 6.

The differences in what are today known as orogenic volumes that these topographic cross-sections present are very important for unraveling the tectonic history of the different zones. Humboldt's Central Andes cross-section, which was largely based on observations by Alcide D'Orbigny, the famous French naturalist who recognized this part of Bolivia in the early 1800s, shows an area of high plateau that is bounded to the west by the even higher Western Cordillera and its volcanoes, and to the east by the slighter lower Eastern Cordillera. The topography in this cross-section contrasts with that in the Northern Andes cross-section, which is dominated by volcanoes and devoid of any plateau area. The difference in orogenic volumes between these two sections is today explained by a lack of thermal uplift in the Northern Andes such as produced the high plateau in the Central Andes, as well as differences in tectonic stacking and subsequent crustal thickening (Isacks 1988).

(e) Geological cross-sections of the Andes

Humboldt then traveled to Mexico in 1803 to meet another former fellow student, Andrés Manuel del Río (1764–1849), who was at the time director of the Mexican *Real Seminario de Minería*, and it was not until then that Humboldt presented his in-depth interpretation of the Andes. During his time in Mexico, Humboldt wrote an unpublished text in French entitled "*Essai de Pasigraphie*" (1803) for the classes of the *Real Seminario*. This text was translated into Spanish and published by Andrés Manuel del Río in 1805, in his second edition of *Elementos de Orictognosia* (Del Río 1805). This Spanish published version, used as a seminary textbook for several decades, revealed Humboldt's first geological cross-sections of the Andes, which preceded by several years D'Orbigny's cross-sections of the Bolivian Andes (D'Orbigny 1842) and Darwin's cross-sections of the Argentinean-Chilean Andes (Darwin 1846). It is, however, important to emphasize the differences in the criteria on which the various cross-sections were based. In the first place, both Humboldt and Andrés del Río were disciples of Abraham Werner and strongly influenced by his stratigraphic principles: The geological cross-sections presented in Fig. 7 are devoid of tectonic features. Humboldt's main objective was to demonstrate the geological composition of the various mountain ranges and to recognize that they consisted of countless different lithologies. In his work, he emphasized as one of his main points that the rocks found were like those that existed in Europe, albeit based on quite simplistic criteria.

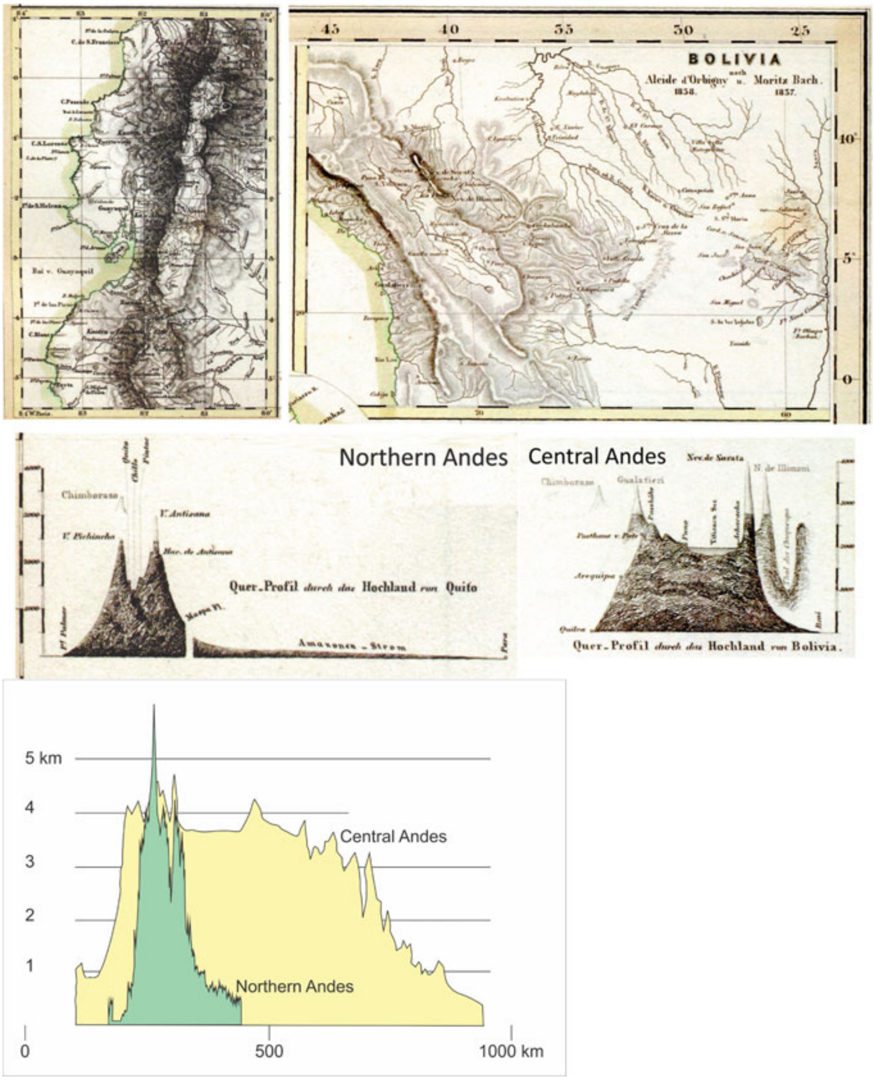


Fig. 6 Topographic maps of the northern and central Andes, together with cross-sections drawn up by Humboldt (von Humboldt in Berghaus 1845; Berghaus assembled these maps and charts following different researchers and artists), with topographic profiles based on digital elevation model shown below for comparison. Note the contrast between the Central Andes with a high plateau (the Altiplano) and the cordillera in the Northern Andes (with no high plateau) in which the topography is dominated by volcanoes

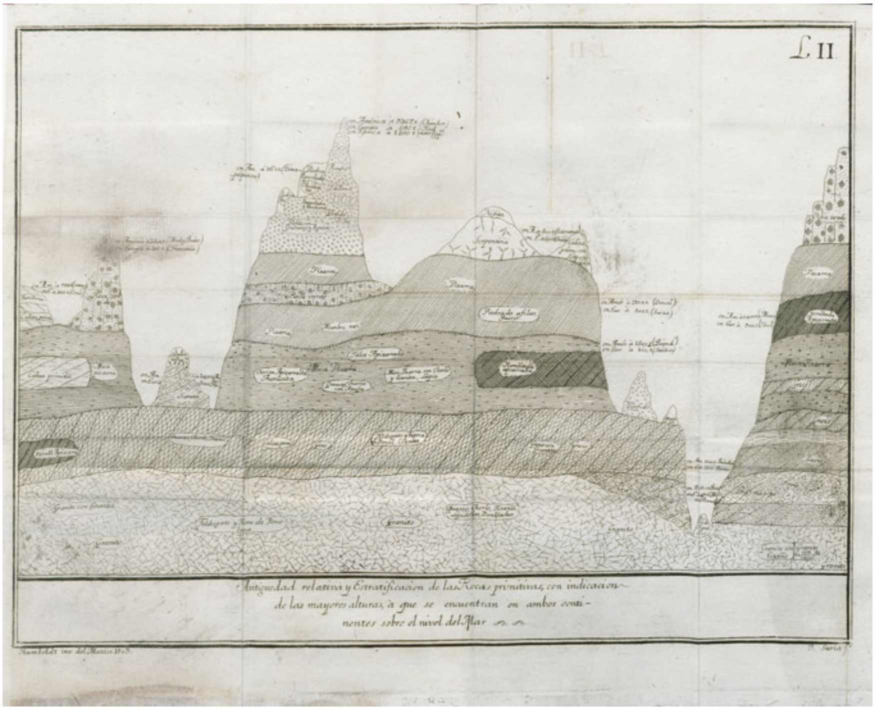


Fig. 7 One of the geological cross-sections produced by Humboldt in 1803, which was published in Spanish: "Antiguedad relativa y Estratificacion de las Rocas primitivas, con indicacion de las mayores alturas, à que se encuentran en ambos continentes sobre el nivel del Mar. Humboldt inv. del. Mexico 1803. F. Suria f.t", in: "Introducción a la pasigrafía geológica del Señor Baron de Humboldt", in: Andrés Manuel Del Río, Elementos de Orictognosía, Teil 2, Mexico 1805, S. 160–173 (courtesy of University of Bern/Staatsbibliothek zu Berlin)

However, in his various cross-sections he discriminated between primitive, secondary and stratified rocks,[3] which he showed at their maximum heights in the Andes and then compares them with those found on other continents, but mainly in Europe.

An analysis of the French text in "*Essai de Pasigraphie*" written by Humboldt in 1803, which remains unpublished,[4] reveals that Humboldt had a good command of mineralogy which allowed him to identify and describe a whole range of different rock types that he encountered on his travels through the Andes.

[3] Based on Abraham Werner' classification of rock types.

[4] See the edition by Hanno Beck: Alexander von Humboldts "Essay de Pasigraphie", Mexiko 1803/1804. In: Forschungen und Fortschritte, Bd. 32, Heft 2, 1958, pp. 33–39.

Humboldt's Legacy and His Geological Interpretation of the Andes

The descriptions of Humboldt's observations in different parts of the Northern and Central Andes, together with copies of his intense correspondence with other scientists, reveal his interpretation of this mountain chain. It is important, however, to bear in mind that Humboldt was a disciple of the school of thought promoted by Werner's *Bergakademie Freiberg*, which had not yet been exposed to the novel ideas of Charles Lyell. Nevertheless, Humboldt's more advanced thoughts led him to affirm in a very timid way that "*human spirit is sometimes allowed to wander from the present into the past, to suspect what cannot yet be clearly recognized*" (von Humboldt 1823).

In his interpretation of the Andes, Humboldt clearly emphasized the importance of volcanism, the alignment of volcanoes over hundreds of kilometers, and their distribution along the axial region of the mountain system. He understood how volcanic forces penetrate the surface and produce lava flows, that this material was transported from deep beneath the earth's surface, and that it could be extruded through fissures. The relationships that he observed between volcanism and the mountain system were much closer to Hutton's ideas than to those of his former teacher, for whom volcanism was merely an accidental hazard.

Humboldt's good basic knowledge of mineralogy helped him to realize that some volcanic rocks were like those that existed in Europe, but he found some others, which were different. He called them "*hornblende trachytes*" a variety that he had not seen in Europe, but he had to wait a for few years before Leopold von Buch identified them as the new rock type that he called andesite.

Humboldt was also the first to document that the active volcanoes of the Andes occurred in three discrete zones, a claim that resulted in a great deal of controversy over subsequent decades. The three zones have been taken as proof that plate tectonic theory and subduction of the oceanic crust beneath the continent could not apply to the Andes (Zeil 1970), but also as one of the most important pieces of evidence for new processes that are today well accepted, such as crustal delamination and lithospheric removal (see discussion in Ramos 2021).

Humboldt's detailed discussion of the association of earthquakes with volcanic eruptions, and of the relationship between specific volcanic eruptions and the major earthquakes at Riobamba (1897) and Caracas (1811), anticipated subsequently accepted concepts by several decades.

His detailed geological cross-sections may be considered to be rather simplistic, but they expressed the current state of knowledge at the time and were pioneering steps toward our current understanding of the geology of the Andes.

However, in order to fully appreciate this great naturalist and his comprehensive perception of the natural world, it is important to remember that these geological observations went hand in hand with a deep understanding of the distribution of plants and animals, of the climate, and of ocean currents. It is no accident that Einstein stated in 1920 "*In my youth... Humboldt's Cosmos was the Natural History Bible for an entire generation*".[5]

Acknowledgements I would like to express my thanks to the Leopoldina Nationale Akademie der Wissenschaften for providing me with the opportunity to participate in the Symposium on the occasion of Alexander von Humboldt's 250th birthday and his legacy in modern Earth System Science. I am also grateful to Professor Manfred Strecker from Potsdam University and the other participants in the symposium for the lively discussions that increased my appreciation of von Humboldt's legacy in other disciplines. This manuscript has benefited from critical reading and comments from Manfred Strecker and an anonymous reviewer. This presentation is the R-381 contribution from the Pablo Groeber Institute of Andean Studies of the University of Buenos Aires-CONICET.

References

Banks, J. 2000. The letters of sir Joseph Banks. A selection, 1768–1820. Editor Neil Chambers, Imperial College Press, London.

Baran, E.J. 2017. Alexander von Humboldt en Göttingen. Anales Academia Nacional de Ciencias Exactas, Físicas y Naturales, 61: 7–12, Buenos Aires.

Barazangi, M. and Isacks, B. 1976, Spatial distribution of earthquakes and subduction of the Nazca plate beneath South America: Geology, v. 4, p. 686–692.

Berghaus, H. 1845. Physikalischer Atlas oder Sammlung von Karten, auf denen die hauptsächlichsten Erscheinungen der anorganischen und organischen Natur nach ihrer geographischen Verbreitung und Vertheilung bildlich dargestellt sind. Verlag von Justus Perthes in Gotha.

D'Orbigny, A. 1842. Voyage dans l'Amérique méridionale exécuté pendant les années 1826, 1827, 1828, 1829, 1830, 1831, 1832 et 1833. tome troisième. 3e partie: Géologie. p. bertrand, V. levrault, 289 p., Paris, Strasbourg.

Darwin, C. R. 1838. On the connexion of certain volcanic phaenomena, and on the formation of mountain-chains and volcanos, as the effects of continental elevations. Proceedings of the Geological Society 2: 654–660, London.

Darwin, C.R. 1846. Geological observations on South America. Being the third part of the geology of the voyage of the Beagle, under the command of Capt. Fitzroy, R.N. during the years 1832 to 1836. Smith Elder and Co., 280 p., London.

Dassow Walls, L. 2009. The Passage to Cosmos, Alexander von Humboldt and the Shaping of America. The University of Chicago Press, 404 p., Chicago.

Del Río, A.M. 1805. Elementos de Orictognosia ó del conocimiento de los fósiles, dispuestos, según los principios de A.G. Werner para el uso del Real Seminario de Minería de México. 252 p., México.

Hall, M.L. 2001. Alexander von Humboldt: In A. Stark (comp.) El Regreso de Humboldt, Museo de la Ciudad de Quito, 129–138, Quito.

Krafft, F. 1993. Alexander von Humboldts "Mineralogische Beobachtungen über einige Basalte am Rhein" und die Neptunismus-Vulkanismus-Kontroverse um die Basalt-Genese. In: Studia Fribergensia. Vorträge des Alexander-von-Humboldt-Kolloquiums in Freiberg vom 8. bis 10. November 1991 aus Anlaß des 200. Jahrestages von A. v. Humboldts Studienbeginn an der

[5] Moszkowski (1921).

Bergakademie Freiberg. (Beiträge zur Alexander-von-Humboldt-Forschung, Band 18) Berlin: Akademie Verlag 1994, S. 117–150.

Isacks, B. 1988. Uplift of the Central Andean plateau and bending of the Bolivian orocline. Journal Geophysical Research 93: 3211–3231

Monsalve, M.L., Galarza, J. J., Zuluaga, I. and Laverde C.A. 2014. Mapa de amenaza volcánica del volcán Puracé actual (Cauca - Colombia). Servicio Geológico Colombiano, segunda versión, 48 p., Bogotá.

Monzier M., Samaniego P., Robin C., Beate B., Cotten J., Hall M.L., Mothes P., Andrade D., Bourdon E., Eissen J.-P., Le Pennec J.-L., Ruiz A.G., Toulkeridis T. 2002. Evolution of the Pichincha volcanic complex (Ecuador). Fifth International Symposium on Andean Geodynamics, Toulouse (France), Extended Abstracts, Institut de Recherche pour le Développement, pp. 429–432, Paris.

Moszkowski, A. 1921. Einstein: His work explained from dialogues with Einstein. Horizon Print. 15 th. Edition (1973), 246 p.

Ramos, V.A. 2009. Anatomy and global context of the Andes: Main geologic features and the Andean orogenic cycle. In Kay, S.M., Ramos, V.A. and Dickinson, W. (eds.), Backbone of the Americas: Shallow Subduction, Plateau Uplift, and Ridge and Terrane Collision, Geological Society of America, Memoir 204: 31–65.

Ramos, V.A. 2021. Fifty years of plate tectonics in the Central Andes. Journal of South American Earth Sciences, 105: 102997.

Ramos, V.A. and Alonso, R.N. 2019. Tadeo Haenke: primer naturalista del Virreinato del Río de la Plata. Anales de la Academia Nacional de Ciencias Exactas, Físicas y Naturales, 70 (2018): 117–146, Buenos Aires.

Sengör, C. 2020. Plate Tectonics, in Symposium on the occasion of Alexander von Humboldt's 250th birthday and his legacy in modern Earth System Science, this volume.

von Humboldt, A. 1823. Ueber den Bau und die Wirkungsart der Vulcane in verschiedenen Erdstrichen. Abhandlungen der Physikalischen Klasse der Königlichen Akademie der Wissenschaften, Januar 1823, 137/155, Berlin.

von Humboldt, A. 1849. Cosmos: Sketch of a Physical Description of the Universe. Translated by E. C. Otté, vol 1, 369 p., vol. 2, 359 p. 6th ed. Henry G. Bohn, London.

von Humboldt, A. and Bonpland, A. 1805. Geographie des plantes equinoxiales. Tableau physique des Andes et pays voisins. París.

von Humboldt, A. and Bonpland, A. 1807. Personal narrative of travels to the equinoctial regions of America during the years 1799–1804, Volume 1. George Bell & Sons. London.

von Humboldt, A. and Bonpland, A. 1822. Personal narrative of travels to the equinoctial regions of America during the years 1799–1804, Volume 3, Second edition, Longman and Hurst, 591 p., London.

Zeil, W. 1970. The Andes: A geological review. Beiträge zur Regionalen Geologie der Erde, Bd.13, Verlag Borntraeger, 260 p. Berlin-Stuttgart.

Víctor A. Ramos is a structural geologist and professor emeritus at the Universidad de Buenos Aires, Argentina, He has contributed to the better understanding of paleogeography and plate tectonics of South America. He is member of the Academy of Science of Brazil, Chile, Argentina, America Latina, US Academy of Sciences and the World Academy of Sciences. He won in 2013 the Premio México de Ciencia y Tecnología and the Lenovo Science Prix of TWAS in 2017.

Humboldt, His Relevance for Contemporary Education Strategies and the Political Discourse

Fig. 1 Ponts naturels d'Icononzo. Voyage de Humboldt et Bonpland. Premiere Partie. Relation Historique. Atlas Pittoresque. Paris. F. Schoell. 1810. Vues des Cordilleres, et monumens des peuples indigenes de l'Amerique. (Courtesy of David Rumsey Collection)

Should Alexander von Humboldt Be Part of Contemporary Geography Education?

Thomas Hoffmann

Abstract Geography education has passed through profound changes and recently faces again a discussion about its educational value and societal benefit. As such, it is vital to reflect on recent meaning and contribution of geography's role in education. It has become obvious that especially the combination of systemic approach, the consideration of different spatial levels, the solution-oriented as well as action- and future-oriented didactic approaches of geography education supplies an important input. Against the background of a globalized world along with numerous global challenges such as climate change, soil degradation, poverty or mass migration and the "2030 Agenda" as global strategy to counteract these trends, it reveals that education for sustainable development offers appropriate didactic concepts. That can be combined with those in geography education. It is within this framework that Alexander von Humboldt's geographical approach appears absolutely modern despite his influence on geography education being negligible. This leads to the question whether Alexander von Humboldt's work can contribute to contemporary geography education.

Keywords Geography · Education · Education for sustainable development · 2030 agenda

Introduction

Without any doubt historians of geography agree: Alexander von Humboldt was the most important scientist and geographer of modern times (e.g. Beck 1982, p. 83; Osten 1999, p. 33; Meyer 2011, p. 34). He was the first to describe the northern part of the South American continent as detailed as no one before him; he was the first to map rivers as well as mountains and plains in South America, Europe, Russia and Siberia, the first to identify and locate plants as well as geological structures,

T. Hoffmann (✉)
Leuphana Universität Lüneburg, Studienseminar Karlsruhe, Karlsruhe, Germany
e-mail: thomas.hoffmann@semgym-karlsruhe.de

G. C. Falk et al. (eds.), *Alexander von Humboldt*,
https://doi.org/10.1007/978-3-030-94008-9_6

deposits of gems, gold or other precious metals, climatic phenomena as well as cultural specifications, and this just names a few of his contributions. No other geographer before or after him covered such a broad variety of geographic subdisciplines and therefore contributed such profound knowledge in the areas of research.

But the collection of data and information was not his main intention, writing that: “Alles ist wichtig, was die Grenzen unseres Wissens erweitert und den Geist neue Gegenstände der Wahrnehmung oder neue Verhältnisse zwischen dem Wahrgenommenen darbietet” (“Everything is important that expands the frontiers of our knowledge and holds up new objects to the intellect, either to be fathomed or to establish new relations between the perceived”). And even more importantly, the new ways that geographers of the day attempted to understand the world were not as radical as the multitalented Prussian’s. With an inexhaustible knowledge on topics of space and time, Humboldt was not only often cited as an “academy on his own”, but also connected facts separated by disciplines to yield genuinely new, three-dimensional, dynamic and systemic understanding of his contemporary world, and was therefore a “genius of interdisciplinarity”, as Osten rightly judged (Osten 1999, p. 32).

In spite of his tremendous output spanning more than seven decades in cause of geographic knowledge and understanding, Alexander von Humboldt plays just a minor role in today’s geographic education and teaching. No German geography syllabus instructs to discuss his findings and just a few geography textbooks refer to him at all. When they do, it is generally reduced to an episodic mentioning of his American journey or to a modernized and heavily reduced version of his most famous three-dimensional complex drawing of the Andes. This finding holds for schools and teacher seminars even if universities deal in more detail with his thoughts here and there, and here mainly from a historical perspective. Yet recent jubilees like the 200th anniversary of his American journey in 1999 and his 250th birthday in 2019 gave reason to stage exhibitions in Bonn and Berlin. The number of visitors to both exhibitions provides evidence of a given general interest in Alexander von Humboldt, so too does the success of Wulf’s brilliant biography “The Invention of Nature” (2015).

Are Humboldt’s scientific findings, his lifelong experiences and his value-oriented convictions of liberty, humanism and anti-racism all that can be worth understanding out of his “Cosmos”? Or can Alexander von Humboldt’s holistic and systemic view of the world contribute more to contemporary geography teaching and education?

Aim of Contemporary Geography Education

As with any other scientific discipline, the interest of geographic research has undergone fundamental changes over the last two hundred years. While topographic knowledge of coastlines was the focus before 1800, topographic knowledge of the inlands of the continental land masses was the focus in the nineteenth century. The value of geographic education at that time was, according to Carl Ritter, the effort to bring nature and human spirit together. Humboldt generally agreed with Ritter's conviction, and indeed he created a new term to express it: "Naturgemälde", rendered directly into English as "a painting of nature". Humboldt's idea behind this term was to bring geo-physical understanding and a deep sensitivity for nature together as the crucial value of geographic understanding and education in his sense.

At the same time, the end of the eighteenth and the beginning of the nineteenth century saw an increasing division among the hitherto existing different sciences that were subsumed under philosophy and, thanks to the new Enlightenment, the beginning of the natural sciences as we conceive it today. This splintering led to the emergence of new scientific disciplines such as geology, hydrology, botany and even the beginning of climatology. Since then, the research interests of the single sciences have become more and more specialized at the cost of the cultivation of a comprehensive perspective. Due to the reality of global challenges, it has only been in recent years that the pendulum has swung back to a more holistic approach. More interdisciplinarity is required to reach a deeper understanding and develop the individual ability to handle complex situations and to contribute to cross-societal efforts towards sustainable lifestyles and societies. The "2030 Agenda"—with its seventeen Sustainable Development Goals (SDGs) puts into writing the global need for and implementation of a worldwide roadmap for sustainability—finally mirrors this global necessity and consequent realization of a worldwide road map towards sustainability.

A specific challenge of our time is the lesser and lesser experiencing of nature for an increasing part not only of western, but of global societies and going along with that an increasing alienation of individuals from nature. Against this background, contemporary geography education has to push against this trend and, as such, focus increasingly on a more systemic approach, incorporating the local to the global level. Beside this, the value of contemporary geography education lies in its ability to offer an integrative systemic approach combining both natural and societal sciences on different spatial levels, an activity as well as solution-oriented approach along the needs of sustainable development and finally the consideration, if not the focusing of future as the main timewise dimension of leading questions in geography. At the same time contemporary geographic education is based on a strict competencies-oriented approach, which prefers constructive learning, rather than instructional learning settings.

Bringing these different lines together, it becomes obvious that geographic education at the beginning of the twenty-first century is highly interconnected with the ideas and aims of education for sustainable development. This didactic and pedagogic approach summarizes all contributions of educational processes which are suitable to support the development of any society on its way towards sustainability. Sustainability in this context should be understood as a societal situation, which is characterized by a Human Development Index (HDI) value of 0.8 or more, and at the same time, by an ecological footprint of less than 1.8 global hectares. The HDI represents a statistic that combines the reality of life expectancy, health care, nutrition quality, educational quality and economic capacity including the individual's share and purchasing power. Sustainable development in this context describes the way societies have to go to reach what is the defined situation. While developing countries first of all seek to improve their economic and social development without increasing their ecological footprint over the defined frontier line, developed countries primarily have to decrease their ecological footprint without losing ground concerning the economic and social status they have already achieved. The common goal shared by ESD and contemporary geography teaching illustrates the need for a comprehensive and holistic education in our time characterized of massive threats caused by climate change, degradation of soils, scarcity of water, loss of biodiversity, increasing poverty, nutrition insufficiency, intercontinental mass migration and urbanization.

Contemporary geography education is based on a combination of global challenges, related topics and a mixture of specific geographical and ESD-competencies. The "Deutsche Gesellschaft für Geographie", the German Association of Geography, identified a set of six areas of competence for geographic education and allocated central competencies to each of them as follows (Table 1).

To meet the standard of contemporary geographic education, these geographic competencies should be combined with the set of eight key competencies of education for sustainable development as identified by UNESCO in 2017 (Table 2).

The value of contemporary geography education can be summarized in the combination of future, action and problem-solving oriented geography along the concepts of a cross-societal sustainable development. This requires a systemic

Table 1 https://www.researchgate.net/figure/Key-Competencies-for-Geographical-Education-German-Geographical-Society-2007_fig1_292159832 (Deutsche Gesellschaft für Geographie (DGfG) 2006)

Area of competence	Central competences
Subject-specific knowledge	Ability to understand spaces of different scales as physical and human geographical systems and to analyze the interrelations between man and environment
Spatial orientation	Ability to orientate oneself in space (topographical orientation, map reading competence, orientation in real spaces and reflection upon spatial perceptions)
Gathering information/methods	Ability to collect and evaluate geographically/geo-scientifically relevant information in real space and in media, as well as how to describe the steps taken to gather the information
Communication	Ability to understand geographical information, to express, present and to discuss it appropriately with others
Evaluation	Ability to evaluate spatial information and problems, information in the media and geographical insights in terms of specific criteria and in the context of existing values
Action	Ability and willingness to act in accordance with natural and social conditions in various fields of action

Table 2 UNESCO (2017, p. 10) (Deutsche Gesellschaft für Geographie (DGfG) 2006)

Key competence	Description
Systems thinking competency	Abilities to recognize and understand relationships; to analyze complex systems; to think of how systems are embedded within different domains and different scales; and to deal with uncertainty
Anticipatory competency	Abilities to understand and evaluate multiple futures—possible, probable and desirable; to create one's own visions for the future; to apply the precautionary principle; to assess the consequences of actions; and to deal with risks and changes
Normative competency	Abilities to understand and reflect on the norms and values that underlie one's actions; and to negotiate sustainability values, principles, goals, and targets, in a context of conflicts of interests and trade-offs, uncertain knowledge and contradictions
Strategic competency	Abilities to collectively develop and implement innovative actions that further sustainability at the local level and further afield
Collaboration competency	Abilities to learn from others; to understand and respect the needs, perspectives and actions of others (empathy); to understand, relate to and be sensitive to others (empathic leadership); to deal with conflicts in a group; and to facilitate collaborative and participatory problem solving
Critical thinking competency	Ability to question norms, practices and opinions; to reflect on one's own values, perceptions and actions; and to take a position in the sustainability discourse
Self-awareness competency	Ability to reflect on one's own role in the local community and (global) society; to continually evaluate and further motivate one's actions; and to deal with one's feelings and desires
Integrated problem-solving competency	Overarching ability to apply different problem-solving frameworks to complex sustainability problems and develop viable, inclusive and equitable solution options that promote sustainable development, integrating the above-mentioned competences

approach and accepting the fact that humans are not only integrative part within this system, but have only recently become the strongest and most effective factor of the earth system.

What Could Be Alexander von Humboldt's Contribution to Contemporary Geography Education?

Johann Wolfgang von Goethe's often-cited admiration for Alexander von Humboldt compared the man twenty years his junior with a well with many pipes, under which whenever you put your vessel, it will be filled with never-ending knowledge and joyful insights.

But while Goethe's fame never ended and his literary works especially became a fundamental part of the formal education system and curricula in all different German political systems and federal states over the past two centuries, Alexander von Humboldt faced a totally different fate. He was one of the most famous people of his time, on a global scale much more than Goethe. But in spite of Humboldt's outstanding performance in so many different scientific disciplines—many of which were even founded by him—his memory over time was not kept alive by representatives of these disciplines but only by intellectuals, as Ette points out (1999, p. 25). On the other hand, there were times and regions when Humboldt's works were not only ignored but even forbidden, as was the case during the pre-revolutionary period in Cuba. The fact that parts of his book on Cuba, where he clearly takes his stand against slavery, became a compulsory part of textbooks after the 1959 communist revolution highlights how much Humboldt's own emphasis on social justice and personal liberty were spun and politicized.

Beside these more ideologically based trends other aspects have to be taken into consideration to understand why his fame waned after his death. From a scientific point of view Osten is right with his assessment that Alexander von Humboldt was caught between many stools (Osten 1999, p. 42). Educated in an age when Enlightenment ideas were not yet widespread, Humboldt experienced an intellectual world in struggle with the still ubiquitous dominance of religious dogma on one side and the emphasis on rational approaches on the other. His decision in favour of the new Enlightenment thinking opened a more or less unlimited space to him. His unceasing curiosity set more than an example, but was also judged to be limited. In this regard, Ette hit the nail on the head: "The well was no longer important, since the time of the pipes had begun" (Ette 1999, p. 23). Humboldt was probably the last polymath. The era of these specific humans ended with the increasing division of sciences into more and more disciplines, each of them increasing their specific knowledge and findings in shorter and shorter intervals. This process had already started in Humboldt's lifetime, and he even contributed to this trend, but he could manage to integrate an enormous range of these findings into his intellectual spheres and also into his lifework "Kosmos". But nobody after him was able to do so, nor with the specialization of science did they have the chance. Since then, research projects of all sciences have gone deeper and deeper into their respective fields and continuously split up into new scientific disciplines, often loosing contact to and the perspective of their original intention and focus. As a consequence, we are much more advanced in our findings compared to Humboldt's time; however, a decrease in holistic understanding must also be dealt with, as well as an increasing alienation from nature. Further on, the early nineteenth century started with Darwin's (and Wallace's) theory of evolution and heralded a totally new scientific era. From now on, nature was understood more as contested space than a "Naturgemälde" in the Humboldtian sense.

Apart from the scientific specialization, political conditions explain why Humboldt's fame faded after his death in 1859. Alexander von Humboldt's life covered nearly a century from 1769 to 1859. In this era, drastic changes happened not only in Europe but also in North America, not only politically and societal but also technical and economical. As a young man, Humboldt experienced radical new ways of political and social structures based on the values of the French Revolution and the upcoming democracy of the United States of America. He even met Thomas Jefferson in Washington D.C. for an exchange of thoughts. Personal liberty, social justice and anti-racism were the moral principles which steered his decisions for his entire life.

Financially independent for most of his life and aware of his near-global fame, he did not hesitate to define his position. And his position was a clear humanitarian one, judging slavery to be the greatest evil of his time. He also took a clear global stand. In maximum contrast to his personal conviction, the nineteenth century was characterized by a strong upcoming nationalism and some decades marked by competition-driven colonialism among European powers. Both lines of development flourished mainly from the second half of the nineteenth century, showed increasing hostilities among the national states and continued until the end of the Second World War, finally merging into the era of decolonization.

Nationalism dictated the space in which politicians could think and how emperors reigned their countries. There was no space and no admiration at all for a person whose thought was globally anti-racist and who was convinced of the individual freedom of people. The cosmopolitan Alexander von Humboldt neither shared nor supported the predominant trends (Osterhammel 2009, p. 1164), and as a result, he became "the man between all stools", at the edge of eras, the last of his kind and at least a century ahead with his findings, insights and viewpoints. Against the background of this political, ideological, economical and scientific reality, neither Alexander von Humboldt's holistic world view nor his generally global dimensions of thinking, evaluating and argumentation were much considered in the second half of the nineteenth century. As a result, he became an increasingly marginalized figure and finally became history.

The many challenges born to a large extent from a globalized world set a different framework, needs and demands to the era of nationalism and colonialism. Our "Age of Sustainable Development" as Jeffrey Sachs characterized it at the end of the twentieth and beginning of the twenty-first century (Sachs 2015) has to find global answers for a viable future, which he sees in a consequent sustainable development. The specific challenges, ideas of human development and global ideas of shared values do not only cause different societal processes but also require suitable educational concepts on all levels. It is immaterial whether this new age started with Rachel Carson`s book "Silent Spring", the first book on man-made environmental problems, or with the first picture of the "earth rise" in space taken by the Apollo 8 crew on 23 December 1968 or with the Rio de Janeiro Earth Summit in June 1992 officially titled "The United Nations Conference on Environment and Development (UNCED)". The crucial aspect is that these years saw the breakthrough of the concept of sustainability as the leading idea. Facing this fundamental change, it is worth reflecting on Alexander von Humboldt's thoughts again and considers how they have been integrated and practised in the past twenty years. How can his thought and methods be transferred and adapted to contemporary geography education?

Alexander von Humboldt's methodological approach to scientific questions and work was characterized by the combination of concrete details with higher structures. He was obsessed with measuring and numbers, carried an enormous equipment of around 50 different state of the art instruments through the wilderness and collected millions of data, which he would list and visualize and then search for relations between the documented facts. He recognized the global impact of every detail and vice versa. His descriptions of elements, plants, geological phenomena or vast landscapes are as exact as possible, regardless of whether they were written or drawn. His sketch of the basaltic columns of Santa Maria Regla in the Mexican province of Hidalgo in the northeast of Mexico City, which was turned into a drawing by W. F. Gmelin, provides impressive evidence of this. The chosen perspective, the accuracy of the drawn basalt column both in their vertical as well as their detailed horizontal surface enables the observer to get a near first-hand impression of the given geological site. Further on, Humboldt also shows the sediment layer over the basaltic columns, the recently active erosion and transport caused by the strongly floating creek and the local vegetation in a realistic manner. On the base of such detailed scientific drawing, not only he, but also the scientific community, especially the members of the upcoming geology could discuss the evidence of this geological site in the context of the scientific discourse of that time between Neptunists and Plutonists. During his studies of mining engineering at the University of Freiberg, Germany, Humboldt adopted the position of his academic teacher, Abraham Gottlob Werner, that all changes of landscapes must have had their origin under water. Seeing the sedimentation processes as the main factor of how landmasses and continents were formed, Prof. Werner became not only the founder of, but also the leading representative of the Neptunists. But seeing the volcanoes of the Andes and reflecting on situations as that in Santa Maria Regla, Alexander von Humboldt changed his conviction and converted to the Plutonists, who were convinced that all origin of landmasses must have their origin in volcanic activities. This well-known scientific debate and Humboldt's conversion show how he maintained an open mind and was receptive to stronger evidence (Fig. 1).

Already in his youth, Alexander von Humboldt used his imagination to draw various topics, ranging from flora and fauna to astronomy and landscapes. In all, the emphasis was on accuracy, with the results being used as a basis for further discussion. Humboldt refined and honed this method throughout his life as a scientist. From observation and description, he found the logical method of natural scientific work, forming and articulating a hypothesis and then either verifying or falsifying it. A look at his impressively accurate drawings of the Western and the Eastern global hemisphere, the planetary system or the map of Denmark (Kunst- und Ausstellungshalle der Bundesrepublik Deutschland 1999, p. 35 or Blankenstein et al. 2019, pp. 28–29), which he drew at the age of about fourteen, give us an idea of his precision. In later years, drawings of plants and unknown species from sea mammals to unknown fish or birds, from cultural sites in the Andes and Mexico to more and more detailed profiles of rivers and the stretch of mountain ranges provide evidence as to how he cultivated this method and even refined it qualitatively. The examples stretch from his analytic drawing of the Torullo volcano (sometimes also

Fig. 1 Basaltic columns of Santa Maria Regla, Hidalgo, Mexico; drawing by W. F. Gmelin after a sketch by Alexander von Humboldt. Roches basaltiques et Cascade de Regla. Voyage de Humboldt et Bonpland. Premiere Partie. Relation Historique. Atlas Pittoresque. Paris. F. Schoell. 1810. Vues des Cordillères, et monumens des peuples indigènes de l'Amérique (Courtesy of David Rumsey Collection) (Deutsche Gesellschaft für Geographie (DGfG) 2006)

referred as Jorullo), which combines the ash layers in the foreground with the volcanic cause in the background (Lubrich 2014, p. 99) over detailed studies of river flows to the comparable drawings of snowline altitudes. All these pictures document his permanent effort to understand the relative positions of places, the vertical and horizontal dimensions of spaces, the subsumption of phenomena into a global scale and thus develop an imagination of the world.

Supported by his studies of mining engineering and his real experiences in many mines, he extended the scope of his drawings from surface to underground by combining subterranean geological information with geomorphological forms at the surface. This again opened new fields of understanding processes to him, for example how landscapes come into being. Over the years, he developed this method onto an even bigger scale as his idea to illustrate the geological formation below countries including the volcanic activities and ore deposits of that region.

His long experience of drawing precisely and rendering three dimensions onto paper, coupled with his ability to imagine realities from a bird's eye view, were perfect preconditions for his cartographic works. From his first attempts to map the area around the castle of Tegel, where he grew up in "Palace Boredom" as he called it, through to his sketch maps to understand the phenomenon of a bifurcation (Lubrich 2014, pp. 146–147) and his detailed map of the bifurcation of the Orinoco River through the Casiquiare (e.g. Kunst- und Ausstellungshalle der Bundesrepublik Deutschland 1999, p. 68), many maps document his masterly command over the landscapes and scale.

Alexander von Humboldt's method to design more and more complex models and to illustrate his own increasing systemic understanding reached its peak in his most famous drawing from 1803: the complex geographic representation of the Andes (e.g. Blankenstein et al. 2019, pp. 144–145). The copper engraving was produced by Louis Bouquet in 1807 and was titled "Naturgemälde der Anden". As such, his sketch supplies the characteristic west–east profile of the Andes representing the space between the 10th north and the 10th south latitudes along with its volcanic beauty and activity, its altitude-specific spread of its flora along slopes as well as of inner Andean valleys. It also provides the characteristic altitude and form of clouds and precipitation on the Western and Eastern sides of the Andean mountain range as iconographic information. Above this the picture delivers far more information and findings through numerous additional columns. Parallel to each other, they inform the user among others about west and east side-specific patterns of altitude in metres and the old French unit of length, *toisen*, and it also adds information regarding the horizontal refraction of solar radiation, altitudes of worldwide mountain ranges in comparison with the Andes, the altitude-specific culture of soils, the altitude-dependent change of gravitation, the altitude-specific sky blue, the variation of air humidity with increasing or decreasing altitude, and the variation of air pressure in combination with the measured altitude. The combined presentation of this multitude of information and data opened up a new world of understanding interrelationships in nature, relationships which had hitherto remained hidden. Above and beyond this, Alexander von Humboldt's "Naturgemälde der Anden" provoked and encouraged contemporaries to compare the Andean reality with high mountain ranges in other parts of the world, especially on different latitudes. He designed a comparative picture himself, which shows the geography of plants along the north–south stretch of the Andes at different altitudes and latitudes (Lubrich 2014, p. 395). With this new form of presentation Alexander von Humboldt also inspired Johann Wolfgang von Goethe, who went on to depict the maximum heights of mountain ranges of the old and the new world on scale, thereby making them directly comparable. With these two steps, Humboldt unveiled the hidden mysteries of the Andes and turned it into a general principle of understanding three-dimensional landscapes worldwide in dependency of their latitudinal position.

Finding general principles and regularities and/or visualizing data based patterns with the help of symbols that were abstract but still immediately understandable was one of Humboldt's superior interests since he understood their potentially convincing effect. The invention of the isoline system to illustrate equal data of temperature or altitude, air pressure or precipitation just to name a few, became the most famous result of his efforts.

Beside his own drawings, Humboldt also ordered and or inspired painters and cartographers to illustrate his findings in a convincing, imagination-supporting manner and render them as realistic as possible. Heinrich Berghaus' famous representation of the warm Atlantic and the cold Pacific sea currents, the Gulf Current and the Peru- or Humboldt Current published in 1837 (Kunst- und Ausstellungshalle der Bundesrepublik Deutschland 1999, p. 99), is an appropriate example for the one and Ferdinand Bellermann's painting of the Guácharo Cave from 1843 for the other.

Whether he did sketches, drawings or paintings on his own or ordered others to do so along his instructions, Alexander von Humboldt obviously knew about the inspiring effect of visualized imaginations. The German word for education, "Bildung" derives from the word "Bild", which means picture. To increase one's education is obviously connected with the process to make a picture of something. Alexander von Humboldt did not invent this learning principle and method, but he used it very effectively and he definitely has had an impact on geography didactic learning methods until today.

And there is another remarkable aspect in his "Naturgemälde". Integrating the category "Culture of the Soil on Various Altitudes" and giving altitude-specific information on agricultural activities such as no cattle grazing, potatoes cultures, European grains such as wheat, barley or oat, and for the lower altitudes various tropical fruits, cotton, sugarcane and the lack of African slaves, he weaves humans into his systemic presentation and understanding of nature. On this point, he categorically differentiates himself from the emerging natural sciences of his time. While Alexander von Humboldt was convinced that nature could only be understood by integrating men into the complex system, the new natural sciences looked from a quasi-superior human perspective via nature at nature, studying it without any gaining insights into the interconnecting links and without connecting the insights back to human society. His analysis of the degrading ecosystem around Lake Valencia in the Aragua Valley, which today is part of Venezuela, is probably the most well-known example of his way of thinking. He recognized that the rapidly lowering level of Lake Valencia was not due to an underground outlet, but was caused by the people who lived around the lake and who had successively cleared the adjacent forests. This was the crucial initial step in changing the local ecosystem to the disadvantage of the people. With this finding, Alexander von Humboldt demonstrated his systemic thinking and showcased his ability to find numerous interrelations between factors. Therefore, it is exactly this holistic understanding of men being part of the earth system that makes Alexander von Humboldt thinking worth being part of today's educational efforts in general, and geography education in particular.

Alexander von Humboldt's leading principle to understand the world by combining correct measures and descriptions of small, even pretended minor things with superior structures and systems becomes obvious in this picture, which is one of the most famous info-graph ever drawn.

But at the same time, it is necessary to understand that his drawing of the Andes bio-climatic structure only represents a quite small part of the earth system. In this context, his personal judgement about his Russian expedition of 1829 gives us the possibility to see Humboldt's findings as he saw them when he said about the year of 1829: "Dieses Jahr ist mir das Wichtigste meines unruhigen Lebens geworden" ("For me, this year became the most important of my unsettled life"). Alexander von Humboldt wrote in the second foreword of his book "Ansichten der Natur" ("Views of Nature"). The reason behind this judgement stems from his nine-month-long journey from Berlin via St. Petersburg and Moscow to the Ural Mountains and then another 2000 km further to the east, to the Altai Mountains and the Russian–Chinese border, after which he went down south to the mouths of the Volga into the Caspian Sea, near to Astrakhan. It was on this journey that has the chance to connect his South American findings with his current measures and findings.

Only this experience opened up the possibility to him to reflect and review global connections and interrelations of his earlier studies and his emerging conception of the Earth's system (Suckow 1999, p. 169). On another quasi meta-level scale, Alexander von Humboldt put new pieces of his emerging world jigsaw together. Or to put it into a nutshell: without the Russian expedition there would have been no "Kosmos".

In all this, Humboldt never left the trail presenting those parts of the world he had first dealt with scientifically as a "Naturgemälde", because he was convinced that nature had to be experienced and felt. In this, Humboldt often first provided a narrative, which was then followed by a scientific explanation. This pattern of taking the reader with him and trying to convey his many fascinating global experiences is already presented in his 1807 book "Views of Nature" and then repeated again and again in later works up to the "Kosmos". This was his way to demonstrate the "unity in diversity" as Wulf says (2015, p. 123). Alexander von Humboldt's unique way of thinking for his time can be transposed to our times. As recent debate surrounding the Anthropocene shows, there is a need for a continuous discourse between scientific findings and a future that is both meaningful and sustainable.

The experiences with environmental as well as intercultural education show that most humans need to have an emotional and personal connection to what they ought to respect and protect. Pure rationalism will not succeed. This awareness does not only work with primary school children in their immediate natural environment, but also with adults on any scale of the physical or cultural world. Alexander von Humboldt knew and felt this, and therefore resisted joining the natural scientists of his time.

And he was eager to experience nature. Whenever he had a chance to do so, he did. He did pass up the chance to see mining tunnels in person, to travel through the tropical rainforest or the Russian steppe or to climb higher than anybody before him, when he tried to reach the top of the Chimborazo. These real experiences are in spite of the "experiences" in the era of mass tourism a fundamental deficit of many contemporaries in our time.

Success or failure of teaching and educational processes is closely linked to the personality of teachers, a fact that has come to light since John Hattie published the findings of his global meta-study. Without any doubt Alexander von Humboldt was an impressive person. But could his biography serve as an ideal to enrich geographic education? Contemporaries often described him as the one who continuously called attention to himself and talked nonstop in monologue wherever he was and whoever he met. Charles Darwin's meeting with Alexander von Humboldt is a famous example for that behaviour. The young scientist was more than happy that Humboldt met him, but he didn't even have the chance to address any questions to him. If nevertheless somebody dared to take the turn instead of him, Humboldt became easily offended and demonstrated that egocentricity was not totally strange to him. Moreover, it is clear that his ability to teach beyond monologues was extremely limited.

When focusing on his manifold talents, however, the picture is turned on its head. His intellectual curiosity, his open minded attitude, his fitness and endurance, his tenacity, toughness and consequence, his miscellaneous interests, intelligence, multilingualism and creativity, his active and passive enthusiasm, his critical thinking and openness for other people, cultures and new ideas, his clear value based on his stand for humanism, against slavery and discrimination of dissidents, intellectuals or Jews and his overall desire to see as much as possible of the world and understand how it works is definitely suitable to serve as an ideal, though not for anybody.

Alexander von Humboldt was definitely influenced by the values of the French Revolution. In 1790, only a few days before the first anniversary of the storming of the Bastille, Humboldt stayed in Paris, accompanied by Georg Forster, and busied himself with some of the construction works at the Pantheon and in Paris he also internalized the epochal change of societal structure, attitudes and values of liberté, égalité, fraternité. This experience was radically oppositional to his and family's experiences in Prussia and had an enormous lifelong impact on his attitude and behaviour, his decisions and activities. Because of the values he espoused, Humboldt opposed slavery with his book on Cuba as well as in his discussion with Thomas Jefferson and during his audience at the Palace in St. Petersburg, where he tried to relieve the fate of Polish intellectuals who had been banished to Siberia by the Russian Tsar.

And Alexander von Humboldt showed his unpretentious attitude in opposition to the societal conventions of his time by offering his knowledge and findings to the wider public. He did this by publishing popular books on his journeys, e.g. “Ansichten der Natur” (Views of Nature) (1807) or “Vue des Cordillières et Monuments des Peuples Indigènes de l’Amerique” (Views of the Cordilleras and Monuments of the Indigenous Peoples of the Americas) (from 1810 onward) and he did so in Paris when he presented and discussed the experiences of his American journey with a receptive society; here, he conversed with anyone, regardless of their social status. And in Berlin he gave his famous “Kosmos” lectures not only in the halls of the newly founded university, but parallel to that in the “Singakademie”, a building next to the university. There he allowed citizens from all walks of life, including workers, craftsmen or nobles and also women, who were not allowed to enrol in university at that time, the possibility to listen to him without paying an entrance fee. He was convinced that science had to be also popular and not only something for the inner circles of academic representatives. Alexander von Humboldt as well as his brother Wilhelm wanted to contribute to the education of the people and therefore to society’s move towards free and independent individuals who embodied his own values. And he was eager to improve the health and security of workers: he designed a gas mask or a special light for miners and suggested more safety precautions for Russian mines during his journey to the Ural Mountains to the local overseers. All these episodes document his distinct sense of fairness (Schaper 2016, p. 22). This attitude he also showed in his unselfish support of young scientists and artists, even when his own financial situation would not allow it. The Alexander von Humboldt Foundation—established in 1860—continues to this day what Humboldt had started.

Humboldt did not only advance his only intellectual boundaries but also our own: he opened up new ways of understanding our surrounding nature. That said, he should not be viewed as the measure of all things. Like anybody else, he had his mistakes and made wrong decisions. But he was still admired for his intellect and his sensitivity. This combination makes him unique and makes it worth discussing his thoughts much more closely than we have done.

Conclusion

In the centre of Alexander von Humboldt’s importance for geography is his holistic and systemic approach. While the still-incipient natural sciences focused their interest on the physical earth and didn’t integrate humans into their specific view of the world, Humboldt did the opposite. He did not extend the collection of plants for their own sake, but tried to understand their existence as a function of altitude, soil and climate. And he recognized very clearly that human impact on nature is not necessarily ineffective but might lead to the destruction of livelihoods for many species including humans as the famous report on Lake Valencia documents. For him “Alles ist Wechselwirkung” (All is interdependence) and therefore man was and always is part of nature. And as such he is a very effective factor. This finding lies in the heart of contemporary geographic research and education.

To judge Alexander von Humboldt’s potential contribution to contemporary geography education, it is useful to reflect on his thoughts in the context of geographic as well as ESD key competencies. There is no doubt that he internalized all geographic competencies, from general to manifold-specific geographic knowledge and spatial orientation to the collection of data according to scientific methods. His ability to evaluate and communicate his and others’ findings was alike in clarity and vigour and so was his ability to act in the sense of applied geography. The remarkable finding is that Alexander von Humboldt’s ideas and approaches also achieve the key competencies for sustainable development. With his way of measuring, organizing and contextualizing data he prepared the ground he needed in his search for connections and (inter)dependencies. He is the one who established systemic thinking competence, though it took more than a century to come to the fore. On the basis of this systemic competence, he was able to anticipate future development e.g. the devastating future of the people around Lake Valencia. Without a shadow of a doubt, Alexander von Humboldt showcased his competence of critical thinking as we saw in his attitude towards slavery, in the debate between the Neptunists and Plutonists and many in other contexts. His ability to cooperate in scientific networks was as impressive as his strategic and integrated problem-solving competence, which he evidenced in innumerable situations during his journeys as well as with the invention of safety-improving instruments for miners, while his normative competence appears the strongest in his value based sociopolitical attitudes.

Beyond all these individual abilities and competencies, Alexander von Humboldt’s potential contribution to geography education can be seen in his specific combination of rational explanation of the physical world and his very human sensitivity for the world. Without this emotional dimension—some might refer in this context to the creation in a religious sense while others refer to the ideas of a sustainable world—meaningful geography education will not reach its full potential in schools, especially against the backdrop of global challenges the world faces at the beginning of the twenty-first century.

The integration of Alexander von Humboldt’s methodological approach of collecting, organizing and structuring data and looking for connections between them is in a similar way already an established part of geographic education. But it is often presented to the learners as a highly theoretical approach. Young learners especially would benefit from an approach that would cover these scientific methods with an exciting story about real people e.g. under the headline: “How did they find out?”. Alexander von Humboldt could be a suitable example for such an approach, though other examples like Penck’s theory of the Ice Ages or Wegener’s theory of continental drift might fit even better. Furthermore he could accompany geography students over several years in the sense of a spiral curricular concept and serve as an example of increasing understanding of complex realities, at least those parts of the dynamic human–environment system we are living in and which we are responsible for in our own interest. A renewed focus on Humboldt can definitely help in a time when overcoming traditional, continued and often even hardened paradigms and habits is essential and interdisciplinary thinking and solution-based approaches are needed. Or as Alexander von Humboldt said: “Man dürfe nie als starr ansehen, was seinem Wesen nach unabgeschlossen und wandelbar sei!” (“You should never consider something rigid, that by its very nature is unfinished and changeable!”)

References

Beck, H (1982) Große Geographen. Pioniere – Außenseiter – Gelehrte. Reimer, Berlin
Blankenstein, D, Savoy, B, Gross, R, Scriba, A (eds) (2019) Wilhelm und Alexander von Humboldt. Wissenschaftliche Buchgesellschaft, Berlin
Deutsche Gesellschaft für Geographie (DGfG) (2006) Bildungsstandards im Fach Geographie für den MittlerenSchulabschluss. Bonn
Ette, O (1999) Alexander von Humboldt heute. In: Kunst- und Ausstellungshalle der Bundesrepublik Deutschland (ed.) Alexander von Humboldt. Netzwerke des Wissens. Dr. Cantz’sche Druckerei, Ostfildern-Ruit, p 19–31
Harvey, EJ (2020) Alexander von Humboldt and the United States. Art, Nature and Culture. Smithsonian American Art Museum and Princeton University Press, Washington D.C.
Holl, F, Reschke, K (2019) Alles ist Wechselwirkung. In: Kunst- und Ausstellungshalle der Bundesrepublik Deutschland (ed.) Alexander von Humboldt. Netzwerke des Wissens. Dr. Cantz’sche Druckerei, Ostfildern-Ruit, p. 12–15
Kunst- und Ausstellungshalle der Bundesrepublik Deutschland (ed.) (1999) Alexander von Humboldt. Netzwerke des Wissens. Dr. Cantz’sche Druckerei, Ostfildern-Ruit
Lubrich, O (2014) Alexander von Humboldt – Das graphische Gesamtwerk. Lambert Schneider, Darmstadt
Meyer, C (2011) Geographische Bildung – Reflexionen zu ihren Grundlagen. In: Meyer, C, Henry, R, Stöber, G (2011) Geographische Bildung. Kompetenzen in geographischer Forschung und Schulpraxis. Westermann, Braunschweig, p. 11–35
Osten, M (1999) Alexander von Humboldt. Über die Freiheit des Menschen. Insel, Frankfurt am Main
Osterhammel, J (2009) Die Verwandlung der Welt. Eine Geschichte des 19. Jahrhunderts. C. H. Beck, München
Sachs, J (2015) The Age of Sustainable Development. Columbia University Press, New York
Schaper, R (2018) Alexander von Humboldt. Der Preuße und die neuen Welten. München. Siedler
Suckow, C (1999) Dieses Jahr ist mir das wichtigste meines unruhigen Lebens geworden. Alexander von Humboldts russisch-sibirische Reise 1829. In: Kunst- und Ausstellungshalle der Bundesrepublik Deutschland (ed.) Alexander von Humboldt. Netzwerke des Wissens. Dr. Cantz’sche Druckerei, Ostfildern-Ruit, p. 161–177
UNESCO (2017) Education for Sustainable Development. Learning Objectives. Paris
Wulf, A (2015) The Invention of Nature. Alexander von Humboldt’s New World. Knopf Borzoi Books, New York

Thomas Hoffmann heads the Geography Department at the Teacher Training Center Karlsruhe and is honorary professor for Education for Sustainable Development at the Leuphana University Lüneburg. Moreover he is lecturer for the Didactics of Geography at the Institute for Geography and Geoecology at the University of Karlsruhe and actively teaches geography, history, politics, and economics at a school in Germany. His work focuses on projects dedicated to education for sustainable development, among others in the international think-tank “ESD Expert Net: India, Mexico, Germany and South Africa”.

Alexander von Humboldt, a Liberal Ecologist—An Essay

Gregor C. Falk

Abstract This essay focuses on Humboldt's eco-sociopolitical approaches that can be traced in an omnipresent sub-context of his writings. The paper discovers some of his liberal ideas, how they may be related to natural systems and human–environment interaction and why Humboldt's way of thinking may be a good counter-concept to any kind of ideologically biased environmentalism.

Keywords Liberal ideas · Naturgemälde · Human–environment interaction · Environmentalism · Ecosystem · Slavery

Introduction

The earth is an unimaginable complex cosmos of an endless number of pieces and fractures.

Since the beginning of the nineteenth century, depicting and understanding the uncountable systems and dynamic circles haven been in the focus of enlightened sciences. Among others, Alexander von Humboldt (1769–1859) has the great merit of comprehending the entire earth as a continuum. In the "Views of Nature"[1] (Humboldt 1808), his favourite book, he distinguishes not only the different climatic zones, but also the influence of the altitude on nature and living environments. Illustrious descriptions of volcanoes, rivers, forests and land use practices alter with reflective insights into the way of life of people and cultures he met and thus delivers a geographical synthesis of various spatial elements in different contexts and on various regional scales.

[1] Ansichten der Natur (Humboldt 1808).

G. C. Falk (✉)
Institute for Geography and Geography Education, University of Education Freiburg, Freiburg, Germany
e-mail: gregor.falk@ph-freiburg.de

G. C. Falk et al. (eds.), *Alexander von Humboldt*,
https://doi.org/10.1007/978-3-030-94008-9_7

On his travels through Europe, Asia and South America, he restlessly collected and recorded thousands of plants, made countless measurements and sketched his observations on hundreds of diary pages. For him, his work was not only scientific work, but also a joyful and philosophical experience.

Guided by subjective impressions, empirical data and based on distinguished perceptions, he outlines facts and descriptions of his “Naturgemälde” (Humboldt 1845: 79 ff.) knowing that he will never be able to finish this challenging academic task of collecting, analysing and understanding (Köchy 2002: 8). In his public lectures at the Singakademie in Berlin and in his “Cosmos” (Humboldt 1845), which became his masterpiece, he at least tries to piece some fragments of this giant mosaic together (cf. Hamel and Tiemann 2004: 34).

An adequate approach to understand Alexander v. Humboldt’s way of scientific and philosophic thinking is to look at his concept of the “Naturgemälde” as he describes it in his “Essay on the Geography of plants” (Bonpland and Humboldt 1807). Different regions are not only socio-culturally diverse, Humboldt also underpins the broad variety of geological and ecological settings. As in an original painting each detail is of fundamental importance. Each item carries unique characteristics and colours. But eventually everything belongs together and makes up the complete image. Alexander von Humboldt created this kind of new holistic perspective on nature, or as Andrea Wulf titles, he invented nature (Wulf 2015). He puts the purity and the unfiltered gaze on the observed natural phenomena into the foreground. The idea of the “Naturgemälde” is used in two of Humboldt’s major publications: for the first time in 1807 in the abovementioned text about the Geography of plants in tropical countries and secondly, some 40 years later, in his most famous text, the Cosmos (Humboldt 1845). In the first of five volumes he explains his scientific idea of the “Naturgemälde” and his conceptual approach on about 150 pages (cf. Knobloch 2004: 35 ff.).

Humboldt explored nature not from an external perspective; he sees himself and all human beings as contributing and decisively shaping parts within the painting (cf. Köchy 2002: 12). Thus, he does not refer to an abstract concept of nature but instead to something we are an integral part of (cf. Harig 1959: 29). That is where philosophy, emotions and a good pinch of romanticism are added.

His conceptual framework is highly complex and may be best described with what contemporary science would call the ecosystem. Understanding “eco” as the Greek “oikos”, the house we all live in or “oikos” as the family we belong to (cf. Bertaux 1985: 7). Based on this approach Bertaux (1985) was the first who called Humboldt an ecologist. As a matter of fact, Humboldt saw nature as something captivating and intriguing, as an intermingled network of diversity, as something aesthetic and something beautiful and last but not least as something very valuable.

> Those who observe from a reflective perspective recognize nature as a unity in diversity, as a connection of the manifold in form and mixture. The embodiment of natural forces and phenomena as a living whole. (Humboldt 1845: 6)[2]

It becomes obvious that Humboldt's approach is far beyond simple description and empiric data collection but combines different perspectives (Eibach 2012: 1). Humboldt combines observation and analysis with emotions and subjective perceptions in a very affectionate way. Although his excessive use of figurative language may imply a kind of romantic transfiguration, his interpretation is clearly based on a solid fundament of knowledge and empiric observation (Köchy 2002: 10). On his expeditions he took uncountable measurements, collected thousands of samples and drew a number of gorgeous sketches (cf. Ette and Lubrich 2006: 14 ff.).

Alexander v. Humboldt was a meticulous and inquisitive character. He was one of the handful of persons of his time who developed an understanding of how global and local ecosystems work. He had a unique understanding of nature which is still highly influential.

This paper does not intend to retell the story of his life or to deliver another encyclopaedic summary of his works but focuses on Humboldt's eco-sociopolitical approaches that can be traced in an omnipresent sub-context of his writings. Not only in a historic context his ideas about society and social justice can be described as liberal; even today his understanding of human rights and equality are more or less common ground among liberal thinkers.

Most of Humboldt's texts are really unique. As in the "Views of Nature" (Humboldt 1808) they are characterized by a charming and poetically stylish mix of detailed ecosystem description (presented in footnotes), nature interpretation and reflections on social, economic and political aspects (Köchy 2002: 13). This mixture makes them a unique literary genre.

Young Humboldt in Prussia—An Ardent Desire to Travel into Distant Regions Emerges

It was 14 September 1769 when Friedrich Heinrich **Alexander** Freiherr von Humboldt was born. It was the same year James Watt patented the steam engine. In other words, Humboldt was born during the immediate take-off phase of the industrial revolution. He was the younger brother of Friedrich **Wilhelm** Christian Karl Ferdinand von Humboldt who was born a bit more than two years before at 22 June 1769.

Societies and the world into which the two brothers Alexander and Wilhelm were born were troublesome, in transition and in turmoil. Since the authority of the

[2] Die Natur ist für die denkende Betrachtung Einheit in der Vielheit, Verbindung des Mannigfaltigen in Form und Mischung, Inbegriff der Naturdinge und Naturkräfte, als ein lebendiges Ganze (Humboldt 1845: 6).

church had begun to diminish just a bit more than two centuries ago, liberal ideas had developed over the age of enlightenment and new scientific insights and research freedoms were born in the "Occident" (cf. Morley 2010: 128 f.). On the other hand there were rivalling and collaborating European monarchies with their absolutistic rulers striving for economic dominance. European societies were highly volatile and countries were at the brink of war, in Europe and overseas. A kind of hyper-mercantilism and fierce competition led to gradually increasing ravines between the dominating central European powers of Prussia, France, Austria, England and Russia (with shifting alliances) and to a dramatic exploitation of overseas dominions, with all negative consequences for the people as Alexander states:

> The Europeans introduced sugarcane, indigo, and coffee - new branches of crop cultivation, which, instead of being beneficial, spread immorality and boundless misery over the human race: the implementation of African slaves, causing the depopulating of parts of the old continent, are the hotbed for new bloody spectacles of discord and revenge. (Bonpland and Humboldt 1807: 171)[3]

Frederick the Great, or "der Alte Fritz" as contemporaries have called him, was the King of Prussia, the new great power of Europe (cf. Ette 2002: 1). He made Prussia great by military strength but also by supporting the ideas of enlightenment, arts and philosophy. However, political decisions were still made by just a few people and some aristocrats; no democracy existed yet, and the vast majority of people was excluded from any kind of learning and decision-making processes. The French Revolution and the American Independence were still to come. New technical inventions were about to change all spheres of life.

Humboldt's father died when Alexander was 10, so he spent most of his childhood with his mother, who stemmed from a family of Huguenots, and his brother in their mansion in Tegel, then a suburb of Berlin. As Prussian aristocrats they were not only wealthy but had also a close relationship to the King.

The first liberal inspirations Humboldt may have gotten from one of his private teachers, namely Joachim Heinrich Campe or later, Gottlob Johann Christian Kunth. Kunth brought both brothers in contact with several other academic teachers, among them Marcus Herz and consequently they got in contact with liberal intellectuals in the "Berlin Salon" of Henriette Herz.

His mother's life was orbiting around the education of her boys, which she monitored with a kind of non-compromising resoluteness. Alexander described her as cold and emotionless. The more he disliked his mother, the more he loved his brother, to whom he had a close and intense relationship all lifelong. Somehow, Wilhelm the older brother, managed to satisfy his teachers and his mother's

[3] Die Europäer haben hier Zuckerrohr, Indigo und Kaffe eingeführt—neue Zweige des Pflanzenbaus, welche, statt wohlthätig zu werden, vielmehr Unmoralität und grenzenloses Elend über das Menschengeschlecht verbreitet haben: denn die Einführung afrikanischer Sklaven, indem sie einen Theil des alten Kontinents entvölkert, bereitet dem neuen blutige Schauspiele der Zwietracht und Rachgier (Bonpland and Humboldt 1807: 171).

ambitions, whereas Alexander was seeking his intellectual independence from the very beginning. He loved collecting all kinds of things in nature, contemplating outside and he had great skills in drawing and painting (cf. Wulf 2015: 14). However, this is not an uncommon relationship between a younger and an older brother. At the age of 33 Alexander wrote:

> From my earliest youth I had felt an ardent desire to travel into distant regions, which Europeans had seldom visited. (Bonpland and Humboldt 1822[3])

This ardent desire to travel may be understood as an escape from the stifling atmosphere of Berlin and the Prussian aristocracy. At least that is how Alexander describes his emotional bondage to his mother town. One of his first international travels brought him to England, where the bustling harbour of London and the River Thames, packed with uncountable sailing vessels, may have stimulated or at least increased his "Fernweh". Together with his friend Georg Forster, who had accompanied James Cook during his second voyage, young Humboldt met some influential members of the Royal Geographic Society (cf. Wulf 2015: 19 f.).

Following their mothers plans both brothers started their academic career in 1787, which first led them from Frankfurt an der Oder, then to Göttingen and to Hamburg. However, interested in science, Alexander eventually enrolled at the Mining Academy in Freiberg (Saxonia), where he completed his academic education in less than a year. What followed was a highly successful career in the mining sector of the Prussian state and some intense empirical research on all kinds of natural phenomena. In the 1790s he spent a lot of time with German Poet and Romantic Goethe, who was, apart from writing poetry, highly interested in science. According to Wulf "it was the time in Jena that moved him from purely empirical research towards his own interpretation of nature – a concept that brought together exact scientific data with an emotional response to what he was seeing" (Wulf 2015: 40). Or in other words, Alexander von Humboldt added the subjective components of beauty and aesthetics to his research concepts.

There are indications that his mother's death from cancer in 1796 must have been a great relief for Alexander, who did not even join her funeral. In a letter to Willdenow[4] he writes:

> Finally death came to my unlucky mother. Just humanity made it desirable for her to die. Humboldt 1796 quoted from Päßler (2019a)[5]

However, she left a large inheritance, which made him independent and opened great perspectives. Immediately he quit his position as Prussian Chief Mines Inspector and began to materialize his great travel plans.

Seeking the liberal spirits of the French revolution, he moved to Paris, where he met his later travel companion Bonpland. His stay in Paris and the intellectual

[4] Carl Ludwig Willdenow (August 22nd, 1765–July 10, 1812) was a botanist and one of Humboldt's mentors and a close friend.

[5] Der Tod meiner unglücklichen Mutter ist also endlich doch auch eingetroffen. Menschlichkeit allein liess ihn heranwünschen (Humboldt 1796).

freedom Humboldt encountered in Paris' academic society have left a very strong and livelong impact (cf. Ette 2002: 2). As Holl states his "attitudes were characterized by ideas of the enlightenment and the ideals of the French Revolution: liberty, equality, fraternity" (Holl 2014: 123).

Due to political instability in Europe caused by the Napoleonic Wars he had to modify his travel plans several times until he received generous support from the Spanish king to visit the Spanish Colonies in South America and in 1799 Humboldt eventually left Europe. With his journey to Central and South America his dream became reality.

Documenting His Journey—Travel Reports and Diaries

In a letter to Willdenow Humboldt delivers a concise description of the first part of his journey:

> At June 5th 1799 we left Coruna on board of the frigate Pizarro heading towards the Canary Islands, were we climbed Pic de Teide up into the crater. [...] Harbour of Cumana at 16th of July. Stayed there and in the Tumiriquiri mountains, among the Indios Chaymas, at Guarpiche. At November 18th navigating towards La Guayara and Caraccas. Exploring the region, climbing up the Silla, afterwards 2 months through Valles de Aragua, the romantic cocoa plantations at Lake Valencia [...] to Portocabello then heading south through the large Llano [...] entering the province Varinas at the border to St. Fe up to Rio Apure. Heading eastwards on this river into the Orinoco to Cabruta, then southwards upstream beyond the terrible Cataracte de Maypure u Atures reaching the mouth of the Guaviare which is coming from Quito. Leaving the Orinoco heading southeast on the small rivers Atabapo, Tuarnini u Temi, 150 miles from Quito up to Monte Pimichin, which is notorious for its snakes. For 3 days Indians carried the Piragua through this forest to the Rio Negro. Navigating downstream in southeastern direction to S. Carlos [...]. Then through the Casiquiare north near the sources of the Orinoco, on this river upstream beyond Dui-da volcano in Dorado [...] then down all the Orinoco to its mouth. [...] Eventually returning back to Cumana at the 1st of September 1800 [...], then, challenging the perils of the sea and terrible storms from Nueva Barcellona to Havana where we arrived at December 19th 1800. [...] (Humboldt 1801, quoted from Päßler 2019b)[6]

[6] Am 5. Juni 1799 segelten wir von Coruña ab auf Fregatte Pizarro nach den Canarien, wo wir den Pic de Teyde bis in den Crater bestiegen. [...] Am 16. Juli im Hafen von Cumana. Bis November dort und in dem Gebirge Tumiriquiri, unter den Indios Chaymas, am Guarapiche. Am 18. November zur See nach La Guayara und Caraccas. Dort in umliegende Gegend, die Silla besteigend, 2 Monate dann durch Valles de Aragua, die Cacao Pflanzungen am romantischen See von Valencia [...] nach Portocabello dann südlich durch das große Llano [...] in die Prov. Varinas an der Grenze von St. Fe bis Río Apure. Auf diesem Fluß östlich in den Orinoco bis Cabruta, dann diesen südlich aufwärts bis zum jenseits der fürchterlichen Catarac-te de Maypure u Atures an die Mündung der von Quito kommenden Guaviare. Dann den Orinoco verlassend auf den kleinen Flüssen Atabapo, Tuarnini u Temi gegen Südost, 150 Meilen von Quito bis an den wegen Schlangen berüchtigten Monte de Pimichin. Durch diesen Wald trugen die Indianer 3 Tage lang die Piragua bis an den Río Negro diesen hinab südöstlich bis S. Carlos [...]. Dann durch den Casiquiare nördlich an den Quellen des Orinoco, diesen aufwärts bis jenseits dem Vulkan Dui-da im Dorado [...] dann den ganzen Orinoco abwärts bis an die Mündung. [...] Endlich am 1. Sept

From Cuba they began the second part of their exploration of South America. Their starting point was Cartagena, from where they began their perilous crossing of the Andes. Near Quito they climbed several volcanic peaks—the best known tour is his ascent of mount Chimborazo. Travelling south via Lima, Humboldt and Bonpland finally sailed from Guayaquil to Acapulco in Mexico where they stayed several month. Already on their way back to Europe they stopped over in the USA, where they met Thomas Jefferson and some other leading men of science. Humboldt was interested in the liberal political system of this young and independent country, or as Rebok formulates, "he had met the founding fathers and architects of the first independent nation on the American continent, and he had seen for himself the functioning of the first republican institutions in the New World. This was the realization of ideals he passionately embraced" (Rebok 2014: 31, quoted after Howell, J. F.).

The heart of Humboldt's activities has neither beaten in the lecture theatres of the world, although he obviously liked to talk to interested crowds and colleagues, nor behind his desk in his study. His scientific knowledge is based primarily on first hand observations and measurements in the field, which he meticulously documented in his diaries.

Apart from his "Personal narrative of travels to the Equinoctial Regions of the continent […]" (Bonpland and Humboldt 1822[3]) he published a number of different papers describing the results of his research tours to South America. As a primary resource this essay concentrates on various texts Humboldt had published after his return to Europe. There are two main reasons for not using Humboldt's diaries as the immediate source for the documentation of his line of arguments in this paper. The first is more practical, as his diaries are by far more difficult to decipher. As a compilation of handwritten papers (large parts are formulated in French), they are not an easy read. The second reason is something I would call the author's reflective distance, which has produced a somehow filtered and more analytical documentation of the findings and observations. The travel reports, edited some years after his return to Europe, are based on the diaries but provide a stylistically well done text and turn out to be an even more sophisticated resource. Humboldt had time to rethink and reformulate his prime observations. That enabled him to integrate numerous cross references to many locations he and other scientist have had investigated over the years.

His writings about his expeditions, be it South or Central America or later Russia, are rather complex, but his animating and straightforward way to compose his texts as a piece of literature allows the reader to follow his line of thoughts. The overall pattern one finds in his travel reports is his attempt to open a holistic view on local places and regional contexts embedding his observations into global contexts. He writes about natural phenomena and sometimes he gets himself lost in

1800 in Cumana zurück […], dann mit vieler Gefahr und schreklichem Sturm von Nueva Barcellona nach Havana wo wir 19. Dezember 1800 ankamen […] (Humboldt 1801, quoted from Päßler 2019b).

page long descriptions of specific natural phenomena such as earthquakes, the blue colour of the sky, plants, rock formations and many more.

The second pillar of his writings reveals Humboldt's modern environmentalist approach and provides insight in his analytic competences. The thorough interpretation of the impact of human–environment interaction, be it mining or agriculture is a central and innovative element. The third pillar is his personal reflections about society and its characteristic elements such as religion, trade, justice or the overall political situation.

Injustice—One of Humboldt's Main Concerns

Travelling through Central and South America Humboldt won a number of disturbing insights into the negative impacts the colonial system had on indigenous people and societies. In particular, he developed a more and more critical distance towards missionary activities and slavery. Studying his frequent remarks about the disrespectful practices documents Humboldt's liberal attitudes as the following examples may illustrate. His main political concern was the injustice within societies manifested in the unequal treatment of human beings such as slaves or local indigenous populations. Following Humboldt's analysis that the import of slaves became necessary due to a lack of workforce, he argues that the local indigenous people withdrew from the white colonialists and that slaves had to replace them—a practice he obviously condemns:

> In the countries of the east, which came under English and Portuguese rule, the indigenous population consisted of hunting tribes roaming the forests. Not intending to become hard working farmers […] they withdrew when the white men approached. The need for working hands and the increased cultivation of sugar cane, indigo and cotton and last but not least greed, which accompanies and dishonours industries, led to the introduction of slave trade, a disgraceful practice. Carrying sad fruits for both worlds likewise. (Humboldt 1828: 37 f.)[7]

One of the most detailed descriptions of the inhumane and degrading treatment of slaves can be found in his eyewitness report about the slave market in Cumana. According to his writings young Humboldt's first real encounters with the business and barbaric practice of slave trade must have been nearly traumatic. In disgust he describes the market scene:

[7] In den Ländern des Ostens, welche in die Gewalt der Engländer und Portugiesen fielen, bestanden die Eingebornen aus herumstreifenden Jägerstämmen. Weit entfernt, einen Theil der ackerbauenden und arbeitsamen Bevölkerung zu bilden, […] zogen sie sich vielmehr bei der Annäherung der Weißen stets weiter zurück. So geschah es denn, daß das Bedürfniß arbeitender Hände, der vermehrte Anbau des Zuckerrohrs, des Indigo's und der Baumwolle, und endlich die Habgier, welche so oft die Industrie begleitet und entwürdigt, hier jenen schändlichen Negerhandel herbeiführten, der für beide Welten gleich traurige Früchte trug (Humboldt 1828: 37 f.).

> The slaves to be sold were young people between fifteen and twenty years of age. Every morning they had to smear coconut oil on their bodies to give their skin a shiny black appearance. There were always potential buyers investigating the teeth to learn about the age and the health condition of the slave. They opened their mouths with force as it is a common practice on horse markets. […] It makes us feel downhearted, that there are still European colonists […] who brand their slaves with glowing iron to identify them, in case they escape. Is that the way to treat those who save other human being's troubles to saw, work in the field and harvest, just to live. (Bonpland and Humboldt 1815: 508 f.)[8]

Not to compromise those who financially support his travels (Holl 2014: 128), he avoided open criticism on the establishment of colonies but, as documented above, different subcontexts help us to understand his liberal position. As in many other passages he expresses deep respect and empathy for the lives and hardships of the black people which were kidnapped from Africa.

> In the character of black people from Africa exists an inexhaustible source of movement and cheerfulness. After a week of repression and hard work he dedicates himself to music and dance instead of finding an early sleep. We must not condemn this mixture of thoughtlessness and carelessness. It helps them to sweeten the evil sides of a life full of deprivation and pain. (Bonpland and Humboldt 1815: 511)[9]

Even if he does not address the Spanish Kings directly, he sends many signals to the colonial powers promoting the abolition of slavery. As the following passage documents, the colonies may even benefit from freeing the slaves:

> In the context of abolishing slavery in this region he [Graf Tovar] gave away and rented out some of his lands. Returning to America four years later he found beautiful cotton plantations and a little hamlet of 30 to 40 houses […]. Most of the inhabitants […] are mulattoes, zambos or free negroes. Luckily this example of leasing land was copied by several other influential landowners […]. For the inhabitants of Europe this may proof, what none of the enlightened residents of the colonies would ever doubt, that the mainland of Spanish America is capable to produce sugar, cotton and indigo with the help of free workers, and that unlucky slaves may indeed become farmers, tenants or landowners. (Bonpland and Humboldt 1820: 108 f.)[10]

---

[8] Die zum Verkauf ausgesetzten Sklaven waren junge Leute von fünfzehn bis zwanzig Jahren. Man vertheilte ihnen alle Morgen Cocos-Oel, um sich den Leib zu schmieren, und ihrer Haut ein glänzendes Schwarz zu geben. Jeden Augenblick kamen Käufer, die nach dem Zustand der Zähne, über das Alter und die Gesundheit der Sclaven urtheilten; sie öffneten ihnen mit Gewalt den Mund, wie man auf den Pferd-Märkten zu thun pflegt. […] Man seufzt bei dem Gedanken, dass es selbst jetzt noch […] europäische Colonisten gibt, die ihre Sklaven mit einem glühenden Eisen brennen, um sie wieder zu kennen, wenn sie entfliehen. So behandelt man diejenigen, die andern Menschen die Mühe ersparen, zu säen, das Feld zu bearbeiten, und zu ernten, um leben zu können (Bonpland and Humboldt 1815: 508 f.).

[9] Die Völker Afrikas von schwarzer Farbe haben in ihrem Charakter eine unerschöpfliche Quelle von Bewegung und Fröhlichkeit. Nachdem sich der Sklave die Woche durch harten Arbeiten ergeben hat, zieht er an den Festtagen die Musik und den Tanz einem verlängerten Schlaf vor. Lasst uns diese Mischung von Sorglosigkeit und Leichtsinn nicht tadeln, welche die Uebel eines von Entbehrungen und Schmerzen erfüllten Lebens versüsst! (Bonpland and Humboldt 1815: 511).

[10] In grossmüthiger Beschäftigung mit den Massnahmen zu allmähliger Austilgung der Sclaverey der Neger in diesen Gegenden, […] hatte er [Graf Tovar] einen Theil seiner Grundstücke […]

Criticism and scepticism also underpin his analysis about the role of religion and missionary activities. As later letters to Varnhagen von Ense and others document, his scepticism towards religious institutions (not religion!) and their manipulation for political purposes remains a lifelong companion. He states that:

> Christian religion, which originally supported the freedom of men, served the greed of the Europeans as an excuse. Those single individuals who were captured before having been baptized, were regarded to be slaves. (Bonpland and Humboldt 1815: 283 f.)[11]

In addition he describes the negative impact of missions in local contexts, which took away the freedom of the indigenous population and caused their intellectual impoverishment. Reading the following excerpts from his travel reports about local people who became Christians illustrates not only his liberal attitudes but also Humboldt's sceptical position towards the church and its institutions:

> Their number has increased dramatically, but not their intellectual scope. Gradually they have lost the strength of their characters and their natural vivacity, which are presented as the most precious fruits of human independence. Even the most insignificant household duties are uncompromisingly regulated by laws. That has changed them into subservient but also dumb creatures. However, they have their regular food, their conduct is more peaceful, but limited and restricted by the sad monotony of the missionary rule. Their sombre appearance and taciturnity documents how reluctantly they have given up their freedom to receive tranquillity. (Bonpland and Humboldt 1818: 4 f.)[12]

Certainly having in mind the stifling impact the catholic church had over the last centuries, he sees the same restricting impact factors mirrored in the colonial institutions of the Church.

---

vertheilt und verpachtet. Vier Jahre später, bey seiner Rückkunft nach America, traf er an eben dieser Stelle schöne Baumwollpflanzungen, und einen kleinen Weiler von 3o his 40 Häusern, […]. Die Bewohner […] sind fast alle Mulatten, Zambos und freye Neger. Es ist dies Beyspiel der Verpachtungen glücklicherweise von mehreren andern grossen Eigenthümern nachgeahmt worden. […] Die Einwohner von Europa [können] den Beweis darin finden […], das, worüber bey den aufgeklärten Bewohnern der Colonien längst kein Zweifel mehr waltet, das Festland des spanischen America, mittelst freyer Arbeiter, Zucker, Baumwolle und Indigo erzeugen kann, und dass hinwieder die unglücklichen Sclaven gar wohl Bauern, Pächter und Eigenthümer werden können (Bonpland and Humboldt 1820: 108 f.).

[11] Die christliche Religion, welche in ihrem Ursprung so mächtig die Freiheit der Menschen begünstigte, diente der Habsucht der Europäer zum Vorwande. Jeder Einzelne, der vor empfangener Taufe gefangen gemacht wurde, war Sklave (Bonpland and Humboldt 1815: 283 f.).

[12] Ihre Zahl hat sich beträchlich vermehrt, aber ihr Ideenkreis keineswegs. Sie haben nach und nach jene Charakterstärke und jene natürliche Munterkeit eingebüßt, die in allen Verhältnissen des Menschen als die edlen Früchte der Unabhängigkeit sich darbieten. Dadurch, dass auch die geringfügigsten Verrichtungen ihres Haushalts nach unwandelbaren Vorschriften geregelt wurden, hat man sie in gehorsame, aber dumme Geschöpfe verwandelt. Ihre Nahrung ist über haupt gesicherter, ihr Betragen ist friedlicher geworden; aber dem Zwang und der traurigen Einförmigkeit des Missionenregiments unterworfen, verkündigt ihr düsteres und verschlossenes Aussehen, wie ungern sie ihre Freyheit gegen die Ruhe vertauscht haben (Bonpland and Humboldt 1818: 4 f.).

> From generation to generation they hamper the evolution of intellectual powers, they block all mutual communication of the people and suppress everything that may inspire mental enlightenment and widen the horizon of concepts. (Bonpland and Humboldt 1818: 4 f.)[13]

From his liberal point of view, Humboldt sees the dangers of an externally forced intellectual standstill for a prosperous human development, "[…] if societies do not follow the law to which our human spirits obey, […]" (Bonpland and Humboldt 2018: 4).[14]

Humboldt's Perspectives on Man-Made Impacts on the Environment

As a scientist Humboldt's main intention was not only to investigate isolated natural phenomena but to contextualize his observations with regional land use practices or, as we would say today, to analyse human–environment interactions. Among many other scientist Alexander von Humboldt was aware of the fact that human activities are not exclusively determined by natural impact factors but that man-made interventions may modify ecological structures decisively. Travelling through Venezuela he observed and documented some prominent examples of excessive and thus inadequate land use practices, which were introduced by colonial settlers. On his position as a mining expert Humboldt had collected detailed knowledge about various reasons for deforestation in Europe and he was well aware of related negative effects, not only on ecosystems but also on the economy. Thus it is no surprise that some of his most detailed analytical approaches in South America reveal problems related to the negative impacts of shrinking forests in areas of intense agricultural use. Already at the very beginning of his expedition, in the Hinterland of Cumana at the East coast of Venezuela, he notices the problem of serious water scarcity and relates it to his experiences made in Franconia.

> Taking into account the hot temperatures and arid winter months in America it is unbelievable that trees are cut here as excessively as in Franconia - causing timber- and water scarcity likewise. (Humboldt, quoted from Faak 2000: 215)[15]

In addition references to conditions in Europe like the following do not only underline his global perspective but may be read as a direct warning for farmers in the colonies.

[13] Sie hemmen von Geschlecht zu Geschlecht die Entwicklung der Geisteskräfte, sie hindern die gegenseitigen Mittheilungen der Völker, und unterdrücken alles, was den Geist erheben und die Begriffe erweitern kann (Bonpland and Humboldt 1818: 4 f.).

[14] […] wenn die Gesellschaften nicht dem Gesetze folgten, dem der menschliche Geist gehorcht, […] (Bonpland and Humbold 2018: 4).

[15] Unbegreiflich, daß man im heißen, im Winter wasserarmen Amerika so wüthig als in Franken abholzt und Holz- und Wassermangel zugleich erregt (Humbold, quoted from Faak 2000: 215).

> Farming people have reduced humidity of the climate by a complete destruction of the forest. All bogs felt dry and the sphagnum mosses, which made large pieces of land inhabitable for the old Germanic nomads, have been replaced by all kinds of useful plants. (Bonpland and Humboldt 1807: 8)[16]

Sentences like those quoted above may have inspired biographers like Andrea Wulf to call him the "Forgotten Father of Environmentalism",[17] which is an expression of honour but by far a too idolized perspective. As Klein states Humboldt's approach does not imply a new interpretation of Nature as his "insights into the dangers of overexploitation and his claim for a sustainable use of Nature are based on practical experiences in mining and forestry" (Klein 2016: 126). According to Klein Humboldt's idea was to develop technical strategies which may help to avoid negative impacts on ecosystems. A thorough scientific understanding of ecosystems is of fundamental importance to minimize man-made impacts (cf. Klein 2016: 126).

Apart from the general observation that forests have vanished all over Venezuela Humboldt delivers a detailed analysis of ecological causes and effects. He even takes into account that reckless natives contribute to the problem.

> There are frequent and intense forest fires triggered by reckless Indians who do not extinguish the fires on which they cook their food while travelling. (Humboldt 1808: 21)[18]

However, according to Humboldt the principle reason for deforestation in large parts of Central and Southern America can be found in agriculture and inadequate irrigation methods. On his way from Caracas to the Orinoco River in February 1800 he describes the environmental conditions between Antimano and Las Ajuntas near the River Guayre with a dramatic sharpness of observation:

> Sugarcane, Indigo and the Coffee tree can only grow, where running water exists, which may be used for irrigation during dry seasons. The first colonists have carelessly devastated the forests. Evaporation from the stony soil is very high. The ground is encircled by rocks reflecting back heat from all sides. (Bonpland and Humboldt 1820: 54)[19]

---

[16] Durch Ausrottung der Wälder haben ackerbauende Völker die Nässe des Klima vermindert. Die Sümpfe sind nach und nach abgetrocknet, und das Sphagnum, welches den Nomaden des alten Germaniens ganze Länderstrecken unbewohnbar machte, ist durch nutzbare Gewächse verdrängt worden (Bonpland and Humboldt 1807: 8).

[17] Wulf (2015). In: The Atlantic.

[18] Oefters entstehen auch ungeheure Waldbrände durch die Sorglosigkeit der Indianer, die auf ihren Wanderungen das Feuer, wobey sie ihre Speisen kochten, zu löschen unterlassen (Humboldt 1808: 21).

[19] Das Zuckerrohr, der Indigo und der Kaffeebaum mögen nur da gedeihen, wo sich laufendes Wasser befindet, das während der grossen Trockenheit zu künstlichen Bewässerungen gebraucht werden kann. Die ersten Colonisten haben sehr unvorsichtig die Wälder ausgerottet. Die Ausdünstung ist gar beträchtlich auf einem steinigten Boden, der von Felsen umgeben wird, welche von allen Seiten Wärme zurückstrahlen (Bonpland and Humboldt 1820: 54).

Another example for Humboldt's holistic approach to investigate human–environment interaction is his visit at the shores of "wonderful and pittoresque" Lake Valencia which are characterized by intense agricultural structures. A serious problem for nearby farmers and fishermen was the dramatically shrinking water table of the lake; a phenomenon nobody could really explain so far, although several interesting speculations were circulating among local inhabitants. Some made a subaquatic "hole" responsible for the loss of water, a theory Humboldt dismissed.[20] As a starting point for his analysis of the situation, Humboldt formulated several questions to put the observed phenomenon into a larger context:

> What is the reason for the reduction of the amount of water in the lake? Is the decrease rate higher today than centuries ago? May we speculate that the balance between inflow and outflow will be reestablished, or do we have to fear the lake to disappear completely? (Bonpland and Humboldt 1820: 114)[21]

His seemingly simple answers document the Humboldtian ecological approach of contextualization which was more or less new to science at the end of the eighteenth century. Finally he puts all hydrological, ecological, social and economic bits and pieces together to deliver a kind of "Naturgemälde" of Lake Valencia:

> The impact on inflow rates which was brought about by deforestation, by land reclamation in the valleys and by the cultivation of crops like Indigo for more than half a century, on the one hand side and evaporation from soils under arid conditions on the other side, deliver convincing arguments, to explain intensified shrinking processes of Lake Valencia. Those around the world who are cutting trees which are covering mountain peaks and mountain slopes cause a double nuisance for future generations; scarcity of firewood and water. The intense and careless destruction of the forests which is practiced by European colonialists in America have dried out the lake completely or at least reduced the amount of water flowing in. Beds of small creeks, which remain dry for some periods of the year, are changing into torrents whenever heavy rainfall pours down on the slopes. As a consequence of the loss of shrub and trees grass and mosses are vanishing along the ridges. No gradual infiltration compensates run-off peaks. Heavy down-pours cause the erosion of steep ravines, wash away loose earth and lead to sudden flashfloods destroying the land. (Bonpland and Humboldt 1820: 122)[22]

---

[20] Seiler et al. (1992) documented that "a subsurface outflow has been detected and localized for the first time". Curtis et al. (1999) provide a detailed description of the hydrological situation of Lake Valencia during the Holocene.

[21] Woher rührt die Abnahme des Seewassers? Erfolgt diese Abnahme heutzutage schneller, als es vor Jahrhunderten der Fall war? Lässt sich vermuthen, das Gleichgewicht zwischen Zufluss und Verlust dürfte sich bald wieder herstellen, oder hat man ein gänzliches Verschwinden des Sees zu besorgen? (Bonpland and Humboldt 1820: 114).

[22] Die Veränderungen, welche die Zerstörung der Wälder, das Urbarmachen des Bodens in den Ebenen und der Anbau des Indigo seit einem halben Jahrhundert in der Masse der Zuflüsse hervorbrachten, gehen einerseits, und die Ausdünstung des Bodens mit der Trockenheit der Atmosphäre liefern anderseits hinlängliche Gründe dar, um die fortschreitende Verminderung des Valencia- Sees zu erklären. Durch Fällung der Bäume, welche die Berggipfel und Bergabhänge decken, bereiten die Menschen unter allen Himmelsstrichen den kommenden Geschlechtern gleichzeitig eine gedoppelte Plage, Mangel an Brennstoff und Wassermangel. Die Zerstörung der Wälder, wie die europäischen Colonisten dieselbe in America allenthalben mit unvorsichtiger Eile

In conclusion he summarizes his observations and blames local man-made impact factors for the receding water table of the lake.

> By clearing the forests and due to the intensified cultivation of sugarcane, indigo and cotton all sources and natural inflow rates into the Lake of Valencia were gradually reduced year by year. (Bonpland and Humboldt 1820: 123)[23]

All local observations and landscape interpretations have merged into a unique and Humboldt specific approach to understand nature and environmental processes. With his own words he describes his concept as follows:

> In the context of manifold intermingled causes and effects no substance, no activity must be observed isolatedly. The balance amidst the perturbances of quarrelling elements results from the free game of dynamic forces. And a complete understanding of nature, the final objective of all physical studies, can only be achieved, if no force, no formation is neglected, and that is likewise the preparation of a wide and fertile field for the philosophy of nature. (Bonpland and Humboldt 1807: 39 f.)[24]

Underpinning the philosophical aspect of nature-related study and research, he does not only deliver hints to an ethical responsibility and moral obligation, and he challenges many of his colleagues. Sentences like the following were a sheer provocation for many of them:

> The empiricist counts and measures the immediate appearance of phenomena: It is for the philosophy of nature to understand overall links holistically and to explain basic principles. (Bonpland and Humboldt 1807: 90)[25]

Humboldt's understanding of nature is beyond traditional perspectives and descriptive statistics, as he seeks to combine nature and philosophy as something united. Not all of his contemporaries liked this idea which, at least from their

---

vornehmen, hat die gänzliche Austrocknung oder wenigstens die Abnahme der Quellen zur Folge. Die Betten der Bäche, welche einen Theil des Jahrs trocken bleiben, Verwandeln sich in Bergströme, so oft Gussregen auf den Höhen fällt. Und weil mit dem Gesträuche auch der Rasen und das Moos auf den Gräten der Berge verschwinden, so wird der Ablauf des Wassers durch nichts weiter aufgehalten: anstatt, mittelst eines allmähligen Durchseihens, die Gewässer der Bäche langsam für dauernd zu unterhalten, furchen sie bey heftigen Regengüssen die Hügelabhänge aus, schwemmen das losgerissene Erdreich fort, und bilden jene plötzlichen Anschwellungen, welche das Land verheeren. […] (Bonpland and Humboldt 1820: 122).

[23] Mit der Zerstörung der Bäume, und mit dem vermehrten Anbau des Zuckerrohrs, des Indigo und der Baumwolle haben sich die Quellen und alle natürlichen Zuflüsse des Valencia-Sees von Jahr zu Jahr vermindert (Bonpland and Humboldt 1820: 123).

[24] In der grossen Verkettung von Ursachen und Wirkungen darf kein Stoff, keine Thätigkeit isolirt betrachtet werden. Das Gleichgewicht, welches mitten unter den Perturbationen scheinbar streitender Elemente herrscht, dies Gleichgewicht geht aus dem freyen Spiel dynamischer Kräfte hervor; und ein vollständiger Überblick der Natur, der letzte Zweck alles physikalischen Studiums —kann nur dadurch erreicht werden, dass keine Kraft, keine Formbildung vernachlässigt, und dadurch der Philosophie der Natur ein weites, fruchtversprechendes Feld vorbereitet wird (Bonpland and Humboldt 1807: 39 f.).

[25] Der Empyriker zählt und misst, was die Erscheinungen unmittelbar darbieten: der Philosophie der Natur ist es aufbehalten, das allen Gemeinsame aufzufassen und auf Principien zurückzuführen (Bonpland and Humboldt 1807: 90).

perspectives, opens spaces for subjectivism, emotion and imagination. In other words this kind of understanding environments allows everybody to take a share. His excellent communication and networking capacities may be one of the reasons why Humboldt became so extremely popular after his return to Europe.

A Spirit of Freedom—Liberal Ideas Are Gaining Momentum

After his return from the USA in 1804 he did not move to Berlin, where he still had his family links, but to Paris. In several letters Humboldt describes his disrespect to the living conditions in Berlin. He describes the Prussian capital as a small place without literature, full of picky bureaucrats who are complaining all the time. At the same time he sees the "great" French world he can experience in Paris. In a letter to Varnhagen[26] he writes:

> Luckily the great French world is free from mean mockery and of permanent criticalness, which prevails in Berlin and Potsdam. Here mindless people are brooding over self-created distorted pictures of faint imagination. (Humboldt 1837, quoted from Brockhaus 1860: 42)[27]

Apart from short visits in Berlin he stayed in Paris until 1827 where he sorted out all data and material he brought home from his expedition. As a clever networker and excessive letter writer, he established many useful contacts to well reputed scientists of his days. According to what we have learned from his biography, he was a gregarious and very talkative person who dominated everybody. In 1827 Humboldt was nearly bankrupt and thus he reluctantly followed the request of his king who demanded his presence at court. The way he lived shows the extreme bipolarism of this genius: he was both nearly bankrupt most of his life but also so well organized in all question related to his work—every letter and detail was stored in boxes, and each small note was fixed on pieces of jotting paper.

During his stay in Paris, heavily influenced by the Napoleonic Wars and the revolutions he had witnessed during his lifetime, he further elaborated his ideas about freedom, the independence of the colonies and global economic liberalism. It was the time when Humboldt stayed in intense contact with Simon Bolivar (Harig 1959: 14), the Venezuelan revolutionist, whose ideas to free America from Spain were publicly supported by Alexander von Humboldt. Not astonishingly Bolivar, who says about Humboldt "The real discoverer of South America was Humboldt,

[26] Karl August Varnhagen von Ense (February 21st, 1785–October 10th, 1858) was a chronicler and diplomat. He corresponded intensively with Alexander v. Humboldt.

[27] Glücklicherweise ist man in der großen französischen Welt ganz von der kleinlichen Moquerie und Tadelſucht frei, die in Berlin und Potsdam herrscht, wo man Monate lang gedankenleer an einem selbstgeschaffenen Zerrbilde matter Einbildungskraft naget (Humboldt 1837, quoted from Brockhaus 1860: 42).

since his work was more useful for our people than the work of all conquerors" (quoted from Wulf 2015), tries to gain political profit from his popular supporter.

To his understanding the independence of the colonies constituted a win–win situation for both sides and he also emphasized the positive effects on the European states.

> Of course, after the great revolutions which the constitutions of the States have endured, public wealth, the common heritage of civilization, must be found differently distributed among the peoples of the two worlds; but gradually the equilibrium is restored, and it is a sad, I would almost say godless, prejudice, considering the growing happiness of any other part of our planet as a misfortune for the old Europe.
>
> The independence of the colonies will not separate them from us; it will rather bring them closer to the other peoples. Trade will unite, which a jealous policy has separated for so long. Moreover, it is in the nature of civilization that it can advance, without necessarily disappearing where it originated. (Humboldt 1828: 38)[28]

In his essay about the political situation in the island of Cuba, he provides a clear statement not only for democracy but also for free trade, which is a fundamental liberal claim and perspective. In the context of his personal situation as a Prussian aristocrat serving the King, the following lines must have sounded like a kind of treason in written form.

> The blunting of the peoples is the consequence of oppression exercised by either internal despotism or a foreign conqueror; it is always accompanied by increasing impoverishment. Free, vigorous institutions, founded for the sake of all remove these dangers; and the growing civilization of the world, the competition of activity and exchange, cannot be dangerous to the states whose wealth flows from natural sources. The productive and active Europe will benefit from the new order of things in Spanish America, […]. (Humboldt 1828: 38)[29]

[28] Freilich muß nach den großen Revolutionen, welche die Verfassungen der Staaten erlitten haben, der öffentliche Wohlstand, das gemeinsame Erbtheil der Civilisation, unter den Völkern der beiden Welten verschieden vertheilt sich finden; aber allmählig stellt sich das Gleichgewicht wieder her, und es ist ein trauriges, ich möchte fast sagen gottloses, Vorurtheil, wenn man das wachsende Glück irgend eines andern Theiles unsers Planeten als ein Unglück für das alte Europa betrachtet. Die Unabhängigkeit der Kolonien wird sie nicht von uns absondern; sie wird sie vielmehr den längst gebildeten Völkern näher bringen. Der Handel wird vereinen, was eine eifersüchtige Politik so lange getrennt hatte. Außerdem liegt es in der Natur der Civilisation, daß sie vorwärts schreiten kann, ohne deßhalb nothwendig da, wo sie entstand, zu verschwinden (Humboldt 1828: 38).

[29] Die Abstumpfung der Völker ist die Folge der Unterdrückung, welche entweder innerer Despotismus oder ein fremder Eroberer ausübt; stets ist sie von zunehmender Verarmung begleitet. Freie, kräftige Institutionen, im Interesse Aller gegründet entfernen diese Gefahren; und die wachsende Civilisation der Welt, die Konkurrenz der Thätigkeit und des Austausches, kann den Staaten nicht gefährlich werden, deren Wohlstand aus natürlichen Quellen fließt. Das produktive und handelnde Europa wird bei der im spanischen Amerika eintretenden neuen Ordnung der Dinge gewinnen, […] (Humboldt 1828: 38).

Conclusion

Alexander von Humboldt delivers a holistic understanding of Earth Systems and Society, he writes a multidimensional story of ecosystems and human–environment interactions. As he does not employ any kind of moral imperative or no ideology, Humboldt's environmentalism differs in a positive way from todays "save the planet" campaigns. Following Knobloch's argumentation about Humboldt's point of view "free nature is faced with spiritual and political freedom. Humboldt talks about the legitimation of intellectual freedom […]" (Knobloch 2004: 36).

Eco-related activities of social groups and individuals may be resulting from insights and understanding which are the final result of education and research. That is the very core of liberal thinking. It is the free individual that is responsible. According to Holl "Humboldt's ideal is a world of self-determined free individuals which are related to each other in a respectful and peaceful manner" (Holl 2014: 129). Embedding his chains of arguments into the historical context, I personally like this Humboldtian eco-liberal approach: it is analytic rather than moralizing and it is based not in ideology but on understanding. He believed that people have strong capabilities to learn and that action should not be dictated but be steered by logical insights. However, it must not be forgotten that Humboldt, as a highly competent miner, has a positive attitude towards technical innovations (cf. Klein 2016: 123), which may help to increase economic benefits. Depicting a too idealized image of a man whose premier intention was to save the environment is misleading and a kind of historic transfiguration.

Although many of his ideas have been further developed, reconceptualized or even proven wrong the work of Alexander von Humboldt is still a rich resource to investigate and understand early concepts of humanism, liberalism and systematic earth and environmental sciences. Among many other attributes that may be ascribed to Humboldt his liberal attitudes and his way of interpreting ecological processes and cycles are of particular relevance.

References

Bertaux, Pierre (1985): Vorwort. In: Beck, Hanno and Wolfgang H. Hein: Alexander von Humboldt: Leben und Werk. Ingelheim: Böhringer.

Bonpland, Aimé & Alexander v. Humboldt (1807): Ideen zu einer Geographie der Pflanzen nebst einem Naturgemälde der Tropenländer. Auf Beobachtungen und Messungen gegründet, welche vom 1 ten Grade nördlicher bis zum 1 ten Grade südlicher Breite, in den Jahren 1799, 1800, 1801, 1802 und 1803 angestellt worden sind. Tübingen: Cotta.

Bonpland, Aimè & Alexander v. Humboldt (1815): Reise in die Aequinoctial-Gegenden des neuen Continents in den Jahren 1799, 1800, 1801, 1802, 1805 und 1804 Band 1. Stuttgart, Tübingen: Cotta.

Bonpland, Aimè & Alexander v. Humboldt (1818): Reise in die Aequinoctial-Gegenden des neuen Continents in den Jahren 1799, 1800, 1801, 1802, 1805 und 1804 Band 2. Stuttgart, Tübingen: Cotta.

Bonpland, Aimè & Alexander v. Humboldt (1820): Reise in die Aequinoctial-Gegenden des neuen Continents in den Jahren 1799, 1800, 1801, 1802, 1805 und 1804 Band 3. Stuttgart, Tübingen: Cotta.

Bonpland, Aimé & Alexander v. Humboldt (1822)[3]: Personal narrative of travels to the Equinoctial Regions of the continent, during the years 1799–1804. Vol. I & II. Written in French and translated by Helen Maria Williams. London: Longman.

Brockhaus, Friedrich, A. (ed.) (1860): Briefe von Alexander von Humboldt an Varnhagen von Ense aus den Jahren 1827 bis 1858. Nebst Auszügen aus Varnhagen's Tagebüchern und Briefen von Varnhagen und Andern an Humboldt. Leipzig: Brockhaus.

Curtis, Jason et al. (1999): Climate change in the Lake Valencia Basin, Venezuela, 12600 yr BP to present. In: The Holocene 1999: 9, pp. 609–619.

Eibach, Joachim (2012): Tasten und Testen. Alexander von Humboldt im Urwald, viewed 01 April 2020 <http://www.zeitenblicke.de/2012/1/Eibach/index_html>.

Ette, Ottmar (2002): "… daß einem leid tut, wie er aufgehört hat deutsch zu sein" Alexander von Humboldt, Preußen und Amerika. In: Ette, Ottmar & Eberhard Knobloch (eds.): HiN Alexander von Humboldt im Netz, III, 4. Potsdam: Potsdam Universitätsverlag, pp 1–2.

Ette, Ottmar & Oliver Lubrich (eds.) (2006): Alexander von Humboldt. Über einen Versuch den Gipfel des Chimborazo zu ersteigen. Frankfurt am Main: Eichborn.

Faak, Margot (ed.) (2000): Alexander von Humboldt, Reise durch Venezuela: Auswahl aus den amerikanischen Reisetagebüchern. Berlin: Akademie-Verlag (Beiträge zur Alexander-von-Humboldt-Forschung, 12).

Falk, Gregor C. (2005): Alexander von Humboldt – Die Reise nach Südamerika. In: Abdelouahab, Farid (ed.): Unterwegs! Reisetagebücher aus fünf Jahrhunderten. Kehl: RvR/Kubik, pp 124–137.

Hamel, Jürgen & Klaus-Harro Tiemann (eds.) (2004): Alexander von Humboldt. Die Kosmos Vorträge 1827/28 in der Berliner Singakademie. Frankfurt am Main and Leipzig: Insel.

Harig, Gerhard (ed.) (1959): Alexander von Humboldt. Eine Auswahl. Leipzig and Jena: Urania.

Holl, Frank (2014): „Zur Freiheit bestimmt" – Alexander von Humboldts Blick auf die Kulturen der Welt. In: Ette, Ottmar & Eberhard Knobloch (eds.): HiN Alexander von Humboldt im Netz, XV, 29. Potsdam: Potsdam Universitätsverlag, pp 123–133.

Howell, James F. (2016): Recasting the Significant: The Transcultural Memory of Alexander von Humboldt's Visit to Philadelphia and Washington, D.C. In: Humanities 2016, 5(3), 49.

Humboldt, Alexander v. (1808): Ansichten der Natur. Tübingen: Cotta.

Humboldt, Alexander v. (1828): Amerika und Europa (Essai politique sur l'île de Cuba. Paris 1826). In: Das Ausland. Nr. 10, pp. 37–38.

Humboldt, Alexander v. (1845): Kosmos. Entwurf einer physischen Weltbeschreibung. Erster Band. Stuttgart and Tübingen: Cotta.

Klein, Ursula (2016): Alexander von Humboldt: Vater der Umweltbewegung? In: Abhandlungen der Humboldt Gesellschaft 37, pp. 115–130.

Knobloch, Eberhard (2004): Naturgenuss und Weltgemälde. Gedanken zu Humboldts Kosmos. In: Ette, Ottmar & Eberhard Knobloch (eds.): HiN Alexander von Humboldt im Netz, V, 9. Potsdam: Potsdam Universitätsverlag, pp 33–47.

Köchy, Kristian (2002): Das Ganze der Natur. Alexander von Humboldt und das romantische Forschungsprogramm. In: Ette, Ottmar & Eberhard Knobloch (eds.): HiN Alexander von Humboldt im Netz, III, 5. Potsdam: Potsdam Universitätsverlag, pp 2–16.

Morley, Neville (2010): Envoi: Decline and Fall. In: The Roman Empire: Roots of Imperialism. London and New York: Pluto Press, pp. 128–135.

Päßler, Ulrich (ed.) (2019a): Alexander von Humboldt an Karl Ludwig Willdenow. [o. O., nach 19. November 1796] In: Ette, Ottmar (ed.): Edition Humboldt digital Version 5. Berlin: Berlin-Brandenburgische Akademie der Wissenschaften. Viewed 07 April 2020 <https://edition-humboldt.de/briefe/detail.xql?id=H0001201&l=de>.

Päßler, Ulrich (ed.) (2019b): Alexander von Humboldt an Karl Ludwig Willdenow. Havanna, 21. Februar 1801. In: Ette, Ottmar (ed.): Edition Humboldt digital Version 5. Berlin: Berlin-Brandenburgische Akademie der Wissenschaften. Viewed 07 April 2020 <https://edition-humboldt.de/briefe/detail.xql?id=H0001181&l=de>.
Rebok, Sandra (2014): Humboldt and Jefferson: A Transatlantic Friendship of the Enlightenment. Charlottesville: University of Virginia Press.
Seiler, Klaus-Peter et al. (1992): Das Grundwasser im Umfeld des Lago de Valencia, Venezuela und seine anthropogene und geogene, nachteilige Beeinflussung. In: Zeitschrift der Deutschen Geologischen Gesellschaft Band 1992, 143, pp. 398–403.
Starbatty, Jürgen (2001)[7]: Alexander von Humboldt. Die Reise nach Südamerika. Göttingen: Lamuv.
Weigl, Engelhard (2004): Wald und Klima: Ein Mythos aus dem 19. Jahrhundert. In: Ette, Ottmar & Eberhard Knobloch (eds.): HiN Alexander von Humboldt im Netz, V, 9. Potsdam: Potsdam Universitätsverlag, pp 74–92.
Wulf, Andrea (2015): The Forgotten Father of Environmentalism, viewed 01 April 2020 <https://www.theatlantic.com/science/archive/2015/12/the-forgotten-father-of-environmentalism/421434/>.
Wulf, Andrea (2015): The Invention of Nature: Alexander von Humboldt's New World. New York: Penguin.

Gregor C. Falk's research interests focus on the intermingled social, political and ecological dimensions of land use, climate and landcover change. As a teacher trainer and professor of Physical Geography at Freiburg University of Education he is involved in research activities related to education, learning and digitalization.

Humboldt: Empathic Patron, Consultant and Communicator of Science

Fig. 1 Travelling the rivers Apure, Orinoco, Cassiquiare and Rio Negro. Taken from: Journal de la navigation sur l'Apure, l'Orenoque, le Cassiquiare et le Rio Negro (Voy. par les Llanos de Caracas S. Fernando de Apure) Statistique de Cumanas Pta Araya. Page v22. This source is sometimes referred to as Travel Journal IV of the American Journey (cited from and courtesy of Staatsbibliothek Berlin/Kaliope-Verbund)

The Humboldt Paradox: Science, Communication and Mythology

Oliver Lubrich

"Wie gern möchte ich nur einmal Humboldten erzählen hören."
("How much I would enjoy just once hearing Humboldt talk!")

Johann Wolfgang von Goethe,
Die Wahlverwandtschaften
(*The Elective Affinities*, Goethe 1809)

"I read and re-read Humboldt."
Darwin (1887)

Abstract The way in which we perceive an author or scientist is largely a result of their own communications. In the case of Alexander von Humboldt, his communications were so effective that they were counterproductive. The eminence of the researcher overshadowed his research, and the renown of the author reduced the resonance of his writings. It is rare to see such a great disparity between the fame of an author and the visibility of his written work. For many decades, Humboldt was celebrated more than he was read. There have been more statues than editions, more speeches than monographs. How did it come to this? How did Humboldt communicate his work in the public sphere? And how did he become a victim of his own communication and his own success?

Keywords Alexander von Humboldt · Communication of science · Public intellectual · Literary genres · Data visualisation · Epidemiology

Paper presented at the German National Academy of Natural Sciences Leopoldina, Halle, 21 June 2019. Translated by Rachel Holland.

O. Lubrich (✉)
Institute of German Studies, Comparative Literature, University of Bern, Bern, Switzerland
e-mail: oliver.lubrich@unibe.ch

G. C. Falk et al. (eds.), *Alexander von Humboldt*,
https://doi.org/10.1007/978-3-030-94008-9_8

Introduction

Alexander von Humboldt's name is well known around the world, from Germany to Latin America, but only a few of his many books are widely read. *Ansichten der Natur (Views of Nature)* (1808, 1826, 1849) and *Kosmos (Cosmos)* (1845–1862) were bestsellers (Fiedler and Leitner 2000), but this was by no means the case for most of his other publications. The richly illustrated account of his American voyage, *Vues des Cordillères et monumens des peuples indigènes de l'Amérique* (*Views of the Cordilleras and Monuments of the Indigenous Peoples of America*) (1810–1813), one of his most attractive works and perhaps his most original, was so expensive due to its elaborate picture plates in folio format that only 600 copies were printed. No German edition was published until 200 years after the original (Lubrich and Ette 2004; Fiedler and Leitner 2000). The narrative of his expedition, *Relation historique du Voyage aux régions équinoxiales du Nouveau Continent* (*Personal Narrative of Travels to the Equinoctial Regions of the New Continent*) (1814–1831), is still not available as an unabridged German edition (Ette 1991; Beck 1997; Weigl 1992). Cuba has named a national park, a museum and a professorship after Humboldt, issued stamps with his picture and erected a statue of him in its capital city, but has only published one of his books—*Essai politique sur l'île de Cuba* (*Political Essay on the Island of Cuba*) (1826) (Ortiz 1930).

The impact that Humboldt made during his lifetime was due much more to the publication of numerous shorter articles, many of which were distributed through mainstream media with high circulation, than to his books. No less than 750 of his papers, articles and essays, together with their edits and translations, have been published in newspapers and magazines or in volumes produced by other authors and editors worldwide, making a total of at least 3600 versions. In *Cosmos*, Humboldt presented "the whole world in a book", and he described it again in a completely different way in his essays, namely in a fragmented, mosaic-like manner as "the whole world in a thousand writings". His shorter texts formed his other *Cosmos* (Lubrich and Nehrlich 2019b).

These shorter texts in particular were largely forgotten after Humboldt's death, and only five per cent of them have been reprinted posthumously. It was not until the 250th anniversary of Humboldt's birth, in 2019, that they were brought together and published in a collection of his *Complete Writings* (*Sämtliche Schriften*) (Lubrich and Nehrlich 2019a; Brönnimann 2019; Lubrich 2019a, 2020).[1]

[1] Collaborators for Lubrich and Nehrlich (2019): Sarah Bärtschi, Michael Strobl, co-editors: Yvonne Wübben (volume I: texts 1789–1799), Rex Clark (volume II: texts 1800–1809), Jobst Welge (volume III: texts 1810–1819), Norbert Wernicke (volume IV: texts 1820–1829), Bernhard Metz (volume V: texts 1830–1839), Jutta Müller-Tamm (volume VI: texts 1840–1849), Joachim Eibach (volume VII: texts 1850–1859); sub-editors: Norbert Wernicke (volume VIII: apparatus), Corinna Fiedler (volume IX: translations), Johannes Görbert (volume X: research). www.humboldt.unibe.ch.

As a result, we now have the opportunity to reconstruct Humboldt's publication record and scientific journalism over a period of seven decades (1789–1859). The numerous contributions that he published across various media rather than in book form are particularly valuable in helping us understand how Humboldt communicated his research to different audiences. He made use of a variety of strategies, which he changed over time and according to his target groups, and his communications had far-reaching consequences.

Multilingualism and Internationality

Humboldt communicated in many languages right from the start. The first of his writings was published in French (Humboldt 1789, in Berlin), the second in German (Humboldt 1790a, in Leipzig) and the third in Latin (Humboldt 1790b, in Zurich) (see Humboldt, *Sämtliche Schriften*, volume I in Lubrich and Nehrlich 2019a). Since Latin had by then largely lost its status as the language of science and its use was restricted to descriptive natural history, it only featured to a minor extent in Humboldt's corpus. Although his books about his American expedition (1799–1804) were mostly written in French and published in Paris (Lubrich 2009),[2] his shorter writings, aimed at a wider readership, were mostly written in German.

Humboldt's work has been widely translated and has appeared in 15 languages altogether; the original texts in German, French and Latin have been translated into English, Spanish, Portuguese, Italian, Dutch, Danish, Norwegian, Swedish, Polish, Russian, Hungarian and Hebrew (Lubrich and Nehrlich 2019c). Of these, the English language has, perhaps surprisingly, been particularly significant, with 250 of his texts published as English translations during his lifetime and some even appearing in multiple versions, facilitated by a relatively free press in the United States and Great Britain.

It is not always possible to distinguish with certainty between Humboldt's targeted publications and his autonomous circulations. Some of his writings were also distributed, acquired, reprinted, extracted or translated without his knowledge, and some appeared in languages that he did not even speak himself, such as Hungarian and Polish.

It, therefore, took some time to reassemble and reissue his publications after his death. Their widespread distribution made their collection and exploration significantly more challenging. Prior to 2019, some 80% of the 3600 publications in the *Complete Writings* had not even been recorded or referenced bibliographically (Bisky 2019).

The internationality and multilingualism of Humboldt's publications were in part programmatic, with science being understood as an interaction that is not restricted

[2] Twice as many of his books appeared in French as in German.

to major centres of research but is potentially unbounded. Humboldt did not in any way limit himself to European academies but rather addressed an international audience.

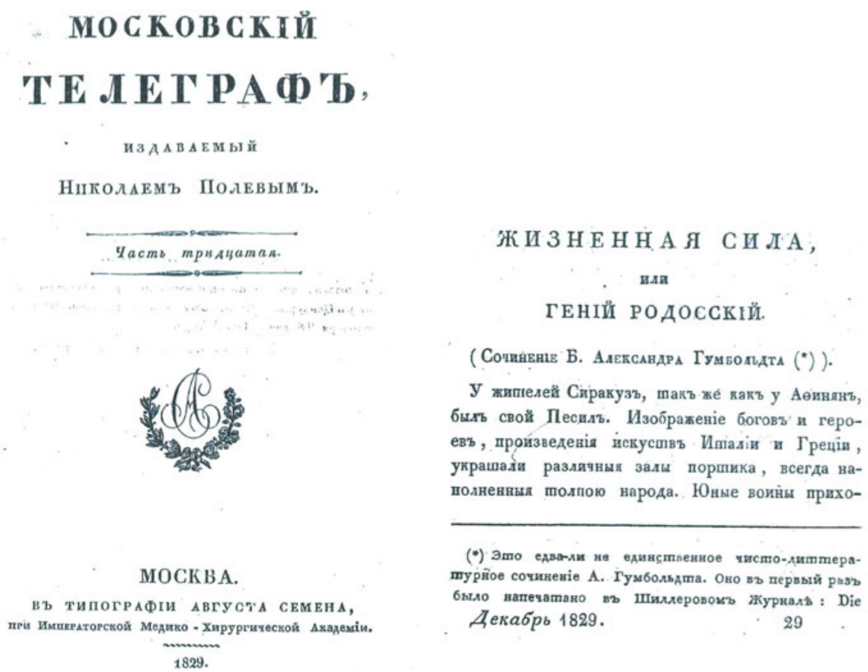
The dissemination of his writings reflected the author's destinations and expeditions, as well as his personal networks, so that following his major voyages through the Americas and Central Asia certain focal points in Latin America, the USA and Russia became apparent. However, Humboldt's writings reached places that the author himself never visited, such as Africa, Brazil, India and China, as well as Australia and New Zealand (Lubrich 2018a). Between 1789 and 1859, his articles were published in more than 400 locations across five continents and featured in more than 1200 periodicals. Alexander von Humboldt was probably the most international publicist of his time (Lubrich and Nehrlich 2015) (Figs. 1 and 2).


The Natal Witness,
AND
AGRICULTURAL AND COMMERCIAL ADVERTISER.
"THE TRUTH, THE WHOLE TRUTH, AND NOTHING BUT THE TRUTH."
No. 229.] PIETERMARITZBURG, NATAL, FRIDAY, JULY 5, 1850. [VOL. V.

NOCTURNAL LIFE OF ANIMALS IN THE PRIMEVAL FOREST.

On leaving the Island del Diamante (in the Orinoco), we entered on scenes of nature characterised by wildness and grandeur. The air was filled with countless flocks of flamingoes and other water birds, which appeared against the blue sky like a dark cloud with continually varying outlines. The river had here narrowed to between nine hundred and one thousand feet, and flowing in a perfectly straight line, formed a kind of canal enclosed on either side by dense wood. The margin of the forest presents at this part a singular appearance. In front of the almost impenetrable wall of giant trunks, there rises from the sandy river beach, with the greatest regularity, a low hedge of Sauso, only four feet high, consisting of a small shrub, Hermesia Castaneifolia which forms a new genus of the family of Euphorbiaciæ. Some slender thorny palms stand next; and the whole resembles a close, well-pruned garden hedge, having only occasional openings at considerable distances from each other, which have doubtless been made by the larger four-footed beasts of the forest to gain easy access to the river. One sees, more especially in the early morning and at sunset, the American tiger or jaguar, the tapir and the peccary, lead their young through these openings to the river to drink. When startled by the passing canoe, they do not attempt to regain the forest by breaking forcibly through the hedge which has been described, but one has the pleasure of seeing these wild animals stalk leisurely along, between the river and the hedge, for four or five hundred paces, until they have reached the nearest opening, when they disappear through it. In the

Fig. 1 Article in Africa: "Nocturnal life of animals in the primeval forest", in: The Natal Witness 5: 229 (5 July 1850)



МОСКОВСКІЙ
ТЕЛЕГРАФЪ,
ИЗДАВАЕМЫЙ
НИКОЛАЕМЪ ПОЛЕВЫМЪ.

Часть тридцатая.

МОСКВА.
ВЪ ТИПОГРАФІИ АВГУСТА СЕМЕНА,
при Императорской Медико-Хирургической Академіи.
1829.

ЖИЗНЕННАЯ СИЛА,
или
ГЕНІЙ РОДОССКІЙ.

(Сочиненіе Б. Александра Гумбольдта (*)).

У жителей Сиракузъ, такъ же какъ у Аѳинянъ, былъ свой Песилъ. Изображеніе боговъ и героевъ, произведенія искуствъ Италіи и Греціи, украшали различныя залы портика, всегда наполненныя толпою народа. Юные воины прихо-

(*) Это едва-ли не единственное чисто-литтературное сочиненіе А. Гумбольдта. Оно въ первый разъ было напечатано въ Шиллеровомъ Журналѣ: Die

Декабрь 1829. 29

Fig. 2 Essay in Russia: “Жизненная сила, или гений Родоский”, in: Московский телеграфъ 30: 24 (1829), pp. 423–431

The Young Scientist

Humboldt’s publishing activity can be broadly divided into three stages. As a young scientist, his initial education was in a range of subjects, in particular botany, mining and physiology, and his work was published in the corresponding journals —for example in the *Magazin für die Botanik* (Botanical Magazine), the *Bergmännisches Journal* (Mining Journal) and the *Chemische Annalen* (Chemical Annals). Humboldt managed to gain access to the scientific community in general, as well as to the specific networks of individual scientific disciplines.

The first decade of his publishing activity (1789–1799) was dominated by research articles in which he presented his own observations, together with critical reviews in which he dealt with the work of authoritative scientists (Bärtschi and Wübben 2019). It is through these writings that we can trace the development of his career from its beginnings.

Since Humboldt’s contributions were often published in the form of letters to colleagues or editors, in which he shared his findings, they also served to highlight his place within the scientific community. He reported the results of his physiological experiments to his tutor in Göttingen, Johann Friedrich Blumenbach

(Humboldt 1795a) and his “lamp preserver” and “rescue cylinder” inventions to the Inspector of Mines, Friedrich Wilhelm Heinrich von Trebra (Humboldt 1796a).

Many of Humboldt’s publications aimed to make his monographs more widely known in professional circles and beyond. His publishing house, Cotta, later released targeted extracts and advance excerpts.

Humboldt understood the strategic importance of reviews and made every effort to ensure that his own work was discussed. In a letter to Paul Christian Wattenbach dated 18 February 1792, he explained:

> “Zum Schriftstellerischen Handwerk gehört Läuten, darum halte ich etwas auf Rezensionen” (“The trade of the writer needs to be advertised, and that is why I hold the review business in high regard”). (Jahn and Lange 1973)

Humboldt’s first published text is in fact a review of a Latin dissertation by Carl von Linné’s successor, Carl Peter Thunberg, on the East Indian poison tree Bohon-Upas, *Arbor Toxicaria Macassariensis* (Humboldt 1789). Further reviews followed, namely of the Dutch study on crop production by Steven Jan van Geuns, his companion on his first research voyage (Humboldt 1790c), of the report by Thaddaeus Haenke and others on their botanical expedition to the Riesengebirge, located in the eastern corner of Germany (Humboldt 1791a), of the dissertation by Christian Philipp Ripke on the merits of the people of Hamburg with regard to natural history (Humboldt 1791b), and of transcripts of lectures by Carl von Linné (Humboldt 1791c).

Humboldt’s reviews often went beyond a mere evaluation of somebody else’s work, containing programmatic considerations and sententious statements about his own research interests. He used the expedition report prepared by Haenke et al. to divert from Linné’s system of classification towards a phytogeographical observation of species in their natural habitats. This method is “certainly preferable to the systematic approach”, he explained resolutely (“der Systematischen gewiß vorzuziehen”). By observing how Christian priests spread superstition within the indigenous population, he expanded the testing of contemporary legends (based on Thunberg’s description of the East Asian poison tree) into a general critique of colonialism and the complicity of the Church. In 1789, the year of the French Revolution, Humboldt gave his essay on botany a political twist: “Priests south of the equator behave in just the same way” (“Die Priester ändern sich auch unter dem Äquator nicht”).

Humboldt’s shortest review is of a work on willow grasses by the botanist vicar, George Swayne. Somewhat curiously it contains only two sentences, but a most incisive statement:

> “Very well put! However, it is meant to help make country people familiar with different grass species but costs a pound and a shilling!!” (“Sehr sauber! soll aber dazu dienen, Landleute mit den Grasarten bekannt zu machen, und kostet 1 Pf. St. und 1 Schill.!!”). (Humboldt 1791d)

Humboldt used two exclamation marks to emphasise the contradiction (“aber”, “but”) between the high price of the publication and the frugal income of the target readership: science should be accessible to the widest possible public. He later considered it equally important that his *Cosmos Lectures* should be free, declaring to the press, “one should not pay for the right to attend a public lecture” (“on ne paye pas, pour obtenir le droit d’assister à un cours public”) (Humboldt 1828). In addition to their scientific content, Humboldt’s contributions, therefore, had both practical and social dimensions.

The young researcher’s communications also included more intimate situational interventions. In brief “corrections”, Humboldt rectified mistakes he had made in his monograph entitled *Mineralogische Beobachtungen über einige Basalte am Rhein* (*Mineralogical Observations on Basalts along the Rhine*) (Humboldt 1791e, f), as well as erroneous attributions of authorship by third parties (Humboldt 1794, 1795e). In a “counterstatement”, he polemically asserted himself against the theologian Samuel Simon Witte, who understood pyramids to have formed naturally (Humboldt 1791g). The 21-year-old confidently concluded his criticism in a sarcastic tone that became characteristic, explaining that trusting the “testimonies of the classics” (“Zeugnisse der Classiker”) as well as the evidence of “more recent travel writers” (“neuerer Reisebeschreiber”), he would calmly wait for his opponent to “dispel his doubts”.

The Public Scientist

With the American research expedition (1799–1804), the range of Humboldt’s articles expanded not only geographically, linguistically and thematically but also generically. Before he left and during the journey, he sent numerous letters to friends, colleagues and editors—from Madrid, La Coruña, Tenerife, La Guaira, Caracas, Nueva Barcelona, Cartagena, Contreras, Lima und México—which were subsequently published in newspapers and journals (Bärtschi and Clark 2019).

The letters and reports from the field served as a flexible way of describing the progress of his expedition and sharing his observations, as well as increasing his public profile and satisfying popular interest in his work. Thus, his first letters from his American expedition (Humboldt 1799a, b, c, d) not only outlined its scientific programme, which was to explore nature as a dynamic system of interactions, but also aroused interest in the progress of this exotic adventure (Strobl 2018a). In order to disseminate his work, he acted to a certain extent as his own science journalist and PR agent.

How cleverly Humboldt communicated as a travelling scientist can be seen in his first comprehensive report on the American expedition, which he wrote in 1804 at his final stopover in the United States of America. Unusually, Humboldt disseminated this report under a different name (“von J.-C. Delamétherie”), and it was written in the third person (“Mr von Humboldt travelled…”) (Clark 2019). The result was a seemingly independent but authorised and monitored account that seemed to have been based on personal experiences but was presented objectively —“Mr von Humboldt […] departed Europe in 1799, accompanied by his friend

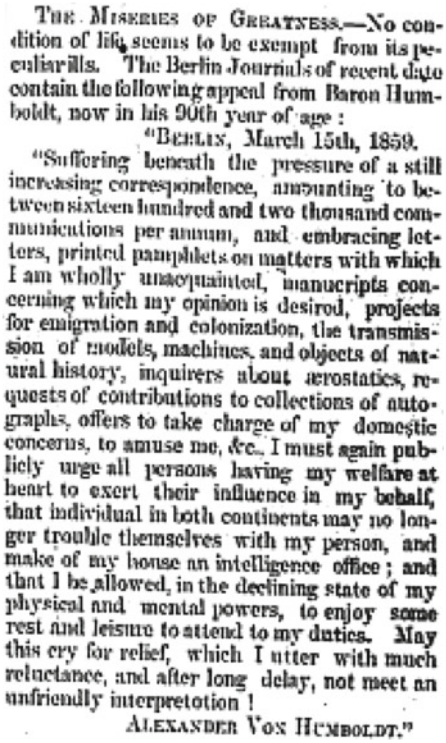
Bonpland […]". ("M. Humboldt […] partit de l'Europe en juin 1799, accompagné de son ami Bonpland […]".) (Humboldt 1804) Humboldt communicated strategically and tactically, with great public awareness.

During his American expedition, he reported on a variety of topics—ethnography, archaeology, colonialism, zoology, botany and climate. In so doing, he pursued his research objectives by combining a number of different disciplines. For example in an article about electric eels, Humboldt went beyond zoology in the narrowest sense, reporting not only on their geographical habitat and the method of capture, but also on the indigenous people with whom he interacted in the field, their cultural practices and their linguistic terms (Humboldt 1807a). Humboldt's ability to bring together sciences "which were not previously thought to be closely related" ("welchen man ehedem keine engere Verwandtschaft zutraute") and thereby to use these "combinations" to arrive at "unexpected results" ("unerwarteten Ergebnissen") was recognised by his contemporaries as an original, post-disciplinary way of working, as pointed out in the entry about Humboldt in the Brockhaus Conversations-Lexikon of 1853 (Brockhaus 1853).

By looking at Humboldt's corpus and comparing his earliest article with his last, we can measure the extent to which his fame increased. His first, "Sur le Bohon-Upas", was published anonymously in 1789 "by a young gentleman of this town" ("par un jeune Gentilhomme de cette ville") (Humboldt 1789), while his last, "Ruf um Hülfe" ("Cry for Help"), was reprinted at least 130 times around the world in 1859. The Vossische Zeitung explained in its opening credits: "A. von Humboldt honours us with the request to publish the following letter" ("A. v. Humboldt beehrt uns mit dem Gesuch, nachstehendes Schreiben zu veröffentlichen") (Humboldt 1859). Here, just a few weeks before his death, Humboldt attempted to protect himself from the burdens of celebrity life such as autograph requests, appeals for his expert opinion and requests for advice on colonial projects, as well as from "offers to take care of me at home, to distract and amuse me" ("Anerbietungen, mich häuslich zu pflegen, zu zerstreuen und zu erheitern") (Lubrich 2018b) (Fig. 2).

As Humboldt's fame and reputation grew, he accumulated symbolic capital[3] which he was able to invest, even for projects that lay outside the sciences. By using it for political purposes, Humboldt went from being a public researcher to a public intellectual.

[3] One indicator of his growing reputation is the number of acceptance speeches and letters of thanks in his corpus. For example: "Alex. von Humboldt's Dankesworte", in: *Magazin für die Literatur des Auslandes* 103 (27 August 1844), p. 412; [Acceptance of the honorary citizenship of Berlin], in: *Berlinische Nachrichten von Staats- und gelehrten Sachen* 21 (25 January 1856), [no pagination]; [The 33rd Assembly of German Naturalists and Medical Doctors in Bonn], in: *Kölnische Zeitung* 261 (20 September 1857), Supplement, [no pagination]; "Antwort Humboldt's", in: *Tagblatt der 34. Versammlung deutscher Naturforscher und Ärzte in Carlsruhe im Jahre 1858* 8 (23 September 1858), p. [69].


THE MISERIES OF GREATNESS.—No condition of life seems to be exempt from its peculiar ills. The Berlin Journals of recent date contain the following appeal from Baron Humboldt, now in his 90th year of age:

"BERLIN, March 15th, 1859.

"Suffering beneath the pressure of a still increasing correspondence, amounting to between sixteen hundred and two thousand communications per annum, and embracing letters, printed pamphlets on matters with which I am wholly unacquainted, manucripts concerning which my opinion is desired, projects for emigration and colonization, the transmission of models, machines, and objects of natural history, inquirers about aerostatics, requests of contributions to collections of autographs, offers to take charge of my domestic concerns, to amuse me, &c., I must again publicly urge all persons having my welfare at heart to exert their influence in my behalf, that individual in both continents may no longer trouble themselves with my person, and make of my house an intelligence office; and that I be allowed, in the declining state of my physical and mental powers, to enjoy some rest and leisure to attend to my duties. May this cry for relief, which I utter with much reluctance, and after long delay, not meet an unfriendly interpretotion!

ALEXANDER VON HUMBOLDT."

Fig. 3 Humboldt's last publication: "The Miseries of Greatness", in: The Semi-Weekly Mississippian 4: 102 (6 May 1859)

The Public Intellectual

Hans Magnus Enzensberger has pointed out that Humboldt's fame likely also put him beyond the reach of autocrats, particularly Napoleon during the time he spent in Paris. In other words, he may also have mobilised the media, and with it public opinion, for his own protection (Enzensberger 2012).

As his reputation grew, he was able to make increasingly direct political comments. A chronological analysis of his corpus shows that his explicitly political articles increased significantly in number across a broad range of media in the 1830s, 40s and 50s (Bärtschi and Kilchör 2020). Humboldt's work appeared in key daily and weekly newspapers such as the then liberal *Neue Zürcher Zeitung* (from 1825), the *Wiener Zeitung* (from 1836), the *New York Times* (from 1853) and *The Economist* (on the 4th September 1852, in the form of a long excerpt).

Humboldt used the media for political purposes (Strobl 2018b), and in so doing, he pursued a consistent agenda (Lubrich 2019b). Looking at the corpus as a whole, Humboldt can be seen to have had ten general areas of concern. He was concerned with safe working conditions, decolonisation, transatlantic co-operation, free world trade, electoral campaigns, the abolition of slavery, the defence of indigenous peoples, the emancipation of the Jews, the democratisation of the sciences and the promotion of young intellectuals. Alexander von Humboldt was an *écrivain engagé*—a writer with a cause.

During his time in the Prussian mining industry, Humboldt had already advocated for the safety and education of miners, and when in America, he criticised the exploitation of the indigenous peoples and the practice of slavery. He became known for his support of the liberal candidate John C. Fremont during the 1856 presidential campaign in the United States of America (Strobl 2018c). He optimistically pondered the relationship between freed colonies and former imperial powers and the possibility of free world trade: "Über die künftigen Verhältnisse von Europa und Amerika" ("On the future relationship between Europe and America") (Humboldt 1826).

On his return to Berlin, Humboldt championed the emancipation and defence of the Jews. In an open letter to the Prussian government, he protested against renewed restrictions on the rights of the Jewish population, explaining: "One must, above all, have the courage to speak one's opinion!" ("Man muß vor Allen den Muth einer Meinung haben!") (Humboldt 1842). In a foreword written for Israel Joseph Benjamin, who had explored the Diaspora in Africa and Asia, Humboldt declared his solidarity with the "scattered and oppressed people"—even in Hebrew (Benjamin 1859).

As far as science itself was concerned, Humboldt was not only interested in the free, public sharing of knowledge (Humboldt 1828) but also in supporting young researchers and artists by writing recommendations (Humboldt 1852) and forewords.[4] These became more and more common in his corpus as his fame increased. He also co-authored publications with many young colleagues, including at least one woman (Humboldt and Möllhausen 1857).

Humboldt protested publicly when the chapter on slavery was edited out of the English translation of his *Essai politique sur l'île de Cuba* (1826) (Humboldt 1856a, numerous international reprints). Indeed, this protest was seen not only in the United States of America but also in India—itself a colony where readers could well identify with the basic principles of Humboldt's critique (Humboldt 1856b).

In one particular case, however, Humboldt was forced to bow to censorship, and even to practise self-censorship. His expedition to Russia and Siberia (1829) was

[4] For example: Robert Hermann Schomburgk's Reisen in Guiana und am Orinoko während der Jahre 1835–1839. Nach seinen Berichten und Mittheilungen an die geographische Gesellschaft in London, edited by Otto Alfred Schomburgk, Leipzig: Georg Wigand 1841, pp. XV–XXIV; [Wilhelm Kiesewetter], Mittheilungen aus dem Tagebuche zu Kiesewetter's ethnographischen Reisebildern. Gesammelt auf 16jähriger Wanderung […]. Bevorwortet von Alexander von Humboldt und Carl Ritter, Berlin: Adolph Stubenrauch & Comp. 1855, p. [V]; Balduin Möllhausen, Tagebuch einer Reise vom Mississippi nach den Küsten der Südsee, Leipzig: Hermann Mendelssohn 1858, pp. [I]–VIII; Zur Erinnerung an die Reise des Prinzen Waldemar von Preußen nach Indien in den Jahren 1844–1846, 2 volumes, Berlin: Deckersche Geheime Ober-Hofbuchdruckerei 1853, volume 1, pp. I–V.

undertaken on the premise that he would not publish anything regarding the social conditions within the authoritarian police state (Lubrich 2019c, d). When following publication of the German edition of his *Asie centrale* (1843), *Central-Asien* (1844), the *Journal des Débats* discussed "the condition of the Russian peasants", referring to a comment allegedly made by Humboldt, he issued a statement in the *Berlinische Nachrichten von Staats- und gelehrten Sachen* on 16th December 1844 that he had "nowhere, neither in his own works, nor in journals, mentioned the conditions of Russian peasants" ("nirgendwo, weder in seinen eigenen Werken, noch in Journalen, der russischen Bauern-Verhältnisse erwähnt") (Humboldt 1844). Limits had been set, even for Humboldt.

Poetics and the Public

Humboldt published only one fictional text—a "tale" about the "Life Force", which was included in Friedrich Schiller's *Die Horen* journal in 1795 (Humboldt 1795b). The work was given added significance by a completely different article he published in the same year—the scientific essay "Ueber die gereitzte Muskelfaser" ("On irritated muscle fibres"), which appeared in the *Neues Journal der Physik* and presented the findings of bioelectric experiments conducted on both animals and himself (Humboldt 1795c, d). The research question and the subject matter were the same, but the procedures and the forms were very different. The natural scientist became a literary author, using all possible means to follow his lines of enquiry.

Many other genres can be found in Humboldt's corpus between the two poles of poetic allegory and scientific papers, as illustrated by the broad range of terms used in the titles of his works: "abstract", "addendum", "additions", "advertisement", "analysis", "announcement", "chronology", "collation", "collection", "comparison", "contributions", "correction", "correspondence", "counterstatement", "description", "discovery", "draft", "essay", "expertise", "explanation", "explanatory notes", "extract", "fragments", "history", "ideas", "inaugural address", "introduction", "investigations", "invitation", "lecture", "letter", "map", "measurements", "message", "narrative", "notes", "notification", "observations", "opening speech", "overview", "painting", "preface", "presentation", "remarks", "reply", "report", "request", "response", "results", "sketch", "speech", "treatise", "trial", "trip", "views", "words of thanks", "work", "written reply" and "writing".

Humboldt's repertoire was vast. From a poetological point of view, the various forms or genres each served to frame their subject differently. They emphasised different points of view and different ways of understanding the subject matter. At the same time, using a range of formats meant that Humboldt was able to appeal to different target groups. He published his observations for diverse audiences—from scientific experts to the wider public—and in publications ranging from the *Journal der Physik* (Physics Journal) to the *Deutsches Magazin für Garten- und Blumenkunde* (German Garden and Floristry Magazine).

A trickle-down effect can be observed. Within the framework of a multi-tiered publication strategy that included preprints, excerpts and edits, research results could appear in the proceedings of academies, in distinguished specialist journals and in high-profile newspapers (such as the *Morgenblatt für gebildete Stände*, "Morning paper for the educated classes"), as well as in mainstream magazines such as the *Taschenkalender für Natur- und Gartenfreunde* ("Pocket calendar for nature and garden lovers"), and eventually be included in school textbooks (Bärtschi 2017, 2018).

Visualisation

In both his books and his essays, Humboldt made use not only of various literary genres and linguistic styles, but also of illustrations. His works contain a total of more than 1500 images (Lubrich 2014), many of which are based on his own drawings (Erdmann and Lubrich 2019). The articles that appeared in newspapers or magazines were, due to the more basic design of these periodicals, more sparsely illustrated than the books, which feature elaborate engravings that Humboldt commissioned at his own expense.

The approximately 30 illustrations in Humboldt's articles relate to anatomy, animals, plants, landscapes, travel scenes and geography. They include maps, mountain cross-sections, diagrams and technical designs, a representation of Humboldt's "rescue apparatus" for miners, a symbolic sign system for pasigraphy, the dragon tree of Orotava, the Caribbean manatee, a scene from an encampment in the South American rainforest, a map of the great river systems and the "Karte von Amerika aus dem Jahre 1500 entworfen von Juan de la Cosa Begleiter des Columbus auf dessen zweiter Reise aufgefunden von Alexander von Humboldt" ("Map of America from 1500 drawn by Juan de la Cosa, companion of Columbus on his second voyage, found by Alexander von Humboldt").

Humboldt's illustrations had a variety of functions. They served to document unexplored species and to present scientific findings to the public. Humboldt was at his most innovative as a graphic artist where he was most innovative as a scientist, namely when he not only depicted individual species as accurately as possible in order to contribute to the traditional study of natural history, but went beyond mere taxonomy and visualise invisible phenomena and complex relationships on the basis of large quantities of data. The best known of his infographics, the "Naturgemälde" ("Nature Painting", *tableau physique*) in *Geographie der Pflanzen*, illustrates the dependence of the Andean ecosystem on multiple influencing factors (Humboldt 1807b); the best known of his data visualisations, the "Carte des lignes Isothermes", shows the global distribution of temperatures (Humboldt 1817, 1819).

In *Kosmos*, Humboldt dialectically related the sciences to the arts. One chapter conceptualised the arts as "a means of stimulating the study of nature" ("Anregungsmittel zum Naturstudium") (Humboldt 1847). Even the most naive paintings or descriptions of landscapes, he argued, contain elements of our understanding of nature and inspire further research. Humboldt's research, as well as his rhetoric, was essentially visual: graphical representation was for him an important tool in both the practice and the communication of science.

The Empty Palace

Humboldt pursued two objectives in his scientific communications—firstly, to present the results of his research for discussion with experts on an international and interdisciplinary level and secondly, to share these results with as wide a public as possible in order to democratise his findings and promote their practical application. In the tradition of the enlightenment, the overall objective in both cases was to contribute to social progress.

Although Alexander von Humboldt was undoubtedly a great communicator, he communicated with such success that his name became detached from his research achievements and an entity in its own right. He became a legend and a monument, a *lieu de mémoire* and an object of celebration. On the 14th September 2019, the 250th anniversary of his birth, a ceremony in his honour was held in Berlin at a newly reconstructed city palace that was named after him (Häntzschel 2019) even though it was still empty, still a construction site. Now that his writings have been gathered together, the writer and scientist behind the myth can be rediscovered. We should celebrate Humboldt less and read him more.

Postscript 2020/2021: Pandemics and Politics

An example of how urgent Humboldt's messages were in his time and how topical they can be today may be found in the field of epidemiology. In a number of articles, he dealt with yellow fever (Humboldt 1813), cowpox (Humboldt 1810, 1812) and remedies for tropical diseases (Humboldt 1797). Scientific communication then—as now—helped in the fight against disease and epidemics.

In one article for example Humboldt discussed the ignorant reaction to epidemics by authoritarian regimes:

> when the Chinese authorities were asked whether they should take any precautions against cholera, they replied that fear alone was the reason why people were falling victim to it and that no preventive measures should therefore be adopted. (Humboldt 1831)

When a "cattle plague" broke out in Germany in 1796 during the Revolutionary Wars, Humboldt made current medical literature ("writings on the epidemic") publicly available in the *Neues Magazin für Aerzte* (Humboldt 1796b, 1797). He discussed drastic measures such as "killing healthy livestock" and "a general lock-down" and criticised "overly-hasty regulations" which "are easier to propose than to implement on a large scale". He also recommended empirical observation and experimental trials, considered various ways of treating the condition with medicines and made proposals regarding hygiene such as "cleaning the empty stables" with chemical agents, which had been used "on English slave ships during epidemics".

Humboldt recognised the fundamental connection between the disease and social conditions ("This is why the cattle disease spreads so inexorably in war, where oxen and cows are worked so hard!"), and he was aware of the economic and social consequences for the "prosperity of the people". He discussed early means of vaccination (Humboldt 1812). As rhetorical as he was scientifically optimistic, Humboldt asked in February 1796: "What would be more benevolent for humanity than to discover a remedy for that evil?"

References

Bärtschi S. (2017), *Layered Reading: Wie kann man das Gesamtwerk eines Autors lesen? Quantitative und qualitative Methoden am Beispiel der unselbständigen Schriften Alexander von Humboldts*, Doctoral Dissertation, University of Bern.

Bärtschi S. (2018), "Wie lassen sich 1000 Texte messen?", in: *UniPress* 174 (2018), p. 25.

Bärtschi S. and Clark R., eds. (2019), Alexander von Humboldt, *Sämtliche Schriften*, volume II (1800–1809).

Bärtschi S. and Kilchör F (2020), "Wie veranschaulicht man ein Corpus? Alexander von Humboldts Schriften als Paradigma bildlicher Evidenz", in: *Rhetorik und Ästhetik der Evidenz*, edited by Olaf Kramer, Carmen Lipphardt and Michael Pelzer, Berlin/Boston: de Gruyter, pp. 171–198.

Bärtschi A. and Wübben Y., eds. (2019), Alexander von Humboldt, *Sämtliche Schriften*, volume I (1789–1799).

Beck H., ed. (1997), Alexander von Humboldt, *Die Forschungsreise in den Tropen Amerikas*, 3 volumes, Darmstadt: Wissenschaftliche Buchgesellschaft.

Benjamin J. J. (1859), "Extract from a letter of His Excellency Baron Alexander v. Humboldt, Member of the King's Privy Council, and Chamberlain to His Majesty, at Berlin", in: J. J. Benjamin, *Eight Years in Asia and Africa. From 1846 to 1855*, Hannover, p. VI; Hebrew: *Sefer Masa'ei Yisra'el, Bo Yesupar Me'aheinu Benei Yisra'el Ha-Nefutsim Be'artsot Asiyah Ve-Afrikah*, Lyck/Ełk 1859.

Bisky J. (2019), "Kanu, Karte, Feder. Eine Sensation: Die Berner Ausgabe vereint zum ersten Mal alle Aufsätze, Artikel und Abhandlungen Alexander von Humboldts. Die meisten sind unbekannt oder vergessen", in: *Süddeutsche Zeitung*, 17/18 August 2019.

Brockhaus (1853), "Humboldt (Friedr. Heinr. Alexander, Freiherr von)", in: *Allgemeine deutsche Real-Encyklopädie für die gebildeten Stände. Conversations-Lexikon*, 10th edition, 15 volumes, Leipzig: Brockhaus, volume VIII, pp. 126–133.

Brönnimann S. (2019), "Man sollte Humboldt weniger feiern und dafür mehr lesen" – an interview with Oliver Lubrich, in: *GeoAgenda* 2:7–9.

Clark R. (2019), "Alexander von Humboldts erster Reisebericht. Ein Spiel mit der Anonymität", in: *Zeitschrift für Germanistik* 29:1, pp. 118–129.

Darwin C. (1887), *The Life and Letters of Charles Darwin, Including an Autobiographical Chapter*, 3 volumes, London: John Murray 1887, volume 1, p. 190.

Enzensberger H. M. (2012), "Wer wen? Alexander von Humboldt im Stammeskrieg zwischen Intelligenz und Macht", in: *Enzensbergers Panoptikum. Zwanzig Zehn-Minuten-Essays*, Berlin: Suhrkamp, pp. 104–109.

Erdmann D. and Lubrich O., eds. (2019), Alexander von Humboldt, *Das zeichnerische Werk*, Darmstadt: WBG.

Ette O., ed. (1991), Alexander von Humboldt, *Reise in die Äquinoktial-Gegenden des Neuen Kontinents*, 2 volumes, Frankfurt: Insel 1991.

Fiedler H. and Leitner U. (2000), *Alexander von Humboldts Schriften. Bibliographie der selbständig erschienenen Werke*, Berlin: Akademie 2000, pp. 35–63, pp. 379–431.

Goethe J. W. v. (1809), *Die Wahlverwandtschaften. Ein Roman*, 2 volumes, Tübingen: J. G. Cotta, volume 2, p. 150.

Häntzschel J. (2019), "Humboldt-Forum muss wohl leer eröffnen", in: *Süddeutsche Zeitung*, 5 June 2019.

Humboldt A. v. (1789), "Lettre à L'Auteur de cette Feuille; sur le Bohon-Upas, par un jeune Gentilhomme de cette ville", in: *Gazette littéraire de Berlin* 1270 (5 January 1789), pp. 4–8; 1271 (12 January 1789), pp. 11–13.

Humboldt A. v. (1790a), "Abhandlung vom Wasser im Basalt", in: *Chemische Annalen für die Freunde der Naturlehre, Arzneygelahrtheit, Haushaltungskunst und Manufacturen* 7:1:5, pp. 414–418.

Humboldt A. v. (1790b), "Observatio critica de Elymi hystricis charactere", in: *Magazin für die Botanik* 3:7 (1790), pp. 3–6; 3:9, p. 32.

Humboldt A. v. (1790c), "Verhandeling over de inlandsche Plantgevvassen […]; door Steven Jan van Geuns, Matth. Z. Haarlem 1789. 8.", in: *Magazin für die Botanik* 4:10, pp. 149–151.

Humboldt A. v. (1791a), "Beobachtungen auf Reisen nach dem Riesengebirge, von Johann Jirasek, Thaddaeus Haenke, Abbé Gruber und Franz Gerstner, mit Kupfern. Dresden, bey Walther. 4. (270 Seit.)", in: *Annalen der Botanick* 1:1, pp. 78–83.

Humboldt A. v. (1791b), "Chr. Phil. Ripke – Dissert. de meritis Hamburgensium in historiam naturalem. Hamburgi 1791. 4. (Seiten 31.)", in: *Annalen der Botanick* 1:1, pp. 87–91.

Humboldt A. v. (1791c), [Notice on Carl von Linné's *Praelectiones in Ordines naturales plantarum*], in: *Annalen der Botanick* 1:1, pp. 172–174.

Humboldt A. v. (1791d), "Gramina pascua or a Collection of Specimens of the commun pasture grasses by G. Swayne, Vicar of Pucklechurch, Gloucestershire. 6 plates (nemlich aufgeklebte Gräser) Richardson. fol.", in: *Annalen der Botanick* 1:1, p. 91.

Humboldt A. v. (1791e), [Rectification], in: *Intelligenzblatt der Allgemeinen Literatur-Zeitung* 155 (20 November 1790), column 1280.

Humboldt A. v. (1791f), "Ueber den Syenit oder Pyrocilus der Alten; eine mineralogische Berichtigung", in: *Neue Entdeckungen und Beobachtungen aus der Physik, Naturgeschichte und Oekonomie* 1, pp. 134–138.

Humboldt A. v. (1791g), "Gegenerklärung", in: *Intelligenzblatt der Allgemeinen Literatur-Zeitung* 20 (12 February 1791), column 160.

Humboldt A. v. (1794), [Rectification], in: *Intelligenzblatt der Allgemeinen Literatur-Zeitung* 20 (26 February 1794), column 160.

Humboldt A. v. (1795a), "Aus einem Briefe des Herrn Oberbergraths von Humboldt an Herrn Hofrath Blumenbach", in: *Neues Journal der Physik* 2:4, pp. 471–473.

Humboldt A. v. (1795b), "Die Lebenskraft oder der Rhodische Genius. Eine Erzählung", in: *Die Horen* 1:5 (1795), pp. 90–96.

Humboldt A. v. (1795c), "Ueber die gereitzte Muskelfaser. Aus einem Briefe an Herrn Hofrath Blumenbach vom Herrn Oberbergrath F. A. von Humboldt", in: *Neues Journal der Physik* 2:2 (1795), pp. 115–129.

Humboldt A. v. (1795d), "Aus einem Briefe des Herrn Oberbergraths von Humboldt an Herrn Hofrath Blumenbach", in: *Neues Journal der Physik* 2:4, pp. 471–473.

Humboldt A. v. (1795e), [Rectification], in: *Intelligenzblatt der Allgemeinen Literatur-Zeitung* 80 (22 July 1795), column 640.

Humboldt A. v. (1796a), "Ueber die einfache Vorrichtung, durch welche sich Menschen stundenlang in irrespirablen Gasarten, ohne Nachtheil der Gesundheit, und mit brennenden Lichtern aufhalten können; oder vorläufige Anzeige einer Rettungsflasche und eines Lichterhalters. Aus einem Briefe des Hrn. Oberbergraths von Humboldt an den Herrn

Berghauptmann von Trebra", in: *Chemische Annalen für die Freunde der Naturlehre, Arzneygelahrtheit, Haushaltungskunst und Manufakturen* 13:2:8, pp. 99–110; 13:2:9 (1796), pp. 195–210.

Humboldt A. v. (1796b), "Ueber die Rindviehseuche als Nervenfieber behandelt", in: *Neues Magazin für Aerzte* 18:5 (1796), pp. 421–425.

Humboldt A. v. (1797), "Auszug eines Briefes des Herrn von Humboldt", in: *Neues Magazin für Aerzte* 19:1, p. 17.

Humboldt A. v. (1799a), "Alexander von Humboldt an den Herausgeber aus Corunna am 5. Jun. 1799", in: *Jahrbücher der Berg- und Hüttenkunde* 4:1 (1799), pp. 399–401.

Humboldt A. v. (1799b), "Aus einem Schreiben des Ober-Bergraths A. von Humboldt", in: *Allgemeine Geographische Ephemeriden* 4 (August 1799), pp. 146–161.

Humboldt A. v. (1799c), "Lettre d'Alexandre Humboldt à J.-C. Delamétherie", in: *Journal de physique, de chimie, d'histoire naturelle et des arts* 49, pp. 433–436.

Humboldt A. v. (1799d), [Two Letters to Friedrich Gödeking], in: *Intelligenzblatt der Allgemeinen Literatur-Zeitung* 163 (21 December 1799), columns 1323–1324.

Humboldt A. v. (1804), "Notice d'un voyage aux tropiques, exécuté par MM. Humboldt et Bonpland en 1799, 1800, 1801, 1802, 1803 et 1804. Par J.-C. Delamétherie", in: *Journal de physique, de chimie, d'histoire naturelle et des arts* 59:2 (Thermidor an 12 [July/August 1804]), pp. 122–139, here: p. 123.

Humboldt A. v. (1807a), "Jagd und Kampf der electrischen Aale mit Pferden", in: *Annalen der Physik* 25:1, pp. 34–43.

Humboldt A. v. (1807b), *Essai sur la géographie des plantes, accompagné d'un tableau physique des régions équinoxiales*, Paris: Fr. Schoell / Tübingen: J. G. Cotta.

Humboldt A. v. (1810), "Cow Pock in Mexico", in: *The Hull Advertiser and Exchange Gazette* 16:865 (15 December 1810), p. [4].

Humboldt A. v. (1812), "Vaccination", in: *The Lancaster Gazette* 11:559 (29 February 1812), p. [4].

Humboldt A. v. (1813), "Bemerkungen über das gelbe Fieber, und dessen Zusammenhang mit der Temperatur", in: *Annalen der Physik* 43:1:3, pp. 257–295.

Humboldt A. v. (1817), "Carte des lignes Isothermes par M. A. de Humboldt. Gravé par Adam", in: Alexander von Humboldt, "Sur les Lignes isothermes (Extrait)", in: *Annales de chimie et de physique* 5, pp. 102–111.

Humboldt A. v. (1819), "Ueber die isothermischen Linien", in: *Neues Journal für Chemie und Physik* 25:3, pp. 254–268.

Humboldt A. v. (1826), "Ueber die künftigen Verhältnisse von Europa und Amerika", in: *Morgenblatt für gebildete Stände* 20:33 (8 February 1826), pp. 129–130; 20:34 (9 February 1826), pp. 134–135.

Humboldt A. v. (1828), "A Monsieur le Rédacteur du Moniteur universel", in: *Berlinische Nachrichten von Staats- und gelehrten Sachen* 48 (26 February 1828), [no pagination].

Humboldt A. v. (1831), "Académie des Sciences (Paris)", in: *The London and Paris Observer; or, Chronicle of Literature, Science, and the Fine Arts* 338 (6. November 1831), pp. 719–720, here: p. 720.

Humboldt A. v. (1842), [On the Emancipation of the Jews], in: *Neue Speyerer Zeitung* 84 (26 April 1842), p. 370.

Humboldt A. v. (1844), [Authorised Correction to an article in the *Journal des Débats* from 6 December 1844], in: *Berlinische Nachrichten von Staats- und gelehrten Sachen* 295, 16 December 1844, p. 3.

Humboldt A. v. (1847), "Anregungsmittel zum Naturstudium", in: *Kosmos. Entwurf einer physischen Weltbeschreibung*, 5 volumes (1845–1862), volume 2, Stuttgart/Tübingen: Cotta, pp. 3–134.

Humboldt A. v. (1852), "Eduard Hildebrandt", in: *Berlinische Nachrichten von Staats- und gelehrten Sachen* 123 (28 May 1852), p. 4.

Humboldt A. v. (1856a), “Insel Cuba”, in: *Berlinische Nachrichten von Staats- und gelehrten Sachen* 172 (25 July 1856).

Humboldt A. v. (1856b), “Humboldt and the Americans”, in: *The Bombay Times* 20:75 (17 September 1856), p. 597.

Humboldt A. v. (1859), *Königlich privilegirte Berlinische Zeitung von Staats- und gelehrten Sachen* 67, 20 March 1859, p. 2.

Humboldt A. v. and Möllhausen C. (1852), “Expedition zur wissenschaftlichen Erforschung des Rio Colorado, in den der Rio Gila einmündet”, in: *Berlinische Nachrichten von Staats- und gelehrten Sachen* 299 (22 December 1857), [no pagination].

Jahn I. and Lange F. G. (1973), *Die Jugendbriefe Alexander von Humboldts*, Berlin (GDR): Akademie, p. 170.

Lubrich O. (2009), “Alexander von Humboldt (1769–1859). Zum 150. Todestag des Naturforschers und Reiseschriftstellers. Dossier”, in: *Zeitschrift für Germanistik* 19:2, pp. 396–402.

Lubrich O., ed. (2014), Alexander von Humboldt, *Das graphische Gesamtwerk*, Darmstadt: Lambert Schneider.

Lubrich O. (2018a), “Humboldt in Afrika. Ein Artikel aus dem Jahr 1850”, in: *Acta Germanica* 46, pp. 23–28.

Lubrich O. (2018b), “Von der ersten bis zur letzten Veröffentlichung. Alexander von Humboldts ‘Sämtliche Schriften’ in der ‘Berner Ausgabe’”, in: *Zeitschrift für Germanistik* 28:1, pp. 119–130.

Lubrich O. (2019a), “Die Entdeckung des Entdeckers. Alexander von Humboldt (1769–1859) zum 250. Geburtstag. Bestandsaufnahme und Aussichten”, in: *Zeitschrift für Germanistik* 29/2, pp. 375–385.

Lubrich O. (2019b), “Kritik und Kompromiß: Humboldt als Politiker”, ‘Kosmos Talk’, Humboldt-Universität zu Berlin, 20 June 2019.

Lubrich O., ed. (2019c), Alexander von Humboldt, *Die Russland-Expedition. Von der Newa bis zum Altai*, with an afterword by Karl Schlögel, Munich: C. H. Beck.

Lubrich O. (2019d), “Forscher in Fürstennähe: Humboldt in Sibirien”, in: Alexander von Humboldt, *Die Russland-Expedition. Von der Newa bis zum Altai*, Munich: C. H. Beck, pp. 185–203.

Lubrich O. (2020), “Wie verändert die Edition seiner Schriften unser Bild von Alexander von Humboldt?”, in: *Abhandlungen der Humboldt-Gesellschaft* 43, pp. 137–158.

Lubrich O. and Ette O., eds. (2004), Alexander von Humboldt, *Ansichten der Kordilleren und Monumente der eingeborenen Völker Amerikas*, translated by Claudia Kalscheuer, Frankfurt: Die Andere Bibliothek.

Lubrich O. and Nehrlich T. (2015), “Alexander von Humboldt als internationaler Publizist. Zur Edition seiner sämtlichen Schriften”, in: *Iberoamerikanisches Jahrbuch für Germanistik* 9, pp. 71–88.

Lubrich O. and Nehrlich T., eds. (2019a), Alexander von Humboldt, *Sämtliche Schriften*, 10 volumes, Munich: dtv.

Lubrich O. and Nehrlich T., eds. (2019b), Alexander von Humboldt, *Der Andere Kosmos. 70 Texte, 70 Orte, 70 Jahre. 1789–1859*, Munich: dtv.

Lubrich O. and Nehrlich T. (2019c), “Der übersetzte Übersetzer”, in: Alexander von Humboldt, *Sämtliche Schriften*, Munich: dtv, volume IX, pp. 11–22.

Ortiz, F. (1930), Alexander von Humboldt, *Ensayo político sobre la Isla de Cuba, con un mapa de Cuba. Introducción por Fernando Ortiz y correcciones, notas y apéndices por Francisco Arango y Parreño, J. S. Thrasher y otros*, La Habana: Colección de libros cubanos.

Strobl M. (2018a), “Alexander von Humboldts Pico del Teide-Aufstieg als mediale Selbstinszenierung um 1800”, in: *Orbis Litterarum* 73:1, pp. 52–79.

Strobl M. (2018b), “Humboldts Denken war politischer Zündstoff”, in: *UniPress* 174 (May 2018), pp. 16–18.

Strobl M. (2018c), “Alexander von Humboldt als *Public Intellectual*: Seine Beiträge in der *Neuen Zürcher Zeitung* (1825–1859)”, in: *Zeitschrift für Germanistik* 38:2, pp. 152–159.
Weigl E. (1992), “Alexander von Humboldt und die ‘Sprache der Zahlen’. Anmerkungen zu neuen Werkausgaben”, in: *Merkur* 521, pp. 711–716.

Oliver Lubrich is a German literary scholar who has been Professor of Comparative Literature at the University of Bern since 2011. Lubrich has edited numerous works by Alexander von Humboldt. He and his collaborators published Humboldt’s *Complete Writings* in ten volumes to mark the 250th anniversary of Humboldt’s birth in the fall of 2019.

The Interdependence of Nature and Culture

Fig. 1 Ethnographische Karte von Sud-Amerika. Hauptsachlich nach Hervas, A. von Humboldt, Vater, Martius, d'Orbigny and von HBgs. Potsdam, Marz 1845. Gotha bei Justus Perthes. 1847. Gez. in der geogr. Kunstsch. z. Potsd. Gest. von Wilh. Alt in Ohrdruff. 8te Abtheilung: Ethnographie No 18. (Courtesy of David Rumsey Collection)

Indigenous Knowledge—Humboldt's Idea of Intercultural Understanding

Simon Schneider

Abstract Today's science is regaining its appreciation for indigenous knowledge, whereas several decades ago, ethno-biology started being receptive to how indigenous communities apply plants and minerals for medicinal purposes, and other areas of science are still too far within a "western academic" science mindset, one that remains closed to non-academic knowledge to a considerable extent. In his more mature years, Alexander von Humboldt—together with him a rather small number of other Explorer scientists of his time—knew that listening to indigenous people could add significantly to the understanding of dynamic processes, interactions and interdependencies of the earth system. They carefully observed as to how and why native people used certain plants and listened to knowledge that was deeply embedded in traditional storytelling. Sometimes, even their lives depended on indigenous knowledge. This openness towards indigenous knowledge did not come naturally to Alexander von Humboldt: within his reports, diary entries and documentations, we can see his slow but fundamental shift from viewing indigenous people either as "inferior creatures" or "romanticized noble savages" to accepting and even respecting their culture and knowledge (Ette in Alexander von Humboldt—Das Buch der Begegnungen. Manesse, 341ff, 2018 [Due to the complex history of Humboldt's original papers, manuscripts and comments, I refer to the original text via Ette's 2018 collection of Humboldt's writing. Page numbers refer to Ette's book, where detailed information about the origins in Humboldt's writings can also be found.]). This more benign and accepting approach towards indigenous knowledge was lost over the following decades and centuries; for generations thereafter, indigenous knowledge was seen as unimportant, unreliable and unscientific. Later, the term "western science" was coined to support the idea of a superior set of knowledge, one only derived from scientific concepts and methods and predominantly shaped by European scientists (some even narrowed this down further to only include male European scientists). Knowledge that was handed

S. Schneider (✉)
Department of Earth and Environmental Sciences, Ludwig-Maximilians-University Munich, Munich, Germany
e-mail: sschneider@geophysik.uni-muenchen.de

G. C. Falk et al. (eds.), *Alexander von Humboldt*,
https://doi.org/10.1007/978-3-030-94008-9_9

down generation to generation was seen as lacking facts and hard evidence, despite having been applied for hundreds if not thousands of years.

Keywords Intercultural communication · Indigenous knowledge · Socio-cultural context · Science communication · Academic knowledge

In this chapter, I argue that Humboldt was one of the last explorer scientists who sets indigenous knowledge on an equal footing to European academic knowledge—at least at the end of his famous South and Latin America Expedition. He went into the "contact zone" (Pratt 2008), a zone where cultures meet each other, and listened to the native people and their stories, whether of extreme natural events, changes to their environment or decreases in natural resources (especially water). "The wild man is the most accurate observer of nature[1]", as Humboldt himself stated (Humboldt 1858, see Ette 2018: 270). His description of, for example the environmental degradation of the Lake Valencia area (Cushman 2011) was not only based on his own observations but also on the stories told by natives. More generally, Gomsu (2004) has shown that Humboldt even thought that indigenous knowledge could be a driving force in academic science. Indeed, supported by the direct contact to native communities, Humboldt started to think about "… another sphere of perception, namely to considerations of a natural philosophical nature" (Gomsu 2004).

Stories helped Humboldt to broadcast his findings and message. While he learned to observe, interpret and survive by listening to stories and advice rooted in indigenous knowledge, he was also one of the great storytellers of his time. His enthusiasm for his material is shown through during presentations, despite sometimes being confusing when he suddenly switched from German to either French, Spanish or English (among other languages). His authenticity and appearance helped him be considered a highly respected storyteller. It also shows that Humboldt instinctively knew about the power of storytelling: to light a spark of curiosity in his audience and to bring the mighty and powerful of his time onboard and listen to his ideas and advice, his stories had to take them across the Atlantic into the lush greenery of the Amazon, Orinoco forests and also to the summit of Chimborazo.

This chapter looks to offer a new and deeper appreciation of indigenous knowledge in modern science by focussing on Alexander von Humboldt. The established divide between "western knowledge" and "indigenous knowledge" must be bridged and—hopefully—closed by integrating the two systems of knowledge within the context of modern scientific education. I argue that even using terms like "western" or "academic knowledge" shows a colonialist mindset that is still part of scientific education. Furthermore, I will show that empathy and an appreciation of the differing socio-cultural perspectives on science will help to

[1] Translations into English are by the author unless otherwise stated.

reconnect academia with the public. All conclusions within this chapter are based on observations and reasoning that are themselves derived from a descriptive review of von Humboldt's works. The aim is to start a debate regarding the responsibility that modern-day science has to implement the basic concepts of geoethics and become sensitive towards the issues and obstacles within intercultural communication and cooperation.

Humboldt's Transition

Alexander von Humboldt understood that travelling the world would broaden his horizons and enable him to observe and analyse all aspects of the earth system first-hand—but that he would also forever be tightly constrained by a Eurocentric perspective. From his writings, it seems that he was aware of this bias and tried to see through the eyes of "the other", ranging from indigenous people, missionaries and all those he met during his travels through Europe, the Americas or Russia. Numerous passages from his travel journals, diaries and publications attest to the fact that he became increasingly critical of European colonialism (Eibach 2012). Despite this, Humboldt still complied with the social structures of the country in which he was travelling. At the same time—as can be observed throughout his writings—he reflected on the impact and implication of colonialism on the socio-cultural aspects of indigenous societies.

The first publication by Alexander von Humboldt—anonymously published in a Berlin newspaper in 1789—focusses on the so-called poisonous Java tree. The tree, it was said, killed all plants and birds would die and fall from the sky when flying over (Lubrich 2019). The young Humboldt already knew that the impact of a good story could go beyond its propositional content and function as a veiled social critique. First, by describing how local people used the tree's poison to create deadly arrows and spears that could then be used against European invaders, Humboldt was aware that this story could both pique interest as well as act as a social critique. Second, by referring to the clerus of India as the creator of this mythical saga, Humboldt not only used this story to tell a good scientific story but also to criticize the social structures in India that had resulted from colonialism (Lubrich 2019). For Humboldt, then, stories were very much double-edged, not just vehicles for the transmission of data.

Later on, Humboldt distinguished between the "wild and free" Indios and those already influenced by Europeans, sometimes called the christianized (Eibach 2012). His approach towards indigenous communities nevertheless can be considered open and inclusive. Keen to communicate via dialogue, Humboldt understood that he would learn considerably more by listening and talking to the people of Amazonia and the Orinoco regions than through direct observation. Therefore, he was eager to explore the languages spoken in the Americas, realizing quite early on that the dominant European idea of degenerated American native languages was far from accurate (Humboldt 1858, see Ette 2018: 76f). Although a polyglot, he was not able to master any indigenous languages—may be because there were thousands of them—and was, therefore, reliant on translators and interpreters, sometimes even chains of them. Humboldt remarked that "… not being able to talk directly to the indigenous communities was a big obstacle …" (Humboldt 1820, see Eibach 2012) in discovering more about the worldviews of those communities. Despite this verbal barrier, Humboldt even tried extensive sessions communicating with locals just in sign languages (Humboldt 1858, see Ette 2018: 167).

This direct approach towards indigenous communities was quite unique among European nineteenth-century scientists. And, it was also highly rewarding. Humboldt was potentially unconsciously biased by his own Eurocentric education and by scientific publications about American native people, the authors of which had sometimes never been to the Americas. However, Humboldt gradually began to change his impression of indigenous communities. Furthermore, Humboldt reflected on the issue of cannibalism (e.g. Humboldt's letter to Wildenow 1801, see Eibach 2012). A topic of discussion going back to Herodotus (see Murphy and Mallory 2000), Humboldt asked whether only untamed savages conducted this unthinkable tradition or if European travellers and sailors were equally guilty of cannibalism (Humboldt 1858, see Ette 2018: 49).

Apart from this topic, Humboldt's approach of meeting, talking and listening to indigenous people opened up a new *Weltanschauung* (or "worldview"). This is best exemplified by Humboldt's description of the Curare-making procedure that he and Bonpland witnessed in the Orinoco region in May 1800. Concerning this episode, Gomsu (2004) has shown that Humboldt, by using academic wording, expressed his respect and appreciation for the scientific work of the native Curare-makers. In other words, he put the native "Giftmeister" on the same professional level as the European, academically trained scientists. Furthermore, Humboldt started to see the "earth system" through the eyes of Indios and Caribe, describing it as "[a] common, lawful and therefore eternal band, embracing the whole organic nature" (Beck 1987–1997). Moreover, he tried to understand the idea of interconnectedness by listening to stories about, for instance the environmental changes that had been brought about by European colonists and missionaries and their malpractices regarding agriculture (Weigl 2004).

Stories, Humboldt recognized early, were more than just words. When facts, knowledge and experiences were shared, they resembled something like science communication interwoven with emotional storytelling. As an outstanding communicator himself, Humboldt recognized the value of storytelling not only to share ideas and new facts but also to convince and educate. Perhaps, then, we have to award Humboldt with just another achievement: he might also have been the first communication researcher in the applied sciences.

It is easy to write about Humboldt in hagiographic fashion. To strike a balance, it must also be pointed out that Alexander von Humboldt's daily routines were characterized by the routine exploitation of natives, slaves and servants as well. Regarding his writings, Pratt has highlighted how Humboldt subsumed everyone within his expeditions into an "ambiguous 'we' by which masters include themselves as agents of their servant's work" (Pratt 2008). Thus, Humboldt implicitly accepted Spanish colonial practices and the oppression of South American native communities without scrutiny or comment. Humboldt, it seems, was caught between Herderian humanism and a sense of European supremacy (Knobloch 2004). With revolutionary ideologies and powers in South America on the rise in the 1780s and 1790s, Humboldt might well have been influenced by the political visions of liberal republics published by revolutionists all over South America. In the wake of these revolutionary currents, perhaps, Humboldt thought that a free and equal society might form.

Western Versus Indigenous Knowledge

Scientists—both in Humboldt's days as well as today—must accept and adapt to the varying communication and interpretation routines of their stakeholders and audiences (Hall 1973). This is widely accepted with respect to audiences from various socio-political and socio-economic sectors. While socio-cultural diversity within audiences is not commonly considered to have an impact on science communication, it might account for scientific findings, facts and recommendations not being accepted or sufficiently appreciated (Gerten 2010). Both communication routines, while firmly based on the processes of decoding (science being dumbed down by communicators) and encoding (where information is interpreted by the audience), are deeply rooted in the different value and belief systems that are themselves strongly linked to cultural and systemic settings and contexts. Thus, within the discussion of intercultural science communication, concepts from social sciences should also be considered. Most importantly, academic and indigenous knowledges have to be recognized and distinguished (see the overview in Tsuji and Ho 2002). The term academic knowledge describes a knowledge system that has also been called western science, Newtonian science and others (Lindberg 1992; Berkes et al. 2000; Aikenhead 2001). Some scholars are uncomfortable with the term "western science" (Medin and Bang 2014), expressing concerns that this term undermines contributions from other traditions, including indigenous, East Asian and Islamic cultures. The idea that the West is the dominant source for scientific knowledge should not be inadvertently reinforced (Raj Pandya, Director of the American Geophysical Union's Thriving Earth Exchange, personal conversation 2018).

While it is probably true that western worldviews frame much of current scientific practice (particularly in scientific publications), it should be acknowledged that there has been a considerable amount of adaptation and westernization of other knowledges (for example in the field of ethno-biology or astronomy), a phenomenon that has been termed "science colonialism" by scholars from the social sciences and by ethnologists (Whitt 2009). Humboldt provides an example of such practice when he prided himself on being the first person to bring guano (a fertilizer) to Europe. Pratt (2008) puts this in the context of the growing European interest in guano and the resulting dependence of Chile and Peru on the

European Banking system. But in proclaiming to be the "discoverer" of guano, Humboldt neglected the centuries-old tradition of indigenous people using guano within agriculture. In other words, Humboldt colonialized indigenous knowledge without, it seems, ever thinking whether such an act could be categorized as appropriation. In a bitter twist of historical fact, Europe would go on to "reintroduce" guano to South America.

I propose to use the term "academic knowledge" that covers what Levi-Strauss (1962) and Feyerabend (1987) named western science but also denotes the research and development in industry and modern research at universities all over the world. Levi-Strauss (1962) characterized the nature of western science as "supremely abstract" and indigenous knowledge as "extremely concrete". Expanding the term further, indigenous knowledge can also denote a concept that is rooted in the social experiences, observations and beliefs that are shared by communities and that "often becomes encoded in rituals and in the cultural practices of everyday life" (Berkes et al. 2000). Thus, indigenous science reflects "… the memories and knowledges that arise from indigenous peoples' living heritages as societies with stories, lessons and long histories of having to be well-organized to adapt to seasonal and inter-annual environmental changes" (Whyte 2017). More narrowly, the term indigenous knowledge is critically discussed in epistemology as well, with some scholars distinguishing between indigenous, traditional or native types of knowledge (Wyndham 2017; Berkes et al. 2007).[2]

Reading Humboldt's publications, one develops the impression that he changed from a scholar defined by the academic (western) science tradition into an advocate for an inclusive science approach that combines academic scientific methods with traditional knowledge (see also Gomsu 2004). Stepped in a European scientific tradition, he learned to think of science as empirical and factual; travelling in Amazonia and the Orinoco basins, he also added sensual and emotional experiences to measurements and numbers. Not only did he count various floral species, he also thought about their interdependencies and the environmental context in which they flourished (Humboldt 1858, see Ette 2018: 46ff). His ability to think systemically rather than within strict disciplinary boundaries is also evidence for his ability to cross the divide between academic and traditional knowledges. And, Humboldt must have been aware of the parallel existence of the two knowledge systems. La Condamine—with whose work Humboldt was quite familiar[3]—wrote in the 1740s that "the naturalists' knowledge existed in parallel with even more valuable local knowledges" (Pratt 2008: 31).

Coming to the present day, the rise of science diplomacy has made communication scientists as well as science managers aware of the potential clash

[2] While this discussion is fruitful in its aim to better understand the relationships and interdependencies between various social systems and settings, we think that in respect to this article it seems appropriate to summarize the different concepts within the concept of indigenous knowledge.

[3] Mathewson for example phrased this as "La Condamine's journals strongly influenced Humboldt's ambitions to experience the "equinoctial regions" first hand, …" (Mathewson 1986).

between academic and indigenous knowledge. Nevertheless, the communication, dissemination and education strategies of science rarely consider the challenges that lie within intercultural communication. While social scientists agree that there is also "… ample evidence that distinct cultural and religious values of individuals and whole societies influence their perception and tolerance of risk as well as their capacity to cope with environmental hazard" (Gerten 2010: 39), the earth and environmental sciences have not yet focussed on how these risks and hazards are transported into and interpreted by the public sphere with respect to various socio-cultural environments (e.g. Weiss et al. 2013; Dowsley and Wenzel 2008). Numerous scholars have focussed on indigenous communities (e.g. Hintjes 1997; Schmuck 2009; Cruikshank 2001); within this debate, it has been pointed out that "disrespect for knowledge systems other than quantitative science and technocratic solutions, or by the characterization of local people's religious viewpoints of environment degradation and natural hazards …" (Gerten 2010: 42), with results that might result in "fatalistic" outcomes (Gerten 2010: 42). These include but are not limited to: strong resistance to evacuation procedures; the denial of the environmental impact of local action; and the social and economic exclusion of indigenous people and local communities. Thus, science—and especially the earth and environmental sciences—should consider the concept of environmental justice (Schlosberg 2007). This approach calls for a detailed understanding of people's worldview and their perception of nature (Gerhardinger et al. 2009), as well as "[r] ecognizing [that] different perceptions can help to understand why individuals and different societies interact with the environment in such strikingly different ways" (Marten 2010). At best, we are currently stranded at a stage of cross-cultural communication (Schneider and Heinecke 2019). To fully integrate, accept and appreciate indigenous knowledge, science and science communication must move forwards and bridge the gap between intercultural communication.

Reconnecting Audiences

Today's science community once again stands at a tipping point regarding how best to communicate its findings. The type of science communication traditionally done since the nineteenth century might not be fit for service anymore. In this day and age, where new news is old within a day, where information can be found everywhere (and often enough not fact-checked or peer-reviewed), science communication must seek to move beyond just the bare facts. Instead, and here, we can learn that from Humboldt, science communication must incorporate the art of storytelling to bring emotion, wonder and curiosity back into the picture and conversation.

Within the last decades, scholars from communication sciences have constantly been refining the theoretical model of communication. The simple Aristotelian sender-receiver model of communication has evolved thanks to the additions such as Shannon and Weaver's information theory model (1949) and a number of enhancements (for example the introduction of social context by Maletzke (1963); the inclusion of the four core dimensions of information by Schulz von Thun (1981); and the separation of sender and receiver processes on the basis of constructivist approaches, e.g. von Glasersfeld (1987)).

A crucial innovation has been implementing "encoding" and "decoding" routines (Hall 1973) themselves based on constructivist ideas (Krotz 2009; Burgoon et al. 2010). Both coding routines include a very individualistic procedure of information processing and describe sources for misunderstandings within communication. If one coding process is undertaken without appreciating the diverse mechanisms of the other coding routine, communication is likely to fail. Science management already accepts this by applying different strategies to different stakeholder sets on a simplistic dimension (for example on the level of identifying audiences as "the public", "politicians" or "industry"), but the depth of understanding and appreciation for the encoding–decoding conundrum is mostly insufficient.

A range of other strategies is available, but none is without its shortcomings. For instance science management aims to identify diverse needs, demands and expectations via public-opinion polls and various media surveys (e.g. for Germany: WiD 2017, for the EU: EC—European Commission 2017), but identification does not equate to understanding. Therefore, science communication often succeeds only on a shallow level (mostly on a sketchy cognitive one). Science communication seeks to facilitate successful decoding processes within the audience by transferring scientific research results from the academic to non-academic sphere and using appropriate language for lay-people. While this is well-meant, individual decoding routines are rarely considered, despite education research showing that, for example boys and girls decode information in significantly different ways (OECD 2015). Differences in decoding routines have also been reported to depend on the professional family background. In this regard, education research especially has gained important insights into how children perceive scientific information (Bourdieu 2001; for the combined effects of gender and social status of children on the perception of science see Lühe et al. 2017). These differences become even more apparent if, for instance children from different cultural backgrounds are observed (Aikenhead and Jegede 1999). It is, therefore, important for science communication to appreciate the strong heterogeneous nature of the audience and to change its routine accordingly.

While not doing communication research himself, it seems that Alexander von Humboldt already knew about the various decoding routines of his audiences. Therefore, he adapted the tone and language used in respect to his readers and listeners, attracting both young and old, male and female. Two examples serve to illustrate this point. First, in his famous *Wahlverwandtschaften*, Goethe praised Humboldt's ability to adjust his communication to the audience in front of him when speaking through the youthful voice of Ottilie: "How I do wish that one day I could listen to Humboldt talk".[4] Second, consider a note by Bayard Taylor, American traveller, translator and man of letters, who wrote from Berlin to the New York Tribune on 25 November 1856: "I came to Berlin, not to visit its museums and galleries, its magnificent streets of lindens, its operas and theatres, nor to mingle in the gay life of its streets and salons, but for the sake of seeing and speaking with the world's greatest living man—ALEXANDER VON HUMBOLDT [sic]" (Foner 1983: 330). These two examples—fictional and historical—showcase the allure of Humboldt and his ability to capture audiences far and wide.

By contrast, generations of scientists after von Humboldt lost this ability to connect with and adjust to their audiences. For the following century, scientists were increasingly seen to be commanding respect—something not asked for but, once given, not objected to. Fortunately, the concept of science communication has been changing over the last decades. Science—it seems—is increasingly accepting its position in society as an equal part of other sub-systems within structural functionalism (Kohring 2005). Science communication is also now moving away from hierarchical concepts (sender-receiver model of communication) and taking the social context into account.

As an example of this more recent approach, the contextual model of intercultural communication (CMIC; Neuliep 2006) looks to combine the encoding and decoding approach with the idea of heterogeneous audiences. CMIC takes all kinds of contexts into account. In doing so, CMIC is not limited to classical definitions of culture, but instead considers physical, social or even psychological contexts and their impact on the communication process. Therefore, CMIC argues that all stakeholders those involved are linked by context (Holliday 2011). It has to be said that this, at least to some extent, is in contrast to the theory of structural functionalism, where all stakeholders or those involved should be seen as independent. The aforementioned notion of hierarchy in the communication process is also recognized by CMIC as a socio-relational context. As a result, intercultural communication also becomes possible by demanding awareness of the interdependencies of contexts and their influence on the communication process itself. Therefore, when communicating research, science should first include an in-depth stakeholder analysis that considers the individual deciphering routines of each scientist and audience member. Most obviously, this can start by reflecting critically on English being an international language of science (EILS), thus excluding or restraining large parts of the global South and Asia; indeed, EILS has also been termed a "Tyrannosaurus rex" for its role in privileging native English publications and research (Tardy 2004).

I have argued that science communication has to become more sensitive to interculturalism among its audience in order to become more efficient. While this in itself will optimize the decoding-encoding process of communication, it might not

[4] Goethe's Wahlverwandtschaften, published in 1809, has been translated variously as Elective Affinities as well as Kindred by Choice. Goethe himself was a close friend of Alexander von Humboldt.

be enough for science to reclaim its leading position in public discourse. In addition to becoming more understandable, science communication also has to become more meaningful to its audience and dialogue partners. This can be achieved by moving away from a totally fact-based paradigm towards—at least slightly—a form of communication that is more emotional. Alexander von Humboldt can serve as the grandmaster in this respect. He wove scientific, factual observation with emotional descriptive elements, taking his readers to the gaping abysses of Mount Chimborazo and the mosquito-infested sandbars of the Orinoco.

It Is About Perspectives

Eibach (2012) interprets some of Humboldt's paragraphs as examples that showcase Humboldt's ability to gain an emotionally charged response. By changing perspectives, ideas and thought processes, the behaviour of the counterpart can be assessed and understood in greater detail. An example of this approach is Humboldt's experience with body-painting in the Orinoco basin:

One day while travelling the Orinoco basin, Alexander von Humboldt experienced a near epiphany while talking to and observing a group of indigenous people. He realized that posture played a major part in the conversation of indios among each other. Moreover, it seemed to him that the interplay between posture and body-art had a major effect on communication among the native people. Both were expressions of emotionality. Brave and burning for action, the beautifully painted natives stood tall with proudly raised heads. Humboldt—curious as ever—was eager to experience this effect himself and asked for his body to be painted as well. Unfortunately, there is no report on how Humboldt felt after being painted. However, we do know that when entering the township of Angostura (today's Ciudad Bolivar) some days later, a faint shimmer of the colours was still present on his face. Humboldt seemed unconcerned by the looks of wonder on local faces (see Meinhardt 2015). It is likely that this event had a lasting impact on Humboldt.

It is not only the change of perspective that stood out. It was Humboldt's willingness to step across a cultural divide that could not have been wider than the one in front of him. It was his conviction that crossing this divide would help to better understand the "other" and thus gain deeper insights than through mere observation. Humboldt—it seems—was convinced that the perception and the understanding of reality were highly dependent on the perspective. Perspective here is meant as a description of the socio-cultural context of each individual. Therefore, empathy and the willingness to step outside one's own perspective and accept and adopt the other one's perspective seem crucial if communication is to be effective and efficient. Without being sensitive to the differences in perspective, false assumptions will be fed into the encoding and decoding process of communication. If we do not accept that our interlocutor or audience will decode information according to their unique individual perspective, communication will fail. Being sensitive to the other's perspective is, therefore, essential for successful communication.

While Humboldt instinctively knew this, he nevertheless was able to change perspective only on a shallow—some might say superficial—level. From today's point of view, the body-painting episode seems rather to be an obscure element of Humboldt's travel reports: for Bonpland and Humboldt, as Pratt (2008) observed, never encountered South America outside the confines of the Spanish colonial infrastructure. While highly precise and filled with details about plants and geographical as well as geological features, Humboldt's writing more often than not neglected the existence of humans. By putting humans into the background of his writing, it might be argued that Humboldt does not neglect human beings but shows that humans are only another subset of "rea", for instance fauna, flora and geology, in his overall concept of nature. An obvious example is one of his foundational publications—the "Views of the Cordilleras and Monuments of the Indigenous People of America" (1810 and 1814)—that includes *indigenous people* writ large in its title without ever discussing their lives, culture and knowledge in greater detail. To cite Pratt (2008), Humboldt "remained relentlessly disparaging" towards pre-Columbian civilizations.

Meinhardt (2015) believes that Humboldt was able to observe his environment and interlocutors without prejudice. He may—perhaps having been strongly influenced by romantic writers such as Goethe and Schiller or by reading the French philosopher Jean-Jacques Rousseau—even have thought about indigenous people in an overly romanticized fashion (Meinhardt 2015; although Osterhammel 1999 objects vehemently to this notion).[5] This bias, rooted in the Eurocentric setting (and origins) of modern academia, can also be observed today. Fortunately, numerous methods are available that can help scientists become more sensitive towards diverse socio-cultural contexts and perspectives and overcome prejudice and preoccupation.

Sensitize Science to Be More Aware of Diverse Socio-Cultural Contexts

As mentioned earlier, Humboldt never went beyond the Spanish colonial infrastructure (Pratt 2008). Thus, he never completely experienced the untouched indigenous regions of South America. Nevertheless, he tried to become engaged with native people as the curare episode shows. To get an impression of the perspective of the indigenous people, Humboldt also took a great interest in their stories and mythology.

[5] Pratt (2008) even sees Humboldt along others to be the archetype of romantic, who actually defines what we take as romantic by saying "Romanticism is Humboldt".

Although clearly not as theorized as today, in this, Humboldt can be considered one of the forerunners of mobile oral history (MOH), a modern approach to initiate and foster intercultural cooperation. There are currently countless methods that seek to develop an appreciation for indigenous worldviews. In briefly outlining three of these approaches, I want to stress that all are able to increase interculturality in project management as well as science communication. The following methods will, for example help scientists to better understand the worldviews and perspective of local communities towards science and research—especially in respect to earth and environmental sciences. The following methods—Photovoice, open space technology and today's version of MOH—have been used successfully in high arctic research for many years and seek to engender mutual understanding. All three methods are also easy to implement and integrate into project designs. To have the most beneficial effect, all methods should be integrated into project management as early as possible.

To increase interculturality, Photovoice and MOH can enhance the co-design of scientific project conceptions (for Photovoice see Wang and Burris 1994; for MOH see Riley and Harvey 2007). The Photovoice method seeks to "emphasize community participation for the purpose of social action" (Kuratani and Lai 2011) and "builds on a deep, historical foundation of individuals and communities blending images and words to express needs, history, culture, problems, and desires" (Nykiforuk et al. 2011). This is achieved by picture-based documentation and refection on places and objects, driven by community-based participation (sometimes incorporated into citizen science project). Despite Photovoice's clear benefit, science foundations as well as project leaders and managers have to be aware that these methods presuppose additional time, a large budget and additional manpower to harness the full potential of the techniques.

Open space technology (OST) is another tool that fosters dialogues across cultures. OST is based on the observation that in local communities all over the world, discussions are conducted by sitting together in open circles. While sub-themes can split from the main circle and form new circles, the participants can freely join and leave circles whenever they choose. Thus, major topics will attract more debaters than minor issues. In addition, with a constant flow of incoming and outgoing debaters, the perspectives on the issue are constantly changing. At the end, a summary of the OST session provides guidelines or recommendations on how to deal with an issue that are rooted in the beliefs, demands and expectations of the participants. Conducting an OST session to conceptualize research with participants from science, local leaderships and all other relevant stakeholder groups can result in an intercultural concept for science that provides benefits for all stakeholders as well as a better understanding behind any resistance or rejection of an issue. By using a technique that is deeply rooted in the traditional communication routines of indigenous communities throughout the world, OST can offer a space that allows all participating groups and individuals to set their own agenda. This provides new perspectives and insights. Decisions are made collaboratively and democratically. As evidence of its success, Swanson and Tetreault (2007) describe the application of OST in empowering conceptual processes in Canada's First Nations.

Another tool in fostering local interculturality in science projects is MOH, which merges methods from traditional oral history interviews and reflections on particular places and landscapes. Landscape and place are crucial for local communities because they bear meanings that are rarely articulated by local residents or are only communicated via mythology and traditional storytelling. MOH seeks to reveal these meanings by visiting the places during the course of an interview. By tentative and respectful questioning during the interview, the significance of these places can be elicited. Like Photovoice, MOH provides opportunities for personal memories and indigenous knowledge to be voiced and offers a platform for discussion, in which perceptions about place, values and memories for wider community groups can be shared (Coherit and OAS 2015). Special consideration should be given to diverse age and gender, the cultural, social and economic context, as well as to geographical location within an MOH study. Like Photovoice, this approach towards local value and belief systems is time-consuming and requires considerable resources. However, the benefits are that local communities feel more fully involved and integrated, and that researchers gain a deeper insight into the cultural and social context during their work.

It must be repeated that true intercultural co-design and intercultural cooperation require additional resources. Photovoice, OST and MOH are only examples of these approaches, but they show that additional time as well as financial and human resources are needed. Moreover, there is a strong demand for intercultural communication skills and a sensitivity towards cultural differences. These skills would be required from each scientist participating in the research project. Science foundations and sponsors have to recognize and acknowledge the need to establish such competences as well as to finance appropriate approaches while the project is initially being conceptualized.

How interculturality can be achieved through structural dialogue strategies has been described recently by Groulx et al. (2017). Here, research in the high arctic regions started as multicultural project (where individuals or groups from different cultural settings work alongside each other without in-depth interaction) and over time turned into real intercultural one (where people and groups from various cultural settings interact, co-create and influence each other). The project applies a strong and thorough strategy that allows, for instance the "rhythm of life in the communities" to be identified (Groulx et al. 2017).

These approaches that move towards increasing interculturality in science and research are matched today by concepts and ideas summaries in geoethics and Responsible Research and Innovation (RRI). Humboldt only made the initial steps and helped to clear the path towards an increased acceptance and integration of indigenous knowledge. Unfortunately, he lived in a time in which colonial thinking and the belief that the European man was superior to indigenous people were the prevailing zeitgeist. From today's perspective, von Humboldt could have done more, could have questioned his own approach towards interculturality more critically and could have raised his voice even more against oppression and discrimination.[6] He should have appreciated the pre-Columbian achievements more vocally; he should have also understood that by making observations on native South American people, he was also making them equivalate to research objects. Seen from the eighteenth-century perspective, his actions can be seen as breaking out his zeitgeist. In some case, his actions contained nascent ideas about interculturalism, ideas which would be more fully theorized in the twentieth and twenty-first centuries. His empathy and a strong sense for the differences in perspective on science due to diverse socio-cultural contexts were extraordinary and matched—unfortunately—only by few scientists of contemporaries and successors. But, von Humboldt should nevertheless serve as an example for science in this day and age to raise as strong awareness as possible concerning the gap between "academic science" and indigenous knowledge. As has been repeatedly stressed, tools to bridge this gap are increasingly being developed and refined; however, that a gap still remains is concerning and requires action on the side of academic science. Humboldt offers inspiration and provides case studies, but in both awareness and deed, academic science must travel further.

Annotation

Within the process of writing this chapter, we were asked to also consider the evolution of science and the epistemology of scientific knowledge over the last 250 years since von Humboldt. We appreciate this stimulus, but we would like to also point towards an assumption that still persists, one which privileges academic or western knowledge over indigenous and traditional knowledges. While there is no doubt that the academia has developed a lot from the late eighteenth century, research in the sciences still exhibits a considerable amount of unethical and oppressive behaviour towards local communities. This is especially obvious within the lack of acknowledgement of traditional communities and their lands, as well as in the appropriation of indigenous knowledge by academia. Thus, von Humboldt's approach towards a better understanding and appreciation of traditional knowledge—while from today's perspective constrained by the socio-cultural context in which he lived—can be seen as basic requirement for today's science. Self-awareness and critically reflecting on one's own (scientific) behaviour are an option open to scientists. It is also an option that must become compulsory.

Acknowledgements Our gratitude goes to the anonymous reviewers who provided valuable feedback to this manuscript. Many thanks to Daniel Prince for beneficial comments, annotations and additions.

[6] Humboldt for example successfully confronted Tsar Nikolai regarding the exiled polishman Witkiewicz (Böttcher 2020).

References

Aikenhead, G.: Integrating Western and Aboriginal Sciences: Cross-Cultural Science Teaching. Research in Science Education 31: 337. https://doi.org/10.1023/A:1013151709605, 2001.

Aikenhead; G. and Jegede, O. J.: Cross-Cultural Science Education: A Cognitive Explanation of a Cultural Phenomenon. Journal of Research in Science Teaching. Vol. 36, No. 3, pp. 269–287, 1999.

Beck, H. (1987–1997): *Alexander von Humboldt – Studienausgabe*. 7 Bände (erschienen in 10 Bänden). Wissenschaftliche Buchgesellschaft, Darmstadt 1987–1997, ISBN 3-534-03100-8.

Berkes, F., Colding, J. and Folke, C.: Rediscovery of traditional ecological knowledge as adaptive management. Ecological Applications. 10(5):1251–1262. https://doi.org/10.1890/1051-0761(2000)010[1251:ROTEKA]2.0.CO;2, 2000.

Berkes, Fikret, Mina Kislalioglu Berkes & Helen Fast (2007) Collaborative Integrated Management in Canada's North: The Role of Local and Traditional Knowledge and Community-Based Monitoring, Coastal Management, 35:1, 143–162, https://doi.org/10.1080/08920750600970487.

Böttcher, H (2020). Humboldts Eskorte. Kontrolle und Sicherheit auf Alexander von Humboldts Russlandreise 1829. HiN 21(41). https://doi.org/10.18443/301.

Bourdieu, P.: Wie die Kultur zum Bauern kommt. Über Bildung, Schule und Politik. Hamburg: VSA, 2001.

Burgoon, J. K., Guerrero, L. K., and Floyd, K.: Nonverbal communication. (1 ed.) Boston, MA: Allyn & Bacon, 2010.

Coherit, and OAS (Organization of American States): Elicitation of Community Heritage Values and Place Perception. http://coherit.com/projectfiles/DeliverableGuide_2_2.pdf, visited August 2018. 2015.

Cruikshank J. (2001): Nature and Culture in the field: Two centuries of stories from Lituya Bay, Alaska. In: de Laet (ed.) Knowledge and Society (Research in Science and Technology Studies: Knowledge and Technology Transfer). Vol. 13. Elsevier. Amsterdam. p 11–43.

Cushman, G. T. "Humboldtian Science, Creole Meteorology, and the Discovery of Human-Caused Climate Change in South America," Osiris 26 (2011): 16–44. https://doi.org/10.1086/661263.

Dowsley, M., & Wenzel, G. (2008). "The Time of the Most Polar Bears": A Co-Management Conflict in Nunavut. Arctic, 61(2), 177–189. Retrieved July 15, 2020, from www.jstor.org/stable/40513204.

EC - European Commission (2017): The new European Consensus on Development 'Our World, Our Dignity, Our Future'. Retrieved from: https://ec.europa.eu/europeaid/new-european-consensus-development-our-world-our-dignity-our-future_en.

Eibach, J.: Tasten und Testen. Alexander von Humboldt im Urwald, in: zeitenblicke 11, Nr. 1 [07.11.2012], URL: http://www.zeitenblicke.de/2012/1/Eibach/index_html, URN: urn:nbn:de:0009-9-33828.

Ette, O. (Edt) (2018). Alexander von Humboldt – Das Buch der Begegnungen. Manesse. ISBN 978-3175-2444-1.

Feyerabend, P.: Farewell to reason. Verso, London, UK, 1987.

Foner, P. S. (1983). Alexander von Humboldt on slavery in America. Science & Society, 330–342.

Gerhardinger L.C., Godoy E.S., Jones P.S. (2009): Local ecological knowledge and the management of marine protected areas in Brazil. Ocean Coastal management. 52(3–4):154–165.

Gerten D. (2010): Adapting to climatic and hydrologic Change - Variegated Functions of Religion. In: Bergmann & Gertens (ed.). Religion and Dangerous Environmental Chance – Transdisciplinary Perspectives on the Ethics of Climate and Sustainability. LIT. Münster, Berlin. p 39–56.

Gomsu, J. (2004): Alexander von Humboldts Umgang mit lokalem Wissen. HiN – Alexander von Humboldt im Netz. Internationale Zeitschrift für Humboldt-Studien 5 (8), S. 5–17. https://doi.org/10.18443/hinvol5iss082004.

Groulx, P., Kirkwood, D. & Lebel, D. (2017). Building Bridges through Science: Increased Geoscience Engagement with Canada`s Northern Communities. Annals of Geophysics, Vol 60 (7), https://doi.org/10.4401/AG-7512.

Hall, S. (1973). Encoding/decoding in Television Discourse. In: Centre for Contemporary Cultural Studies (Ed.): Culture, Media, Language: Working Papers in Cultural Studies, 1972–79 London: Hutchinson.

Hintjes H.M.: What has God to do with sustainable development? A Sahelian dialogue. Worldviews: Environment, Culture, Religion. Vol 1:211–230. 1997.

Holliday, A.: Intercultural Communication and Ideology. London: SAGE. 2011.

Knobloch, E. (2004). Naturgenuss und Weltgemälde. Gedanken zu Humboldts Kosmos. HiN – Alexander von Humboldt im Netz. Internationale Zeitschrift für Humboldt-Studien 5 (9). p.: 34–47, https://doi.org/10.18443/hinvol5iss092004.

Kohring, M. (2005). Wissenschaftsjournalismus – Forschungsüberblick und Theorieentwurf. UVK Verlagsgesellschaft. Konstanz. ISBN: 3-89669-482-0.

Krotz, F.:Stuart Hall: Encoding/Decoding und Identität. In: Hepp, A. et al.(Hrsg.), Schlüsselwerke der Cultural Studies. Wiesbaden: VS Verlag. https://doi.org/10.1007/978-3-531-91839-6_17, 2009.

Kuratani, D. L. G., & Lai, E.: TEAM Lab - Photovoice Literature Review. https://cpb-us-e1.wpmucdn.com/sites.usc.edu/dist/0/198/files/2018/08/Photovoice-Literature-Review-FINAL-22ltfmn.pdf, visited August 2018, 2011.

Levi-Strauss, C.: La pensee sauvage. Librarie Plon, Paris, France, 1962. (English translation 1966, The savage mind, University of Chicago Press, Chicago, Illinois, USA).

Lindberg, D. C.: The Beginnings of Western Science – the European scientific tradition in philosophical, religious, and institutional context, prehistory to A.D. 1450. University of Chicago Press, 1992.

Lubrich, O. (2019). Wir sollten Humboldt weniger feiern – und ihn dafür mehr lesen. Neuste Zürcher Zeitung. 15.9.2019. Retrieved from https://www.nzz.ch/feuilleton/alexander-von-humboldt-vor-250-jahren-wurde-der-forscher-geboren-ld.1507180 (May 2020).

Lühe, J., Becker, M., Neumann, M. and Maaz, K.: Geschlechtsspezifische Leistungsunterschiede in Abhängigkeit der sozialen Herkunft. Eine Untersuchung zur Interaktion zweier sozialer Kategorien. Zeitschrift für Erziehungswissenschaften 20: 499. https://doi.org/10.1007/s11618-016-0720-4, 2017.

Maletzke, G.: Psychologie der Massenkommunikation, Verlag Hans Bredow Institut, 1963.

Marten, G. (2010): Human Ecology - Basic Concepts for Sustainable Development. 2nd edition. Routledge.

Mathewson, Kent (1986) Alexander von Humboldt and the Origins of Landscape Archaeology, Journal of Geography, 85:2, 50–56. https://doi.org/10.1080/00221348608979149.

Medin, D., Bang, M.: Who's asking? Native science, western science, and science education. MIT Press, 2014.

Meinhardt M. (2015). The Romantic Scientist: Alexander von Humboldt under the Palm Trees. Guernica. 22.9.2015. Retrieved from https://www.guernicamag.com/maren-meinhardt-the-romantic-scientist-alexander-von-humboldt/ (May 2020).

Murphy, E. M., & Mallory, J. P. (2000). Herodotus and the cannibals. Antiquity, 74(284), 388–394.

Neuliep, J. W.: Intercultural Communication – a contextual approach. London: SAGE, 2006.

Nykiforuk, C. I. J., Vallianatos, H., and Nieuwendyk, L. M.: Photovoice as a Method for Revealing Community Perception of the Built and Social Environment. International Journal of Qualitative Methods 10(2):103–124, https://doi.org/10.1177/160940691101000201, 2011.

OECD (Organisation for Economic Co-operation and Development): The ABC of Gender Equality in Education: Aptitude, Behavior, Confidence. http://www.oecd.org/pisa/keyfindings/pisa-2012-results-gender.htm, visited on 13th of April 2018, 2015.

Osterhammel, J. (1999). Alexander von Humboldt: Historiker der Gesellschaft, Historiker der Natur. Archiv für Kulturgeschichte, vol 81(1). https://doi.org/10.7788/akg.1999.81.1.105.

Pratt, M. L. (2008). Imperial Eye. Travel Writing and Transculturation. Second Edition. Routledge. New York. https://doi.org/10.4324/9780203932933.

Riley, M., and Harvey, D.: Talking geography: on oral history and the practice of geography, Social and Cultural geography 8(3): 345–351, https://doi.org/10.1080/14649360701488765, 2007.

Schlosberg, D.: Defining Environmental Justice: Theories, Movements, and Nature. Oxford University Press. 2007.

Schmuck, H. (2009): An act of Allah: Religious Explanations for Flood in Bangladesh as Survival Strategy. International Journal of Mass Emergencies and Disasters. Vol 18:85–95.

Schneider S., Heinecke L. (2019): The need to transform Science Communication from being multi-cultural via cross-cultural to intercultural. Advances in Geosciences. Vol. 46:11–19. https://doi.org/10.5194/adgeo-46-11-2019.

Schulz von Thun, F.: Störungen und Klärungen. Psychologie der zwischenmenschlichen Kommunikation. Rowohlt, Reinbek, 1981.

Shannon, C. E. and Weaver, W.: The mathematical Theory of Communication. Board of Trustees of the University of Illinois, 1949.

Swanson, J., Tetreault, S.: A Model for Aboriginal Facilitation: An Open, Empowering Way to Get Consensus and Action. The journal of Aboriginal Management. The National Centre for First Nations Governance, Retrieved from: http://fngovernance.org/resources_docs/ A_Model_For_Aboriginal_Facilitation.pdf, visited December 2018, 2007.

Tardy, C. (2004). The role of English in scientific communication: lingua franca or Tyrannosaurus rex?. Journal of English for academic purposes, 3(3), 247–269.

Tsuji, L. J. S., and Ho, E.: Traditional Environmental Knowledge and western Science: In Search of Common Ground. The Canadian Journal of Native Studies XXII, 2:327–360, 2002.

von Glasersfeld E.: Einführung in den radikalen Konstruktivismus. In: Wissen, Sprache und Wirklichkeit. Wissenschaftstheorie Wissenschaft und Philosophie, Vol 24. Vieweg & Teubner Verlag, Wiesbaden. https://doi.org/10.1007/978-3-322-91089-9_17, 1987.

Wang CC & Burris MA. (1994). Empowerment through Photo novella: Portraits of participation. Health Education Quarterly, 21(2), 171–186.

Weigl, Engelhard (2004): Wald und Klima: ein Mythos aus dem 19. Jahrhundert. HiN – Alexander von Humboldt im Netz. Internationale Zeitschrift für Humboldt-Studien 5 (9), S. 80–99. https://doi.org/10.18443/54.

Weiss K., Hamann M., Marsh H. (2013): Bridging Knowledge: Understanding and Applying Indigenous and Western Scientific Knowledge for Marine Wildlife Management. Society & Natural Resources. Vol. 26(3):285–302. https://doi.org/10.1080/08941920.2012.690065.

Whitt, L.: Science, Colonialism, and Indigenous Peoples: The Cultural Politics of Law and Knowledge. Cambridge University Press, 2009.

Whyte, K.: Indigenous Climate Change Studies: Indigenizing Futures, Decolonizing the Anthropocene. English Language Notes, Forthcoming. SSRN, Available from https://ssrn.com/abstract=2925514, visited April 2018, 2017.

WiD (Wissenschaft im Dialog): Wissenschaftsbarometer. Berlin: Wissenschaft im Dialog GmbH, 2017.

Wyndham, F. S. (2017). The Trouble With TEK. Ethnobiology Letters, 8(1), 78–80. https://doi.org/10.14237/ebl.8.1.2017.1006.

Simon Schneider has made the move from Geophysics to Communication Science and back to the Geosciences. His main research interest is deciphering and understanding the challenges and mechanisms that drive intercultural science communication. He is currently a member of the Department for Earth and Environmental Sciences at Ludwig-Maximilians Universität München.

Humboldt's Journey to Russia and Siberia in 1829—His Dual Role as Consultant and Explorer

Jörg Stadelbauer

Abstract Alexander von Humboldt's Russian–Siberian journey in 1829 differed from his South American expedition in two key regards: the shorter time span and political setting. By then a world-famous scholar, Humboldt was invited by the Russian Minister of Finance to act as a consultant and tasked with investigating the state of mining development in the Urals. For this purpose, he was provided with the necessary support and equipment, from a comparatively comfortable carriage to maps and military protection. Humboldt complied with the instructions associated with his task and tolerated the corresponding care and control. Crucially, however, Humboldt also understood how to push his own interests. This is particularly evident in the wider scope of the travel route to Inner Asia, the Russian–Chinese border, and to the Caspian Sea. Humboldt pointed out inadequacies in the use of resources in the Urals, but had only moderate success in enforcing human rights. The article aims to highlight various political implications of the Russian–Siberian journey and bring to light their distinctive features.

Keywords Russia · Siberia · Resource policy · Consultant · Monetary policy · Human rights

Introduction

> Mein heißester Wunsch ist, Ihnen in Rußland selbst meine Aufwartung zu machen. Der Ural und der nun bald Russische Ararat, ja selbst der Baikal-See schweben mir als liebliche Bilder vor.

J. Stadelbauer (✉)
Institute of Environmental Social Sciences and Geography, Albert-Ludwigs-Universität Freiburg, Freiburg, Germany
e-mail: joerg.stadelbauer@geographie.uni-freiburg.de

G. C. Falk et al. (eds.), *Alexander von Humboldt*,
https://doi.org/10.1007/978-3-030-94008-9_10

> My most ardent desire is to pay you my own respects in Russia. The Ural Mountains and the soon to be Russian Ararat, even Lake Baikal, are most lovely pictures in my mind's eye.[1]

This is what Alexander von Humboldt wrote to the Russian Minister of Finance, Georg von Cancrin, on 19 November 1827, when he submitted a report on the use of platinum as a coin metal that the Minister had requested in the light of his plan to restructure the Russian currency with a new precious metal base. Considering the language of the time, the social status of both sender and recipient, and the fact that the report mainly presented arguments against Cancrin's idea of using platinum as a coin metal,[2] in the extract above Humboldt simultaneously cast out several lures in order to secure an invitation to visit Russia. More precisely, the Ural Mountains, whose natural resources had been exploited since Peter the Great, were important to the Minister of Finance because of their rich resources; moreover, Mount Ararat was the target of a Russian expansion policy rated positively by the European political powers; finally, the mention of Lake Baikal may be seen as an indication that Humboldt was ready and willing to take on the rigours of a long and exhausting journey. No reference was made, however, to the Central Asian Mountains, the destination Humboldt actually longed to visit after his failed attempt to travel to the Himalayas, then under British control and Tibet. In 1793, Humboldt's contact with a fellow student, the Russian Vladimir Yurievich Soimonov, had first inspired him to conduct an expedition to Russia.[3] In 1812, he even envisaged a research journey through Russia that would last several years, but Napoleon's advance into the country thwarted this plan.[4] At that time, the Tian Shan was still outside Russian influence, and only the northwest of the Altai Mountains, rich in ores like the Ural Mountains, had been developed by Russia since the 1720s.[5]

The South American journey shaped Alexander von Humboldt's international reputation. Pictures showing the researcher as an urbane gentleman standing at the foot of Chimborazo or working together with his travel companion, Aimé Bonpland, in a tent in the Andes have often been published and shape our perception of the noble scholar. By drawing Humboldt's Russian–Siberian journey in 1829 out of the shadows of the famous American journey, I argue that the

[1] „Mein heißester Wunsch ist, Ihnen in Rußland selbst meine Aufwartung zu machen. Der Ural und der nun bald Russische Ararat, ja selbst der Baikal-See schweben mir als liebliche Bilder vor." (Humboldt 1869, p. 18, quoted by Beck 1959, p. 77).

[2] In Russia's concrete monetary policy, Cancrin introduced platinum coins as a "luxury currency" in 1828, but nobody was obliged to accept them. The price on which the mintage was based was 4746 roubles for a pud (290 roubles/kg) of platinum. Due to price fluctuations, the nominal and trading values of platinum coins already differed by 137% in 1844. At the beginning of 1845, the minting of platinum coins was stopped; in 1858, the platinum currency was finally abandoned by a Russian coin commission—not least with recourse to Humboldt's counterarguments (cf. Beck 1959a, p. 75f.).

[3] Esakov (1960, pp. 49–51).

[4] Humboldt (2009, p. 432), Ette (2009, p. 327), Kraft (2018, p. 61).

[5] Istoriya Sibiri (1968, 2, pp. 227ff).

political played a key role, for both the Minister of Finance as well as Humboldt, in order to demonstrate the power of but also the limits to Humboldtian science.[6]

If politics and policies is understood as acting for a community or for a larger association of people, then Humboldt's second far-reaching expedition was both a scientific event and a political issue.[7] Indeed, the Russian minister of finance, Cancrin, intended to politicize science, even if thinking more narrowly of applied science:

> "[…] the government's desire is solely to be conducive to science. As much as they can, you will be of benefit to Russia's mining and industry" – as was written in the conclusion of the *Pro Memoria*, the imperial instruction given to Humboldt on his way through Russia, in the tradition of the academic expeditions of the 18th century.[8]

Thus, even if science is never totally free from politics, in Humboldt's expedition we can watch both spheres intertwine.

Science in the Service of Power: Research Versus Resource and Financial Policies

Cancrin originated from a noble Hanau family and had been appointed Russian minister of finance in 1823; Humboldt's letter to him led to the two men meeting in Paris, which in turn resulted in a more intensive exchange of letters in a correspondence that continued after Humboldt's journey to Russia.[9] The platinum base was controversially discussed in the general resource economy, as it was hardly possible to estimate the worldwide reserves and resources. As such, new finds would have immediately burdened the currency due to the falling price in the global market. Russia, however, having discovered platinum in the Ural Mountains in 1822, held deposits and hoped to be able to develop more. Humboldt's journey to the Ural Mountains, it was intended, would provide high-profile backing of the Minister of Finance's monetary policy. The formal invitation was therefore primarily addressed to the expert, who would—to use the language of today—act as a consultant in order to conduct a feasibility study on resource and monetary policy. Seen in this light, then, Humboldt's expertise carried weight at all European courts.

---

[6] Péaud (2011, 2014) compares the political aspects of Humboldt's two major research expeditions.

[7] Thus, Péaud's hypothesis is taken up that politics and policies (in French: le politique and la politique) were fundamental for the development of geographical thinking and geographical knowledge production of the time (Péaud 2016, p. 19f.).

[8] „[…] der Wunsch der Regierung ist einzig der, den Wissenschaften förderlich zu sein. So viel Sie können, werden Sie dabei dem Bergbau und dem Gewerbefleiß Russlands Nutzen schaffen." (Humboldt 2009, p. XIII) (Rose).

[9] On Humboldt and Cancrin (Beck 1959a); for the correspondence, see Perepiska Aleksandra Gumbol'dta … (1962, p. 38ff).

The wider political picture also shows the political forces and currents at play behind Humboldt's journey. Indeed, the *raison d'être* of the expedition was that the two European powers—the Prussian kingdom and the Russian tsarist empire—were seeking a rapprochement beyond that of establishing family ties between the ruling dynasties (tsar Nikolai's wife Aleksandra Fedorovna [Charlotte] was the eldest daughter of King Frederick William III of Prussia). In Russia, despite Alexander I's reform attempts, tsarist policy became altogether anti-liberal when his successor Nikolai I (reigned 1825–1855) initiated a phase of restoration with the bloody suppression of the Decembrist uprising. Meanwhile in Prussia, Frederick William III (reigned 1797–1840) was making an attempt to modernize the economy after the Napoleonic Wars and the Congress of Vienna, but he did not continue with reforms initiated earlier. Humboldt's journey, then, could strengthen ties and divert attention from inner problems of the two states.

There could also be other factors at play. Indeed, it might even have been in Prussian political interests to keep Humboldt busy for a certain period of time, thus preventing him from influencing day-to-day politics in Berlin. According to a note to the Prussian–Polish historian Jacob Caro, Frederick William III had an interest in keeping Humboldt away from Berlin. Some sources assume that von Fahrenbach, a civil servant in the Russian Ministry of Finance, devised the intrigue in 1827.[10] The most convincing interpretation is that the issue of platinum was used as bait by Cancrin to arouse Humboldt's interest in the question of Russian resources and to justify the offer to undertake a journey to the Ural Mountains. A renewed attempt in 1831 to invite Humboldt to Russia is evident from a letter that Prince Wilhelm (later Emperor Wilhelm I) wrote to his sister Charlotte, in which it is said that the Prussian King was keen to have Humboldt "cold-cast" for a certain period of time. However, the Prussian court did not pursue this plan any further.[11]

For Alexander von Humboldt, the possibility of a journey to Russia was of quite different significance, far away as it was from Prussian and Russian politics. Instead, for him it opened a new area for comparative mountain research and offered the chance to delve deeply into the Eurasian continent and even to Inner Asia, as well as adding new knowledge to a natural history of the mountains.[12] Therefore the scientist accepted the political frame that had been set up by Cancrin and gave assurances that the questions regarding the socio-economic conditions of ordinary

[10] Kraft (2018).

[11] For details, see Kraft (2018, pp. 62–64).

[12] Humboldt's previous attempts to carry out an expedition to Central Asia had failed. His long stay in Napoleonic Paris prevented the agreement of the English Crown and the East Indian Company; the destination Samarkand remained unreachable in 1809 (cf. Treue 1990, p. 153), and in 1810 an expedition to Tibet and India, planned in the correspondence with the former Russian Foreign and Trade Minister Nikolaj Petrovic Rumjancev, did not come about (Kalesnik 1959, p. 317; see Perepiska Aleksandra Gumbol'dta … 1962, p. 30ff.). In 1812, Humboldt even drew up an expedition plan for an expedition of several years to Siberia, with which he intended to tie in with the great Siberian Expeditions of the eighteenth century and at the same time bring in his own experiences of South America (cf. Treue 1990, p. 154); this plan fell victim to Napoleon's advance to Russia.

miners in Russia would be excluded from the contents of his journey. Cancrin was certainly interested in information about the mining conditions and asked Humboldt for an oral report, but no publicity at all was wanted. Therefore, we know little about Humboldt's view on the matter, but we learn from his former publications on Latin America and Cuba and from his report to the US American President Jefferson that he was highly interested in questions concerning social conditions.

It was from the imbalance of powers and differences in interests outlined above that the elaborate expedition had to be financed. Having used up his inheritance, Humboldt was unable to contribute his own funds to the expedition. That mattered little because he did not come as private explorer, but travelled as a guest at the invitation of the state. As such, he was assured funds and logistical support by the tsar and his minister. Indeed, at the immediate instigation of the tsar, Humboldt even received 20,000 roubles in St. Petersburg from the Governor, instead of the 10,000 initially promised.[13] Moreover, the General Staff of the Russian Army made available a collection of all available engraved maps of his travel area to him.

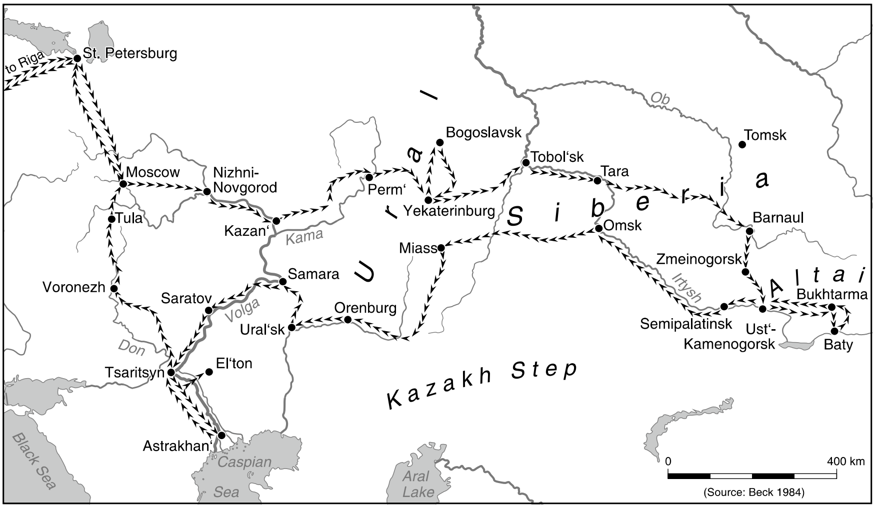
The Journey of Humboldt and His Companions

Let us briefly follow Humboldt's itinerary.[14] The adviser's journey took on the character of a scientific expedition. With a letter to Cancrin, Humboldt was able to arrange that two excellent scientists, the mineralogist Gustav Rose (1798–1873) and the biologist Christian Gottfried Ehrenberg (1795–1876), also join the expedition, with an especially comfortable travel carriage being made available for them. Alongside a designated Russian guide Dmitri S. Men'shenin, a mining officer, some personnel and a mostly small Cossack department were at hand to provide service and protection. Sober figures show the scope of the undertaking: in 23 weeks, the party travelled a total of 14,500 West (approx. 15,470 km) in Russia, with a total of 12,244 horses having to be changed at 658 postal stations (Fig. 1).[15]

[13] Humboldt (1880, p. 173).

[14] Detailed chronology in Beck (1959/61,vol.2, p. 88ff.), essentially according to Rose (1837, vol. I); see also Beck (1984, Wolff 1959), Markin (2002, Ette 2007, Ette 2018, p. 59ff) and Humboldt (2019).

[15] Beck (1959, p. 80), Rose (1837, vol. I). Beck (1984) presents a narrative representation of the journey to Siberia, which, however, also includes the background and places this journey in the overall context of Humboldt's scientific work. Short, judgmental depictions can be found in Stams (1979) and Honigmann (1983), a story animated by quotations in the "biographical portrait" presented by Holl (Humboldt2017); a selection of written testimonies from Rose's travelogue and Humboldt's letters in the new edition of the Central Asia Work procured by Lubrich (Humboldt 2009). We owe a thoughtful interpretation of Humboldt's journey to Siberia to the Göttingen economic historian Treue (1990), who sheds light on the history of ideas as well as economic and political framework conditions and consequences. The source material includes an edition of Alexander von Humboldt's letters to his brother Wilhelm (Humboldt 1880). Since 1994, most sections of Humboldt's itinerary have been visited in order to compare Humboldt's experiences with today's situation (Aranda et al. 2014).



Humboldt's Itinerary 1829

Fig. 1 Humboldt's itinerary from St. Petersburg to the Altai Mountains and back to St. Petersburg in 1829. *Source* Stadelbauer

Humboldt left Berlin on 12 April 1829. The route initially led via Königsberg, Riga and Dorpat to St. Petersburg, where Humboldt stayed for several days, during which time Humboldt was always in close contact with the Tsar's family and Cancrin. The small travel party reached Moscow via the Valdai Hills and passed through the trading centre Nizhni Novgorod, Kazan'—a university town—and Perm', before reaching Yekaterinburg. The actual destination, the Ural Mountains, was scientifically known and economically developed, the heartbeat of the Russian iron and steel industry. Humboldt stayed two and a half weeks in the Central Ural Mountains and visited several mining and industrial sites, including gold and platinum mines. A one-week stay in Yekaterinburg followed.[16] The scientist was prepared to take on the strain of numerous mining expeditions not only because he was aware of the geo-economic significance of precious metals, but because he also wanted to investigate the formation of the deposits.

Humboldt showed applied geoscientific interests whilst exploring possible diamond deposits.[17] As an ecologically minded researcher, Humboldt referred to the dangers of deforestation, then caused by excessive wood consumption in the

[16] For details, see Beck (1984, p. 75ff) and Suckow (1994).

[17] Cf. the documents compiled by Beck (1959, p. 61ff.) on the diamond finds in the Urals, in particular the report of Count Polier (landowner and mining entrepreneur in the Urals; the first diamond in the Urals was found on his property in 1829) to the Russian Minister of Finance Cancrin; on the diamond deposits also Rose (1837, p. 352ff, vol. I). The report on the diamond finds sent to Cancrin by Graf Polier is based on Humboldt's assumptions (Rose 1837, p. 356ff., vol. I).

mines. Cancrin had broached this topic with Humboldt in St. Petersburg and was considering reducing the intensity of usage in order to put a break on the destruction of forests. Whilst there, a high wood consumption was confirmed by Humboldt, but not explicitly mentioned in Rose's travel report; certainly, the analysis of the mines was more critical than the report suggests.

Tobol'sk was actually intended to be the eastern endpoint. But instead of returning, Humboldt continued his journey to southwestern Siberia, where he arrived in Barnaul on the second of August and set off two days later for the Altai Mountains, of which only little knowledge was available in Europe.[18] In a letter to his brother, Humboldt had already indicated in July that he wanted to use the time he had saved to deviate from the original plans; in this respect, he had an eye on travelling further to the Altai Mountains and perhaps to Semipalatinsk, near the Chinese border.[19] Humboldt's official communication to Cancrin that there would be "a small extension of our travel plans" (de facto about 3000 km) took place so late that the minister could only approve of the *fait accompli*. That aside, Humboldt himself did not fail to inform Cancrin when he visited other mines, pointing to time savings in the previous journey and lower financial requirements, and concluding:

> It would hurt me infinitely were I able to intuit that Your Excellency disapproves of this excursion, but in the 6th Article of the extremely liberal Instruction sent to Berlin on 18 January you left it entirely to me to direct my journey where I could hope to reach useful scientific ends. I cannot resist the urge to use an opportunity given to me by you which will never present itself again before my death …[20]

In fact, Cancrin subsequently agreed to the "detour", an agreement made more palatable when Humboldt sent him information about the mines of the Kolyvan-Voskresensk district in later letters.

Apart from measuring magnetism,[21] visits to mining and processing plants foregrounded whilst at lake of Kolyvan', Zmeinogorsk (the most important silver mines of the Altai) and Ust'-Kamenogorsk. The widespread granite landscapes, especially those in Kolyvan', confirmed Humboldt's volcanic–plutonistic view of mountain development.[22] From Ust'-Kamenogorsk, Humboldt and his party

---

[18] Rose (1837, p. 493, vol. I). The most important source is the description at Pallas (1771–76/1967, vol. II, p. 579ff.), dating back to a visit in August 1771 (to Kolyvan' and Zmeinogorsk).

[19] Alexander von Humboldt to Wilhelm von Humboldt on 6./18.7.1829 (Humboldt 2009, p. LXXVII).

[20] „Es würde mich unendlich schmerzen, wenn ich ahnden könnte, daß Ew. Excellenz diese Excursion misfiele, aber Sie haben Selbst in dem 6. Artikel der so überaus liberalen, mir schon am 18. Januar nach Berlin gesandten Instruction es mir ganz überlassen, dahin meine Reise zu richten, wo ich nüzliche wissenschaftliche Zwekke zu erreichen hoffen könnte. Ich kann dem Drange nicht widerstehen, eine mir von Ihnen geschenkte Gelegenheit, die sich vor meinem Tode nie wieder darbietet, zu benuzen … ". Humboldt to Cancrin on July 11/23, 1829 from Tobol'sk (Humboldt 2009, p. LXXXV).

[21] Humboldt (1845/62, vol. IV, p. 51).

[22] Humboldt (1845/62, vol. I, pp. 180, 187).

followed the Irtysh upstream to Bukhtarma and to the Chinese border post at Narym—about 160 km west of today's Kazakh-Chinese border.[23] He received a number of Chinese books from the Chinese border post, which he intended to bring back to his brother, Wilhelm.

Humboldt returned through the north-eastern Kazakhstan steppes to Miassk, located in the southern Urals, where he celebrated his 60th birthday on 14 September 1829. A direct return to Central Russia would have been possible, but Humboldt once again changed his itinerary and informed Cancrin at short notice that he had a fervent desire to see the Caspian Sea:

"I cannot sate myself on their kingdom, I cannot die without having seen the Caspian Sea".[24] Now in the central Volga, Humboldt also visited areas settled by German colonists and developed under Catherine the Great; Lake El'ton with its salt deposits[25]; and the German Herrnhuter settlement Sarepta in the vicinity of today's Volgograd, before travelling to Astrakhan through the peripheral areas of the Kalmyk region. On a boat trip on the Caspian Sea, Humboldt identified old sea terraces as an indication of sea level fluctuations, which he attributed to long-term underground oscillations.[26]

In the autumn of 1829 Humboldt returned from Astrakhan via Tula to Moscow and St. Petersburg, arriving on November 13.[27] In Moscow on October 26/ November 7 (Julian/Gregorian calendar resp.) he gave a lecture on the magnetic measurements he had made during his journey to the *Société Impériale des Naturalistes de Moscou*, who had elected him as an honorary member and celebrated his 60th birthday in a special session.[28] In the report he submitted some days later to the Academy of Sciences in St. Petersburg at the end of his journey, Humboldt described his journey as having been one of the highlights of his career.[29] This report also showed the extent to which Humboldt's expedition was politically constrained; in this regard, it did not go into details concerning the political mission of the journey, but instead limited itself to the scientific results; these certainly included the gold deposits, which he would go on to deal with in later publications, but ignored the diamond finds that had been brought to his

[23] Rose vividly describes the Chinese border post in his travel report, whereby the good Russian–Chinese relationship at the border is also pointed out (cf. Beck 1959, p. 104ff.).

[24] „Ich kann mich nicht an ihrem Reiche sättigen, nicht sterben, ohne das Kaspische Meer gesehen zu haben." Humboldt to Cancrin on September 14/26, 1829 from Orenburg (Humboldt 2009, p. CXLVI).

[25] Humboldt had already visited the salt extraction plants of Iletsk near Orenburg.

[26] Humboldt (1845/62, vol. I, p. 215).

[27] Treue (1990, p. 162f). With a short description of the journey, Beck (1959/61) with a more detailed description.

[28] Roussanova (2013, pp. 38–39).

[29] "C'est un des plus grands jours de ma vie. Je crois que mon discours français sur les avantages que l'étendue de la Russie et sa position offre aux sciences physiques, produira de l'effet."—In a letter to his brother Wilhelm shortly before the lecture on 28 November 1829 (Humboldt 1880, p. 209; cf. Esakov 1960, pp. 68–71).

attention.[30] At the end of December 1829, after eight and a half months of travel, the scientist returned to Berlin.

Science or Power? State Care, Security and Control

Humboldt was not only concerned with the task of evaluating Russia's resource policy—that, at least, was the official line. On the question of monetary policy, he stuck to his principle of rejecting platinum as an economically useful currency base.[31] As for mineral resources, he was particularly interested in the gold deposits. As such, the published results included a precise statistical record of gold mining and the net costs of gold mining in the Ural Mountains compared to Brazil, thus indirectly documenting some weaknesses of the Russian mining activities.[32] As a natural scientist, Humboldt also wanted to determine heights, measure geomagnetism and the climate, investigate the geological problem of volcanism and carry out surveys of flora and fauna. But a trip to Russia was always likely to be subject to central directives and state control, and so a traveller never knew whether they were being protected or monitored on the way. Humboldt travelled as a state guest, receiving the attention of officials everywhere. He wrote to his brother:

> The government's precautions for our trip cannot be pronounced, an eternal greeting, forerunner and ancestor of police officers, administrators, Cossack guards set up! Unfortunately, however, also almost no moment of being alone, no step, without being led completely like a sick person under the armpit![33]

Or from Kazan:

> We were held up with a feast. We have to leave tomorrow morning at 5 o'clock, and the professors and officials threaten to come at 4 ½ to say goodbye. They won't let us go for a moment![34]

---

30 Péaud (2011; 2014, p. 145).

31 In 1838 A.v. Humboldt published a treatise "*Die Schwankungen der Goldproduktion mit Rücksicht auf staatswirtschaftliche Probleme*" ["The fluctuations in gold production with regard to state economic problems"] in the German Quarterly Bulletins, in which he once again commented on the precious metal basis of currencies.

32 Humboldt (1869, p. 123ff); quoted by Beck (1959, p. 57f).

33 „Die Vorsorge der Regierung für unsere Reise ist nicht auszusprechen, ein ewiges Begrüssen, Vorreiten und Vorfahren von Polizeileuten, Administratoren, Kosakenwachen aufgestellt! Leider aber auch fast kein Augenblick des Alleinseins, kein Schritt, ohne dass man ganz wie ein Kranker unter der Achsel geführt wird!" (Humboldt 1880, p. 186; 2009, p. LIV); on the ambivalence of state welfare (cf. Péaud 2014, pp. 142–143).

34 „Man hielt uns noch mit einem Festessen auf. Wir müssen morgen früh um 5 Uhr abreisen, und die Professoren und Beamten drohen, um 4 ½ Uhr zum Abschied zu erscheinen. Man läßt uns keinen Augenblick los!" Alexander von Humboldt to Wilhelm von Humboldt on 27.5./8.6.1829 (Humboldt 2009, p. XLVIII).

After returning from the mines near Bogoslovski to Yekaterinburg, he stressed how that very care and control could become a burden:

> My health, although not all moments of a trip to Siberia are equally pleasant, keeps the terrible mosquitoes, the bumps in the Quibitkas and the eternal visits of degrading carriers. That's the Orinoco plus epaulettes.[35]

And from Barnaul he relayed on 4 August 1829: "Unfortunately, for our security the great and all-too-gracious care of the government is increasing our escort daily […]"[36] To Cancrin, on the other hand, Humboldt spoke only of the "most praiseworthy courtesy of all authorities".[37] In the letters to the Minister, he also referred to observations made during the trip, regularly mentioning his measurements and findings from the mines he had visited. And to his friend François Arago in Paris, Humboldt wrote from Ust'-Kamenogorsk on the Irtysh, dated 1/13 August 1829, of the "greatest order" in which the journey was being conducted.

> I cannot help but interpret all this as a sign of goodwill and personal esteem: It is a public bow to science, a noble generosity in favor of the progress of modern civilization.[38]

But Humboldt knew how to evade too much care: he changed the route twice and could often be found leaving his quarters to take measurements on a nearby hill. This, along with contact with the population, were viewed with suspicion: the police master of a smaller town is said to have sent a report to the Governor General of Tobol'sk that Humboldt cared less about the dignitaries of the town than about Poles and political prisoners. In addition, Humboldt caused a sensation when he climbed a hill and set up strange devices that appeared like small guns.[39]

The tsarist empire's concern for the famous explorer also had positive aspects: Humboldt was able to maintain correspondence with his family back in Prussia and scientists during the whole length of his journey. He received letters from Prussia within a relatively short time and was able to ask his brother to send letters to him and his companions, the passage of which was streamlined by the postal director in Memel, Johannes Heinrich Goldbeck, who bundled them and forwarded them on to

---

[35] „Meine Gesundheit hält sich, obgleich nicht alle Momente einer Sibirienreise gleich angenehm sind, die schrecklichen Mücken, die Stöße in den Quibitkas und die ewigen Besuche von Degenträgern. Das ist der Orinoko plus Epauletten." Alexander von Humboldt to Wilhelm von Humboldt on July 2/14, 1829 (Humboldt 2009, p. LXXIII).

[36] „Leider vermehrt die grosse und allzugütige Sorgfalt der Regierung für unsere Sicherheit täglich unsere Begleitung." (Humboldt 1880, p. 198; 2009, p. XCV).

[37] Humboldt to Cancrin 5./17.7.1829 (Humboldt 2009, p. LXXIII).

[38] „Ich kann nicht umhin, dies alles als Anzeichen des Wohlwollens und der persönlichen Wertschätzung zu interpretieren: Es handelt sich um eine öffentliche Verbeugung vor der Wissenschaft, um eine edle Freigiebigkeit zugunsten des Fortschritts der modernen Zivilisation." (Humboldt 2009, p. CI).

[39] Beck (1984, p. 164f).

the Russian postal director Konstantin Jakovlevich Bulgakov, "who always knows where we are".[40]

The Power of Science: Diplomacy or Crossing Borders? Humboldt and Human Rights

Humboldt lived in the tradition of the Enlightenment and promoted the extension of human rights, as he had explained in his *Essai politique sur le Royaume de la Nouvelle Espagne*. The Russian journey required special diplomatic tactfulness; Humboldt had to adhere to the rules of the game, which he had no part in formulating. Whilst he did not hold a diplomatic position, he did travel with the privileges of a diplomat: he was always received with high respect and did not fail to show respect to representatives of all other ethnic groups and nationalities, including the Chinese border post and the Kalmyk prince Sered-Djab.[41] Gustav Rose's account highlights not only the noble respect Humboldt paid to his hosts, but also his curiosity about foreign cultures. Wherever the travelling party came into contact with members of non-Russian ethnic groups, Humboldt showed great interest in foreign cultures; this applies to the games put on by the Tatars near Kazan and by the Kazakhs near Orenburg, staged for their distinguished guest, as well as to merchants from very different ethnic groups in Astrakhan, whose department stores Rose describes in detail.[42] Humboldt met them not only in the caravanserais, but also at a reception given in his honour, and he mentioned the encounter in a letter to his brother Wilhelm as enriching his imagination.[43]

Humboldt also showed diplomatic skill in his letters to Cancrin; this is particularly evident in the letter of 11/23 July 1829, in which he tries to make the "little detour" plausible. The excursion up to the Chinese border might well have been taken up in St. Petersburg with reservations. Humboldt therefore does not refrain from pointing out the scientific gain:

> … we are hopefully that we can find finally some rare specimens of the animal and plant kingdom near the Chinese Mongolia.[44]

How far could Humboldt go in asking critical questions? In his letters to Cancrin, he went into details about the condition of the mines he had visited and combined references to technical deficiencies with suggestions for improvements.

---

[40] Humboldt an seinen Bruder Wilhelm am May 10, 1929 (Humboldt 2009, p. XXIII) („der immer weiss, wo wir uns aufhalten").

[41] Rose in Humboldt (2009, pp. CX and CXCIV).

[42] Rose in Humboldt (2009, pp. CLXXIV–CLXXVIII).

[43] Humboldt (2009, p. CLXXX).

[44] „…wir haben die Hoffnung in der Nähe der chinesischen Mongoley endlich einmal einige seltene Producte des Their- und Pflanzenreichs aufzufinden" (Humboldt to Cancrin on July 11/23, 1829 (Humboldt 2009, p. LXXXV)).

In the letter to Cancrin that summarized the results of the visit to the Ural mining region, Humboldt addressed the lack of a meaningful division of labour ("non-separation of occupations"), itself stemming from the predicament of the "lower classes".[45] Apart from this, Humboldt was also occupied by the widespread destruction of forests through mining; in this regard, although a supporter of economic liberalism, he saw a growing discrepancy between economy and ecology.[46] In fact, Cancrin responded to these indications and by 1830 he drafted a forestry law, which he then immediately sent to Humboldt.[47] At the conclusion of the mining expeditions in the Urals, the scientist wrote to Cancrin, emphasizing that orders would be followed on the subject of his and the mineralogist Rose's future publications:

> It goes without saying that we will both confine ourselves only to the dead nature and avoid everything that refers to human institutions and the behavior of the lower classes: for what foreigners, ignorant of the language, bring into the world is always reckless, incorrect and, with such a complicated machine as the relations and once acquired rights of the higher classes and the duties of the lower classes, provocative without being of any use![48]

No close contacts were established with political prisoners on the way,[49] although Humboldt had expressed wishes to do so.[50] He noted in his written papers several times that he had been told about exiled persons.[51] After his return, he successfully stood up to Tsar Nikolai regarding the exiled Pole, Johann Witkiewicz and two other young Poles.[52] Aged 14, Witkiewicz (Russian: Vitkevich), who came

---

[45] Humboldt (2009, p. LXXV).

[46] Lippert (2002) refers to analogous observations and conclusions made by Humboldt during his South American journey.

[47] Perepiska Aleksandra Gumbol'dta … (1962, pp. 104–105).

[48] „Es versteht sich von selbst, dass wir uns beide nur auf die todte Natur beschränken und alles vermeiden was sich auf Menschen-Einrichtungen, Verhältnisse der untern Volks-Klassen bezieht: was Fremde, der Sprache unkundige, darüber in die Welt bringen, ist immer gewagt, unrichtig und bei einer so complicirten Maschine, als die Verhältnisse und einmal erworbenen Rechte der höhern Stände und die Pflichten der untern darbieten, aufreizend ohne auf irgend eine Weise zu nüzen!" Humboldt to Cancrin 5./17.7.1829 (Humboldt 2009, p. LXXIV).

[49] Rose reports that the tour group encountered a transport of exiled persons at Perm and thus became aware of the banishment to Siberia (Beck 1961, p. 108; 1984, p. 64).

[50] In the copper mines of Bogoslovsk, travellers were only able to follow a water tunnel for a short distance, because afterwards the path was blocked by an iron grid, which was supposed to prevent the prisoners working there from fleeing (Beck 1961, p. 118 according to Rose 1837, p. 418, I).

[51] In Humboldts handwritten notes, we find remarks like: „8000 Seelen, Kühe, Möbel genommen, je 300 weggeschleppt, ohne Kirche. Nicht zur revis. eingeschriebene schuldlos nach Sibirien. Freiheit praescrib., wenn aus Irrthum auf Liste." ("8,000 souls, cows, furniture taken, 300 taken away, without church. Registered in Siberia, guiltless, not for revision. Freedom praescrib. if erroneously on list.") (Humboldt 2009, p. 791).

[52] Biermann and Suckow (1996), Beck (1959a, p. 82), quotes Alexander von Humboldt's correspondence with Heinrich Berghaus from the years 1825–1858, Leipzig 1863, vol. II, p. 279ff; reprinted by Beck (1959, p. 116ff).

from a rich Polish family, had been arrested and taken to Orsk in the South Urals. Despite having the third volume of Humboldt's *Essai politique sur le Royaume de la Nouvelle Espagne*, a visit from Humboldt came about more by chance; that didn't stop Humboldt from quickly recognizing that Witkiewicz was as an educated man, indeed one who had learned Kazakh, Persian and Arabic in exile. Later to join the Russian service, Witkiewicz visited Kabul in 1835 where he had contact with the British traveller Alexander Burnes, who was exploring the possibilities of approaching Afghanistan on behalf of the British crown. Witkiewicz, having been drawn into the beginnings of the Great Game between Russia and the British Empire for supremacy in Central Asia, returned to St Petersburg, where he took his own life—possibly for the lack of recognition of his efforts.[53]

In Ust'-Kamenogorsk, the highly educated Decembrist Stephan Mikhailovitch Semyonov had been assigned as a companion to Humboldt by the local administration for the several-day detour to the Russian–Chinese border. Humboldt does not mention him, but Semyonov's existence and travel with him are considered historical. Like with Witkiewicz, Humboldt raised the topic of Semyonov with the Tsar after returning to St. Petersburg, but without success. On the contrary: in this case the Tsar is said to have been so enraged about Semyonov having been assigned to Humboldt as a companion that he insisted on punishing the exile and local administrative officials. Later, however, Semyonov was transferred from Ust'-Kamenogorsk, where he had only received a minimal salary, to somewhat better paid positions in Omsk, Turinsk and Tobol'sk. In the dedication Humboldt prefaced in his work, Asie Centrale, the overly exuberant praise for the Russian Tsar can also be read as a hidden irony, as the "free development of mental faculties" nominally granted to him was limited to observation, but denied for action; the freedom to travel was related to space, not to people: "Your Imperial Majesty did not deign to give me any prescriptions as to the areas I wished to visit".[54]

As had been shown, Humboldt had to experience the limits of Enlightenment liberalism. Once his handwritten notes have been fully evaluated as part of the long-term project by the Berlin-Brandenburg Academy of Sciences and Humanities and the University of Potsdam in Digital Humanities, we will probably know more about Humboldt's view on the more negative sides of his journey. The official travel report that Humboldt gave in Berlin on 25 April 1830 satisfied the demands of political correctness and circumvented human rights issues. Humboldt was muzzled from speaking out about the treatment of workers.

[53] Vitkiewicz's materials collected in Afghanistan were not published (Beck 1959, p. 491; Humboldt 2009, p. CXXXVI).

[54] Quoted from the German edition 1844/2009: „die freie Entwicklung der geistigen Fähigkeiten"; „Eure Kaiserliche Majestät geruhten, mir keinerlei Vorschriften zu machen hinsichtlich der Gegenden, die ich besuchen wolle." (Humboldt 2009, p. 7).

Results of the Journey to Russia and Siberia

Humboldt only processed partial results in later works, above all in the three-volume work, *Asie Centrale*, and, with a few passing comments, in his overall summary written later, *Kosmos*.[55] Only fragments from the time immediately after the journey, which hardly touch the economic and social aspect, originate from him.[56] The main material Humboldt included in the publication of single articles were measurements and tabular surveys, but not the politically explosive aspects of the social conditions of miners, political prisoners and exiles, nor more generally that of human rights. In this respect, Humboldt toed the line that had been set by Cancrin at the beginning of his expedition.

In summary, three essential achievements can be seen in this journey to Russia and Siberia:

First, for the second time in his life Humboldt carried out a major expedition, which did not equal the South American journey in duration and intensity, but nevertheless provided essential insights into the interior of the Eurasian continent and the high mountains of Central Asia. However, in his later work *Kosmos* the focus was very much on the general and the abstract, rather than the following through with comparisons between the mountain ranges in Asia and South America, which had been his initial intention. Second, Humboldt established new and deepened already existing contacts, mirroring a modern-day concern for international collaboration, although the extent to which Russia as a European state was integrated into the international scientific community must also be emphasized. Third, Humboldt appeared as an enlightened advocate of modern humanism, which also raised social questions and dealt with the lot of political exile, but this commitment is more difficult to grasp than the technical and resource-oriented side of the journey.

Looking at the wider historical and political context, Humboldt's Russian–Siberian journey falls into the period of incipient nationalism in the European world of states, one which had been reconfigured by the Congress of Vienna. Humboldt still lived in the world of the Enlightenment, emphasizing the unifying aspects of science and the common ground of European cultural tradition. His exploratory work during the expedition benefited the Russian state, which he travelled through as a de facto envoy of Prussia, due both to the dynastic connection between the Prussian royal house and the Russian Tsar's court and to the activities of numerous German and German-Baltic scientists contracted by Russia.

Humboldt's view of the world emerges from the combination of the three above-mentioned areas, to which the results of the journey can be assigned, and which were later written down in *Kosmos*. It is characterized by a tension that includes many levels of the world of experience and essential spiritual–historical currents of the time. It ranges from down-to-earth geography, which is reflected in

---

[55] Humboldt (1844a, b; 1845–1862).

[56] Humboldt (1831).

geological–mineralogical inventories, to liberal economics and the ideas of Enlightenment and Classicism, which are reflected in the enforcement of human rights. It is only in the combined approach that Humboldt finds the comprehensive groundwork for his science. Humboldt thus seems to be the predecessor to physical geography, but pigeonholing him to specific sub-disciplines does not do justice to his approach. Instead, according to Humboldt, a holistic view of science was needed, one that combined both the natural sciences and the humanities and set abstract guiding principles, inspired by the Enlightenment, alongside concrete action.

In his personal assessment, Humboldt described the "detour" to the Altai as the more important part of his journey—although duty-bound to visit mines in the Ural Mountains, he was his own master during the subsequent tour of the Altai and could decide on the direction and purpose of travel. Humboldt wrote:

> The Ural Mountains are of course very important for mining, but the real joy of an Asian journey was brought to us by the Altai Kolivan, Sirianovsky and Bukhtorma.[57]

In Russia, however, Humboldt also made clear the political limits to a scientist's mission. Where they are reached, Humboldt is more coy, arriving at a more modest assessment of his journey:

> A Siberian journey is not as delightful as a South American one, but one has the feeling that one has undertaken something useful and travelled a long way through a country.[58]

After completion of the manuscript for this article, a digital edition of Humboldt's diaries of the journey to Russia and Siberia was made accessible as part of the project "Humboldt auf Reisen – Wissenschaft aus der Bewegung" of the Berlin-Brandenburg Academy of Sciences and Humanities (Kraft, Tobias, Florian Schnee [eds.] (2020): Fragmente des Sibirischen Reise-Journals 1829; https://edition-humboldt.de/reisetagebuecher/index.xql?id=H0018417).

References

Aranda, K., A. Förster, Ch. Suckow [eds.] (2014): Alexander von Humboldt und Russland. Berlin: De Gruyter (Beiträge zur Alexander-von-Humboldt-Forschung; 31)

Beck, H. (1959/61): Alexander von Humboldt. Bd. I: Von der Bildungsreise zur Forschungsreise. Bd. II: Vom Reisewerk zum "Kosmos", 1804–1859. Wiesbaden: F. Steiner

[57] "Der Ural ist freilich bergmännisch von großer Wichtigkeit, aber die eigentliche Freude einer asiatischen Reise hat uns doch erst der Altai Koliwan, Sirianofski und Buchtorma verschaft." (Humboldt from Omsk to Cancrin on August 27, 1929, quoted from Suckow 2014, p. 68).

[58] „Eine Sibirische Reise ist nicht entzückend wie eine Südamerikanische, aber man hat das Gefühl, etwas Nützliches unternommen und eine große Länderstrecke durchreist zu haben." (Humboldt 1880, p. 186; 2009, p. LIV).

Beck, H. (1959a): Graf Georg von Cancrin und Alexander von Humboldt. - In: Alexander von Humboldt, 14.9.1769 - 6.5.1859. Gedenkschrift zur 100. Wiederkehr seines Todestages. Berlin, pp. 69–82
Beck, H. (1984): Alexander von Humboldts Reise durchs Baltikum nach Russland und Sibirien 1829. Aufgezeichnet von Hanno Beck. 2. verb. Aufl. Stuttgart: Thienemann
Biermann, K.-R., Ch. Suckow (1996): Aus dem Nachlass Alexander von Humboldts: Jan Witkiewicz. – In: Sibirien: Kolonie – Region, Berlin 1996 (Berliner Jahrbuch für osteuropäische Geschichte, 1996/2), pp. 189–198
Esakov, V. A. (1960): Aleksandr Gumbol'dt v Rossii. Moskva: Izd. Akademii Nauk SSSR
Ette, O. (2007): Amerika in Asien. Alexander von Humboldts Asie centrale und die russisch-sibirische Forschungsreise im transarealen Kontext. – In: HiN – Humboldt im Netz: Internationale Zeitschrift für Humboldt-Studien VIII (14), pp. 19–40
Ette, O. (2009): Alexander von Humboldt und die Globalisierung. Das Mobile des Wissens. Frankfurt a. M. etc.: Insel
Ette, O. [Hg.] (2018): Alexander von Humboldt-Handbuch: Leben – Werk – Wirkung. Stuttgart: J. B. Metzler
Holl, Frank (2017): Alexander von Humboldt: Mein vielbewegtes Leben. Ein biographisches Porträt. Berlin: Verlag Die Andere Bibliothek
Honigmann, P. (1983): Alexander von Humboldts Journale seiner russisch-sibirischen Reise 1829. - In: Petermanns Geographische Mitteilungen 127 (2), S. 103–113
Humboldt, A.v. (1831): Fragmens de géologie et de climatologie asiatiques. Paris: Gide
Humboldt, A.v. (1844): Central-Asien. Bd. 1–2. Berlin: Klemann
Humboldt, A.v. (1844): Vergleichung astronomischer Ortsbestimmungen in Russland und Sibirien. - In: Schumachers Astronomische Nachrichten XXII, pp. 99–102
Humboldt, A.v. (1845–62): Kosmos. Bd. 1–5. Stuttgart: J.G. Cotta
[Humboldt, A.v.] (1869): Im Ural und Altai. Briefwechsel zwischen Alexander von Humboldt und Graf Georg von Cancrin aus den Jahren 1827–1832. Leipzig: Brockhaus
[Humboldt, A.v.] (1880): Briefe Alexander's von Humboldt an seinen Bruder Wilhelm. Hg. von der Familie von Humboldt in Ottmachau. Stuttgart: J.G. Cotta
Humboldt, A.v. (2009): Zentral-Asien. Untersuchungen zu den Gebirgsketten und zur vergleichenden Klimatologie. Neu bearbeitet und herausgegeben von Oliver Lubrich. Mit einer Auswahl aus Alexander von Humboldts Reisebriefen und Gustav Roses Reisebericht. Frankfurt a.M.: S. Fischer Verlag
Humboldt, A.v. (2017): Mein vielbewegtes Leben. Ein biographisches Porträt präsentiert von Frank Holl. Berlin: Verlag Die Andere Bibliothek
Humboldt, Alexander von (2019): Die Russland-Expedition. Von der Newa bis zum Altai. Herausgegeben von Oliver Lubrich. ;Mit einem Nachwort von Karl Schlögel. München: C. H. Beck
Istoriya Sibiri. Tom 2: Sibir' v sostave feodal'noy Rossii (1968). Leningrad: Nauka, Leningradskoe otdelenie
Kalesnik, S.V. (1959): Zhizn' i tvorcheski put' Aleksandra Gumbol'dta (K stoletiyu so dnja rozhdeniya). - In: Izvestiya Vsesoyuznogo Geograficheskogo Obshchestva 91 (4), pp. 313–323
Kraft, Tobias (2018): Das Russisch-Sibirische Reisewerk. – In: Ette, O. [ed.]: Alexander von Humboldt-Handbuch: Leben – Werk – Wirkung. Stuttgart, pp. 59–72
Lippert, Kathrin (2002): Alexander von Humboldt – ein Wegbereiter ökologischen Denkens? – In: Lomonosow. DAMU-Hefte 2002/2, pp. 11–16
Markin, V. (2002): Aleksandr Gumbol'dt v Amerike i v Rossii. – In: Nauka i zhizn' 2002/4, pp. 70–79
Pallas, P.S. (1771–76/1967): Reise durch verschiedene Provinzen des Russischen Reichs. Bd. 1–3 [St. Petersburg,] Graz: Akademische Druck- und Verlagsanstalt
Péaud, Laura (2011): Le politique, opérateur de la construction des savoirs géographiques modern : l'exemple des voyages d'Alexandre von Humboldt. – In: HiN – Humboldt im Netz: Internationale Zeitschrift für Humboldt-Studien XII (23), pp. 26–40

Péaud, Laura (2014): Du Mexique à l'Oural : l'expertise humboldtienne au service du politique. – In: HiN – Humboldt im Netz: Internationale Zeitschrift für Humboldt-Studien XV (29), pp. 140–150
Péaud, Laura (2016): La géographie, émergence d'un champs scietifique: France, Prusse et Grande-Bretagne 1780–1860. Lyon: ENS Éditions (Thèse de doctorat 2014, Université Lumière Lyon 2, Université de Lyon)
Perepiska Aleksandra Gumbol'dta c učenymi i gosudarstvennymi dejateljami Rossii (1962). Moskva: Izd. Akademii nauk SSSR
Rose, G. (1837–42): Mineralogisch-geognostische Reise nach dem Ural, dem Altai und dem Kaspischen Meere. Bd. 1–2. Berlin: Sandersche Buchhandlung
Roussanova, Elena (2013): Hermann Trautschold und die Ehrung Alexander von Humboldts in Russland. - In: HiN - Humboldt im Netz. Internationale Zeitschrift für Humboldt-Studien XIV, 27,pp. 36–54
Stams, W. (1979): Alexander von Humbolts [sic!] Reise zur Mitte Asiens. Zur Erinnerung an seine Forschungsreise durch Rußland vor 150 Jahren. - In: Geographische Berichte 24 (4), pp. 241–253
Suckow, Ch. (1994): Die russisch-sibirische Reise Alexander von Humboldts - eine "mineralogisch-geognostische Reise"? - In: *Studia Fribergensia. Vorträge des Alexander-von-Humboldt-Kolloquiums in Freiberg vom 8. bis 10. November 1991 …* (1994). Berlin (= Beiträge zur Alexander-von-Humboldt-Forschung; 18), pp. 303–307
Suckow, Ch. (2014): Alexander von Humboldt in Ust'-Kamenogorsk. – In: HiN – Humboldt im Netz: Internationale Zeitschrift für Humboldt-Studien XV (29), pp. 61–72
Treue, W. (1990): Alexander von Humboldts Sibirienreise. - In: Lindgren, U. (ed.): Alexander von Humboldt: Weltbild und Wirkung auf die Wissenschaften. Köln, Wien (= Bayreuther Historische Kolloquien; 4), pp. 151–167
Wolff, H. (1959): Die Sibirische Reise von Alexander von Humboldt im Jahre 1829. - In: Wissenschaftliche Zeitschrift der Martin-Luther-Universität Halle-Wittenberg, Math.-Nat. VIII (6), pp. 1127–1136

Jörg Stadelbauer is professor emeritus at Albert-Ludwigs-Universität Freiburg, where he has held the professorship for Geography and Regional Studies since 1991. His research focuses on the transformation processes in Russia and other successor states of the Soviet Union, aspects of Political Geography, the development of cultural landscapes in rural areas of Baden-Württemberg and aspects of high mountain research. He also chaired of the Commission on "Diversity on Mountain Systems" of the International Geographical Union.

An Epilogue

This paper is dedicated with profound gratitude to two people:

to my life-long friend and colleague Hasan Nuzhet Dalfes, an ardent admirer of Alexander von Humboldt and a latter-day imitator of his way of doing science who drilled into my head since our youth von Humboldt's unique importance, on the occasion of his retirement from active teaching at the ITU

and

to Andrea Wulf for reminding the world that today, if we wish to avoid a global catastrophe that might destroy the human race, or even all life on this planet, we ought to emulate the way Alexander von Humboldt tried to understand Nature.

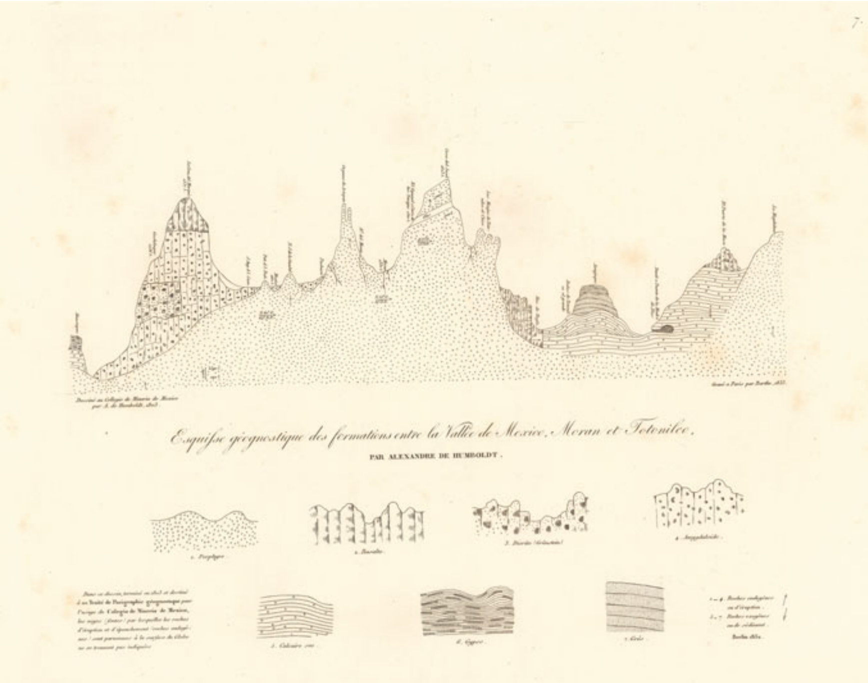


Fig. 1 Tableau geognostique des formations de roches entre la villee de Mexico, Moran et Totonilco. Voyage de MM. Alexandre de Humboldt et Aime Bonpland. Atlas Geographique et Physique, pour Accompagner la Relation Historique. Sixieme livraison. Paris, J. Smith, Rue Montmorency, No. 16; Londres, Dulau et Compie., Soho-Square. 1831. Imprimerie de J. Smith. (Courtesy of David Rumsey Collection)

Alexander von Humboldt—Dilettante of Natural History or Oracle of Modern Science?

A. M. Celâl Şengör

This chapter is dedicated with profound gratitude to two people:

on the occasion of his retirement from active teaching at the ITU, to my lifelong friend and colleague Hasan Nüzhet Dalfes, an ardent admirer of Alexander von Humboldt and a latter-day imitator of his way of doing science who drilled into my head since our youth von Humboldt's unique importance

and

to Andrea Wulf for reminding the world that today, if we wish to avoid a global catastrophe that might destroy the human race, or even all life on this planet, we ought to emulate the way Alexander von Humboldt tried to understand Nature.

Abstract The fame of Alexander von Humboldt has declined in the measure that observational sciences lost prestige as against theoretical sciences. This state of affairs is a result of the mistaken view that theoretical sciences deal with 'predictable generalities' while observational sciences study 'contingent particulars', whereas any scientific statement checked against an insufficient number of observations, be it about the entire universe or, say, about biological evolution on one planet, or even about the history of development of one mountain belt, has precisely the same logical structure. The mistaken view has stemmed in part from the inapposite proposal on the 'hierarchy of sciences' by Auguste Comte in his *Cours de Philosophie Positive*. Popular opinion has long contrasted the way Alexander von Humboldt did science in a 'Baconian' way with Einstein's way of doing science in an almost 'Cartesian' way. When examined closely, it is seen that

Present Address:
A. M. C. Şengör (✉)
ITU Eurasia Institute of Earth Sciences and Geology Department, Faculty of Mines, Istanbul, Turkey
e-mail: sengor@itu.edu.tr

G. C. Falk et al. (eds.), *Alexander von Humboldt*,
https://doi.org/10.1007/978-3-030-94008-9_11

this dichotomy is unreal and that both men were trying to solve different problems, both ultimately a part of the larger human project of understanding Nature, and both used essentially the same approach to do it (albeit in different languages: von Humboldt's natural, Einstein's formal), namely putting forward hypotheses and testing them with observation statements with a view to formulating ever better and more comprehensive models of the world around us, including ourselves. This unrealistic polarity assumed to be present in the character of science has had a negative influence on the policies of funding agencies and scientific journals, especially since the collapse, in the twentieth century, of the European colonial empires that had immensely furthered the observational sciences, to the detriment of our understanding of the natural world.

Keywords Alexander von Humboldt · Albert Einstein · South America · Asia · Philosophy of science · History of science

> Reason, observation and experience—the holy trinity of science
>
> Robert G. Ingersoll, 1872[1]

Introduction

In 2019, the sestercentennial birthday (on 14th September) of Alexander von Humboldt was celebrated in various parts of the world. When he was alive he was considered the most famous scientist in the world and one of the most famous people in Europe. His fame was such that it made even Napoleon, in whose capital von Humboldt resided between 1807 and 1827, jealous. At no time since his death on 6 May 1859 was Alexander von Humboldt's name entirely forgotten. He remained well-known to people of culture and inspired numerous scientists, not the least Charles Darwin. Yet, beginning with the late nineteenth century, his pre-eminence had lost its glare, he had come to be regarded, especially outside his home country Germany, more of a dilettante of science than a true scientist, becoming a footnote in ever-decreasing numbers of scientific publications until the recent resurrection of his popularity. This chapter examines the reasons of the temporary eclipse of his standing in science and what that should tell us about how we regard the natural sciences today.

[1] This was published in Ingersoll, R. G., 1873, *An Oration on the Gods*: Daily Bulletin Steam Book and Job Print, Cairo, Illinois, p. 48.

Humboldt's Detractors

In 1921, the famous German science fiction writer, philosopher and satirist Alexander Moszkowski (1851–1934) published a book-length interview with Albert Einstein (1879–1955) about his theory of relativity and his view of the world in general. In the course of the interview, Moszkowski asked Einstein which great geniuses populated his scientific 'Valhalla' naming, as an example, Alexander von Humboldt. Einstein's answer was most unexpected:

> By the way, I would like to remark: as the two Humboldts were mentioned earlier, at least I would not like to count Alexander von Humboldt among the geniuses. I have repeatedly noticed that you mention that name with especial reverence …

Shocked and confused, Moszkowski replied:

> And I noticed also repeatedly, that you, Mr. Professor, gently winced. Therefore, a doubt has arisen in me. But it is difficult to get rid of orders of magnitude that one has carried around for decades. In my youth, people said "a Humboldt", as they say, "a Caesar", "a Michelangelo", to express an unsurpassable excellence. Humboldt's *Kosmos* itself was the natural history Bible for me at that time, and such memories do not remain without influence.

Einstein's response was even more surprising:

> Very understandable. But it must be borne in mind that for us, Humboldt, when we look at the great discoverers, hardly comes into consideration any more. Let us say it more clearly: he does not belong in that line. I admit that he had enormous knowledge and an admirable empathy with the natural world, reminding one of Goethe. (Moszkowski 1921, p. 60)

Do these words express a just evaluation or are they the haughty words of an arrogant theoretical physicist who had just won one of the greatest victories in science in the history of mankind? However, both top-rate scientists such as Charles Darwin (e.g. 1887, p. 247) and some lesser representatives of the world of science (e.g., Rey de Morande 1846, pp. 5–6; Biedermann 1849, p. 137) had already expressed views not dissimilar to those of Einstein.

How is it possible that such negative verdicts about Alexander von Humboldt were expressed by such a diversity of scientists? To understand it, we must take a look at the concept of science and where within it the so-called empirical or observational sciences reside with respect to the so-called theoretical sciences.

Two Kinds of Science?

What is science? So far the most satisfactory definition for science was given by the great science philosopher Sir Karl Raimund Popper, FRS, FBA, CH (1902–1994), one with which most natural scientists are in agreement. According to Popper, science is a system of thought and action in which hypothetical statements can be falsified by observation reports (Popper 1933, 1935, 1980). Among today's philosophers there is a considerable literature disagreeing totally or in part with Popper's concept of science, but the laureate theoretical physicist David Deutsch (1953–) called the objections of that opposition group 'bad philosophy' (Deutsch 2011, Chap. 2), a judgement with which I find myself in agreement. That is why I shall not discuss them any further here and refer the interested reader to Deutsch's chapter.

However, Popper joins most other philosophers of science in thinking that there is a difference between 'history', i.e. the science of investigating the past (natural *or* social), and 'natural science' studying the timeless laws of nature in general. According to that distinction, history deals with singular, contingent objects and/or events, whereas natural science deals with universally valid general concepts about mostly predictable events. This distinction led Popper to consider even Darwin's and Wallace's model of natural selection not scientific, but a 'metaphysical research programme',[2] because he thought it untestable, i.e., unfalsifiable. Popper's view of science is based on David Hume's destruction of the inductive logic in his *A Treatise of Human Nature*: 'there can be no *demonstrative* arguments to prove, *that those instances, of which we have had no experience resemble those of which we have had experience*' (Hume 1739[1978], p. 89, italics Hume's; see also Hume 1777[1902], pp. 32ff.), in other words 'an "ought" cannot be deduced from an "is"' (Grice 1970, p. 89). Hume later alluded to the implication of this truism, which Grice called 'Hume's Law', for the study of the past: 'As to past *Experience*, it can be allowed to give *direct* and *certain* information of those precise objects only, and that precise period of time, which fell under its cognizance' (Hume 1777[1902], p. 3, italics Hume's). Hume's remarks about our knowledge of the past has an extremely important implication: Hume's Law applies equally well to the past, as it does to the future. Therefore, *'Hume's Law' has a cruel symmetry in time with respect to the present* (Şengör 2001).

As pointed out above, Popper thought that the nature of the theory of natural selection was different from that of physical theories. But is that so? The argument below shows the fallacy of Popper's point concerning the difference between theoretical and observational, including historical, sciences (Şengör 2001):

Let us consider the universe to be represented by the set $\boldsymbol{U}$ of a countably infinite number of points:

$$\boldsymbol{U} = \{n\}, n = \infty$$

Let hypothesis A assert that a certain condition c obtains at all n. This means that we must make an infinite number of observations for A to be completely verified. This in turn means that the statement A with respect to $\boldsymbol{U}$ must forever remain

[2] Metaphysical, as employed in philosophy and theology, usually means 'above or after nature' (as the Greek words μετά and φύσις indicate), i.e. uninvestigable without some supernatural help, and that is how it had been used for more than two millennia since Aristotle. Popper's usage is different: he means by metaphysical those researches the statements of which may not be testable, but usable heuristically.

unverified. That is Popper's position for all hypotheses pertaining to 'generalities' in the universe (e.g. 'gravity affects space-time').

Now let a subset of the universe set $\boldsymbol{U}$ be the set $\boldsymbol{S}$ and be represented by any finite number of points larger than unity:

$$\boldsymbol{S} \subset \boldsymbol{U} \,\text{and}\, \boldsymbol{S} = \{n\},\ n > 1$$

Let $\boldsymbol{S} = \{a, b\}$, where b is for some reason not ever observable (e.g., a volume of rock eroded away) and W is a hypothesis claiming that a certain condition q obtains at both a and b. This means that for W to be completely verified we must observe both a and b. Since we cannot observe b, W must forever remain unverified, i.e., hypothetical, with respect to $\boldsymbol{S}$. An overwhelming number of geological theories are of this nature.

We thus see that there is no logical difference between the statement A with respect to $\boldsymbol{U}$ and the statement W with respect to $\boldsymbol{S}$. But we call all-inclusive statements that pertain to $\boldsymbol{U}$ universal, or general statements (these include 'natural laws'), but all those pertaining to $\boldsymbol{S}$ individual, or specific statements.

The preceding argument shows that *any hypothesis checked against inadequate information has exactly the same logical basis whether it applies to a general or a particular case*. This would be much easier to understand if the whole universe is considered a particular object which we are studying and that all the so-called laws of physics constitute simply our hypotheses formulated to describe this one particular universe (i.e., an individual object) to which we have access.

Humboldtian Science Versus Einsteinian Science: Any Difference?

In the light of the above discussion, let us compare the scientific accomplishments of Alexander von Humboldt and Albert Einstein. One is commonly considered to have made a very large number of observations and encouraged others to do so with a view to collecting as much quantitative data as possible to be able to facilitate comparisons connecting disparate parts of the natural world in a single comprehensive view—and failed, whereas the other is believed to have made no observations at all, yet developed an all-encompassing theory that changed humanity's basic concepts of time and space and has since been hailed by many as the greatest scientist who ever lived. This is the popular view of these two men. But now, let us look at them in somewhat greater detail.

Von Humboldt

European studies: Son of an aristocratic Prussian family, Friedrich Wilhelm Heinrich Alexander Baron von Humboldt (1769–1859) enjoyed a broad education. After his mother died in 1796, his only surviving parent at the time, he inherited a large amount of money giving him complete independence. Until 1792, he had wandered from one university to another to hear the best teachers in the subjects that his mother thought important for a future career as a high-ranking civil servant in Prussia, finally ending up in the famous mining academy in Freiberg (now *Technische Universität Bergakademie Freiberg*). While in Göttingen in 1789 he met Johann Georg Adam Forster (1754–1794), and together they travelled to Georgian England.

During this trip, von Humboldt examined the Quaternary basalts around Unkel and Linz, between Koblenz and Bonn, and decided for their 'neptunian' origin (von Humboldt 1790). This earliest scientific publication by von Humboldt already betrays the way and the style in which the mature explorer and scientist was to work: he wished to make observations with a view to deciding which of the two then competing hypotheses about the origin of basalts was right: neptunist or vulcanist. We discover further that he was a good observer making sure that he checked the observations of previous workers in the same area; for instance, he criticised the Swiss 'biblical naturalist' Jean-André Deluc (1727–1817), for seeing on outcrop what he wished to see. Von Humboldt also familiarised himself with the published literature on basalts on a global basis! The knowledge of our 21-year-old author about the problem he wished to solve is extremely impressive—reaching from antiquity to his own day. However, we note another characteristic: he shied away from making strong, definitive statements about his conclusions. He opted for the neptunian origin indeed, but after a most thorough review of the literature and in an almost timid manner. That timidity about making forceful statements on his conclusions too stayed with him all his life. In Freiberg, he was an extremely diligent student and finished a normally three-year course in only eight months and in the meantime published in 1793 his later much lauded *Florae Fribergensis Specimen Plantas Cryptogramicus Praesertim Subterraneas Exhibens* (von Humboldt 1793). This is mainly a descriptive work, but von Humboldt opens it with a careful description of the rocks and ends with a learned treatise on the place of the organisms he studied in the organic world. Here too one admires the young researcher's comprehensive knowledge of the subject he treats, ranging from antique to modern authors and from chemistry to botany and his predisposition to see things as parts of Nature writ large.

Between 1792 and 1797 he was Assessor of Mines in the service of the Prussian State, not only enlarging his knowledge of the rocks and the bureaucracy involved in mining, but also deepening his concern for the lot of the poor people working in mines under conditions he thought needed improvement. This phase of his life has been admirably described by Klein (2012) and I refer the interested reader to her article. In the conclusion of her paper, Klein (2012) asks how should one classify a man like von Humboldt? She tries to find the answer in the diversity of things von

Humboldt did and concludes that he was a typical member of a class of people at the time who had a well-rounded education in addition to being skilful in technical matters. They were savant-technological experts in her words. I prefer to seek an answer to Klein's question through a different route, namely by considering the questions von Humboldt was trying to answer between 1792 and 1797. What did he think were the questions that really mattered? A short quote from a letter that Klein cites pretty much answers my query: 'I am destined for practical mining, which I love because it brings me closer to direct observation of nature' (Klein 2012, p. 65). What is important in this statement is not its first part, which destiny remained unrealised, but the second part where he enunciates his main aim: direct observation of Nature. So, his main desire was to quench his thirst for an understanding of Nature. Did he just 'look' at Nature? Yes and no. He always went after questions: whether when studying the Unkel basalts or when describing the subterranean flora in Freiberg or indeed considering the improvement of the lot of the workers in Prussian mines (see, especially, Bunge, 1969). Such questions were about limited problems; but as he came into contact with Nature more, he hit upon the idea of understanding how everything in Nature is related to one another and how Nature worked as a single unit. Understanding the functioning of Nature as a whole, i.e. as a unified entity, became the problem—and his most important discovery[3]—determining the central purpose of his life. He felt the lack of such a comprehensive approach among the natural philosophers of his time. So the statement quoted by Klein (2012) is an expression of his resolve to use local observations (first part of the statement) to penetrate into the whole of Nature (second part). At heart, the young baron was already more of a naturalist than a savant-technological expert. The mature scientist expressed the same aim in no uncertain terms:

> But the highest purpose of physical description of the earth, as already mentioned above, is the recognition of the unity in multiplicity, searching for the commonality and the inner connexions in the telluric phenomena. (von Humboldt 1845, p. 55)

After he left the service of the state, von Humboldt summarised, in a two-volume book, his experiments on what in those days was called 'irritability' i.e. responses to stimuli, of live tissues (von Humboldt 1797a, b). My concern here is why von Humboldt undertook that research. In view of his other interests at the time, it is not an obvious choice for a research problem. What was the question he asked himself? He gives us the answer in the first sentence of the (untitled) preface of his book:

> For a number of years I have been trying to compare some of the phenomena of the animal tissues with the laws of the inanimate Nature. (von Humboldt 1797a, p. 1)

[3] During his lifetime, a debate was already raging between the 'generalists' and 'specialists' in natural sciences (for an excellent account of this debate in France, see Corsi 1988; for its development in Europe in general during the eighteenth century, see Gascoigne 2003). One would expect von Humboldt to be on the side of the generalists, but his view of generality of Nature studies, based on a vast number of minute, quantitative observations and abundant help from specialists such as Cuvier, was very different from the broad-brush approach of contemporary generalists such as Buffon, Delaméterie, Daubenton, Lacepède and Lamarck.

Here again, his numerous, some of which personally harmful, experiments were directed to answer a question: to what degree the processes of life may be related to those of lifeless Nature? What helps us to get into von Humboldt's mind at the time when he wrote this book is the motto he placed on the title pages of both of the volumes, which is a quote from Francis Bacon's (1561–1626) *De Dignitate et Augmentis Scientiarum, libri IX* (1623):

> A further error is the premature and rash reduction of scientific knowledge to doctrines and methods; every time that happens science usually makes little or no progress.

This advice he obviously thought commonly sanctioned, but himself did not follow it, as he ended up reducing what he learnt from his experiments (which he acknowledged were as yet incomplete) and the methods he developed, to hypotheses, i.e. what Bacon would have called doctrines (*artes* in the Latin original). This is a very interesting contrast between what von Humboldt implies to be generally admitted to be proper and what he himself actually does. Von Humboldt was wiser than Bacon, but, possibly not to upset the prevalent inductivist fashion, tried to give the impression to his readers that he was a good follower of the Lord Chancellor (1561–1626), just like Newton had been, when he said *hypothesis non fingo*!

American studies: von Humboldt's great longing was to go on an expedition in little-known faraway lands. After his hopes of going to Upper Egypt along with the scientific corps to follow General Louis Charles Antoine Desaix de Veygoux's (1768–1800) planned expedition had been frustrated by the failure of the French invasion and a caravan journey from Tripoli to Cairo in the company of pilgrims going to Mecca could not be realised either, he obtained an unusually generous permission from the Spanish King Carlos IV (reigned 1788–1808) to tour and study whatever he wanted with his friend, the French botanist Aimé Jacques Alexandre Bonpland (1773–1858), in the Spanish colonies in Latin America and sailed on board the Spanish light frigate *Pizarro* from A Coruña at 9 o'clock in the morning on 5 June 1799 to reach South America.

On the way to America they stopped for a week in the island of Tenerife and used the opportunity to climb the famous El Teide, the 3718-m-high (a.s.l.) stratovolcano, nested in the third, i.e. the last Las Cañadas caldera (actually a giant collapse scar similar to the Valle del Bove in Mount Etna) now housing the late Pleistocene stratovolcano of Pico Viejo in addition to El Teide, visited the old garden of orchids and the newer botanical garden in Puerto La Cruz (see Gebauer 2017, for a detailed account of von Humboldt's visit to Tenerife). Both on the way to the Canaries and during their passage to South America, von Humboldt repeatedly measured the temperature of the seawater at various depths corroborating earlier reports by mariners that sea-floor highs significantly influence the temperature of the water column above them.

Von Humboldt and Bonpland spent the next four years in America touring the northern parts of South America, the northern Andes, the island of Cuba and Mexico, returning to Europe via Washington DC and arriving in Bordeaux on 3 August 1804. The results of this expedition have been enormous. Von Humboldt and Bonpland mapped areas previously unseen by Europeans, fixed numerous

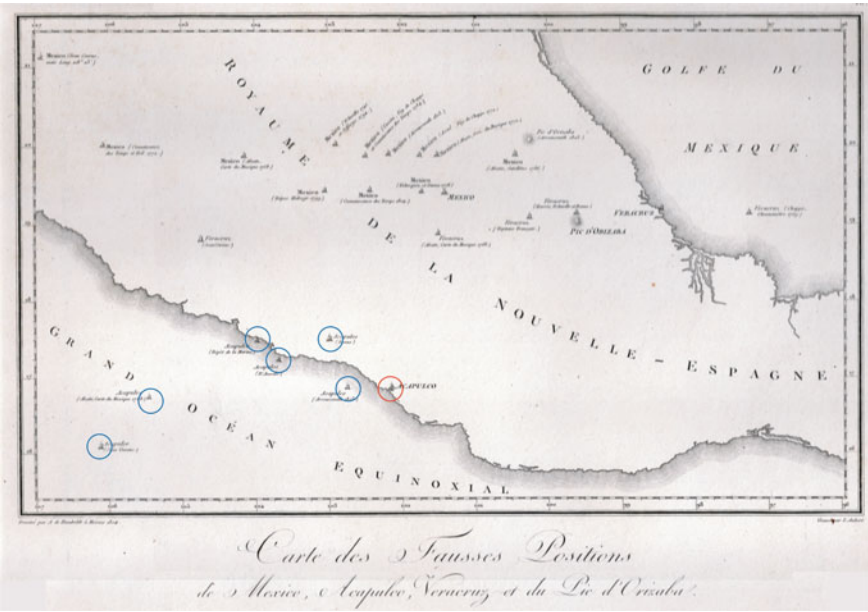


Fig. 1 The various erroneous determinations (in blue circles) of the position of the port of Acapulco in New Spain (now Mexico) compared with von Humboldt's own determination (in red circle; from von Humboldt 1811, map 10). The coloured circles are additions by the author

astronomically determined locations, measured elevations, confirmed the presence of such astonishing geographical features as the natural canal of the *Casiquiare* connecting the vast drainage basins of the Orinoco and the Amazon, at the time a subject of incredulity among the most respectable geographers (see de Humboldt 1805, pp. X–XI), climbed the then-known highest mountain, the giant volcano of Chimborazo up to 5575 m a.s.l. (not the 5844 m he claimed as shown by Edward Whymper in 1891, p. 94) where their ascent was blocked by an unbridgeable abyss (for a delightful account and a collection of most of the documents relating to that ascent, see Lubrich and Ette 2006; see also Whymper 1891–1892, for more of the technical details) and corrected many earlier maps even in the supposedly better-known Mexico (Fig. 1).

They garnered a rich harvest of specimens both from the living and inanimate kingdoms of nature.

I think, what von Humboldt and Bonpland accomplished in terms of new discoveries and observations in the Atlantic Ocean and in Latin America would have been quite sufficient to make both of them immortal in the annals of natural history. Had Alexander von Humboldt left his endeavours as mere expedition reports, then Einstein's, Rey de Morande's, Biedermann's and Darwin's separate verdicts would have been perfectly justified. But, von Humboldt's greatness begins after he had returned from Latin America and began evaluating his observations!

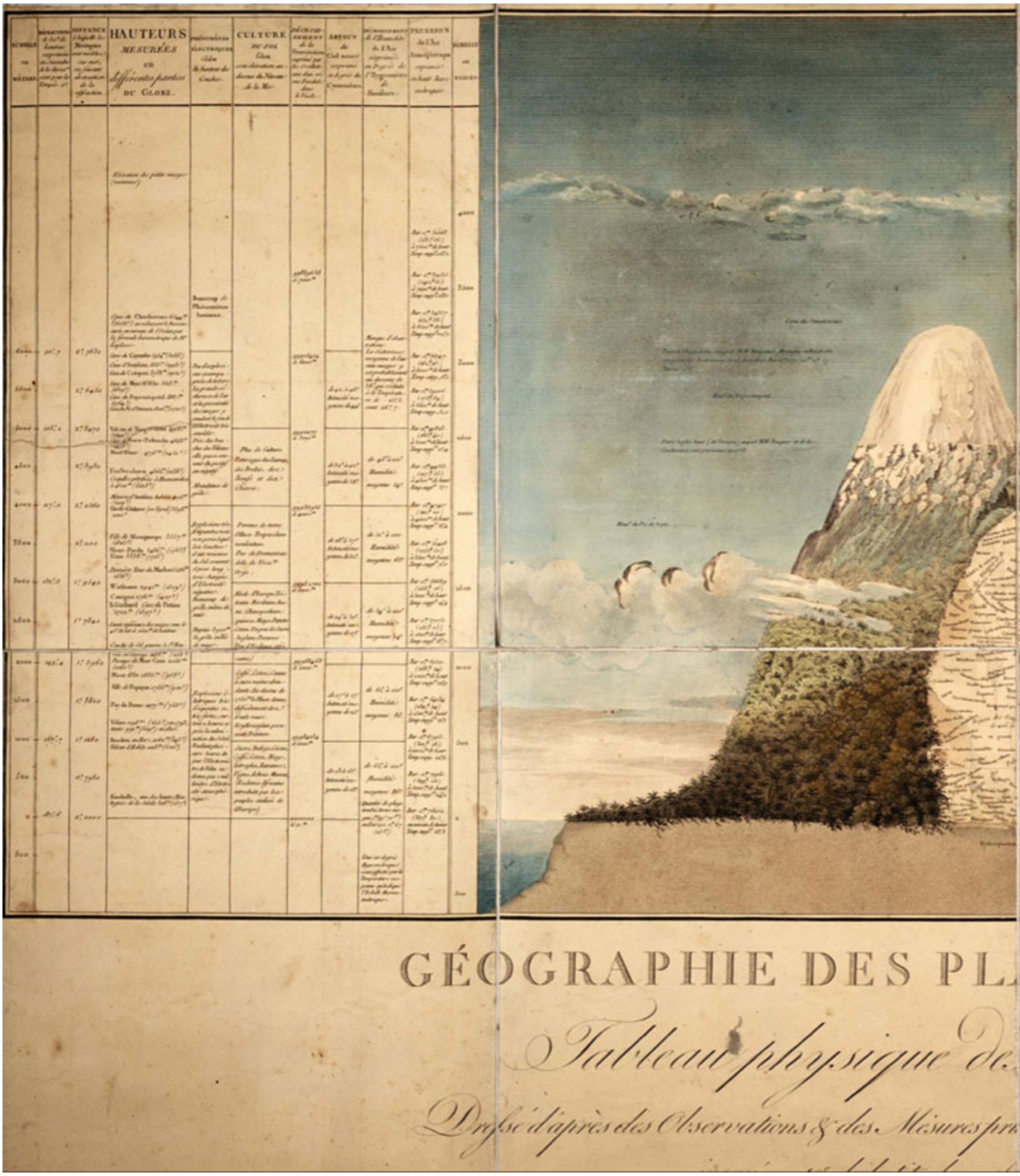
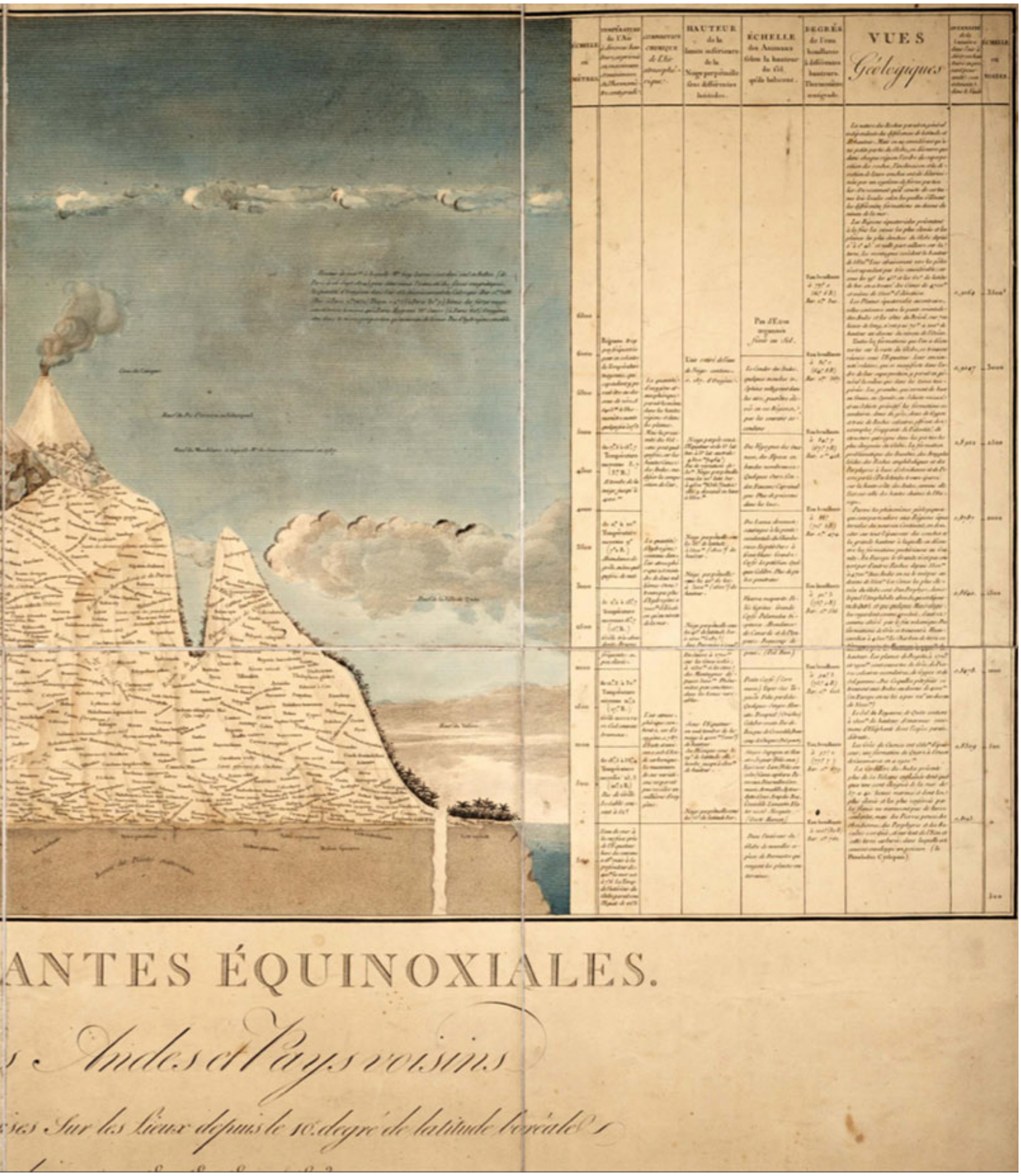


Fig. 2 Alexander von Humboldt's magnificent and justly famous *Tableau Physique des Andes et Pays Voisins* illustrating the *Géographie des Plantes Équinoxiales* published in his *Essai sur la Géographie des Plantes* (von Humboldt 1805). The publication of the book and the stunning *Tableau* is generally considered marking the birth of biogeography. *Source* https://www.biodiversitylibrary.org/item/37872#page/155/mode/1up



In the first major publication that followed his return to Europe, the famous *Essai sur la Géographie des Plantes* (von Humboldt 1805), he wrote in the preface that the public expected a narrative of the expedition from him, but

> before talking about myself and the obstacles that I overcame during the course of my operations, it would be better to draw the attention of the physicists[4] to the grand phenomena that Nature displays in the regions I traversed. (p. V)

Figure 2 is von Humboldt's famous *Tableau Physique des Andes et Pays Voisins* illustrating the *Géographie des Plantes Équinoxiales* published in his *Essai sur la Géographie des Plantes* (von Humboldt 1805). This is quite an astonishing diagram in its details. In the fine print under the main title it says that what is on display is a summary of the observations and measurements between 10° N and 10° S latitudes made during the years 1799–1803. What the *Tableau* represents is a composite picture, (von Humboldt emphasises this on his p. 54) but it is composite of even more than just the two volcanoes shown. The *Tableau* displays mountain heights on which to show at what altitudes which specific plants were found; that the two volcanoes are depicted is because it is on these giants reaching higher than any other mountain known then that von Humboldt and Bonpland made their highest altitude collections.

Now let us look at von Humboldt's diagram in some more detail: one reads many plant names placed according to altitude, even some subterranean ones. But there is more: von Humboldt distinguished 'regions' defined by altitude: the 'region of lichens and Umbilicaria' (actually this is also a lichen) between 4800 and 4400 m, is the highest region. Next lower is the habitat of *Poaceae* or *Gramineae*, i.e. grasses (*le Paxonal*, referring to alpine lawns or small grasses: see von Humboldt 1843b, p. 342), between 4600 and 4100 m. Below that, down to about 2000 m is the region of Chuquiraga shrubs and gentian herbs; von Humboldt noted that the lower part of this region is also the upper limit of trees. I do not wish to fatigue the reader by continuing to list von Humboldt's regions indicated in his diagram, except to point out that he marked the upper limit of the genus *Cinchona* (LINNAEUS 1742), the plant which has been the main source of quinine until its artificial synthesis in 1944 and thus of the greatest importance to colonial administrators of his day.

Von Humboldt's diagram is flanked by a number of columns (Fig. 2) From left to right they show the following (1) scale in metres; (2) refraction of light in the atmosphere at an altitude of 50° [i.e. the angle subtended by the height of the Sun from the horizon] at a temperature of 0° (which temperature scale is used is not given, but it is Celsius); (3) distance at which mountains are visible at sea disregarding refraction; (4) altitudes measured at different places on the globe; (5) electrical phenomena observed according to the height of the layers [of the atmosphere]; (6) culture of the soil as a function of its elevation above sea-level; (7) decrease of gravity measured by the oscillations of the same pendulum in void; (8) the intensity of the blueness of the sky measured by a cyanometer; (9) decrease of the humidity of the air in degrees (von Humboldt here means the percentages) shown on the dial of the de Saussure hygrometer; (10) scale in toises

[4] Every time von Humboldt writes 'physicists', read 'natural scientists', physics being used in its original ancient Greek meaning (φύσις; *phusis*), namely Nature.

[1 toise = about 2 m; in France, 1 toise was exactly 2 m from 1812 to 1 January 1840]; (11) scale in metres; (12) chemical composition of the atmospheric air; (13) lower limit of the permanent snow at different latitudes; (14) scale of animals according to the altitude of the ground they inhabit; (15) temperature (in Celsius degrees) at which the water boils at different altitudes; (16) geology; (17) intensity of light at different altitudes measured against the intensity in void; (18) scale in toises. This is what one might call a complete shopping list of an ecological study. Von Humboldt placed the plants he observed in their natural environments taking into account all the parameters of those environments.[5]

One might be inclined to think, at a first glance, that this is observation and measurement for their own sake; a kind of brainless Baconian activity. But the impression of a brainless Baconian collector is dissipated quickly when one reads von Humboldt's introduction to the *Essai sur la Géographie des Plantes* between pp. 1 and 35. He begins by criticising botanists for confining their activity to discovering and naming new plants and worrying about their anatomy. But the geography of plants, he says, is at least as important and as interesting. He at length gives examples of how geography influences plant distribution and their associations. He states that if he would be so bold, he would say that the germs of the cryptogams (i.e. seedless plants, fungi and blue-green algae) are the only ones that nature develops spontaneously in all climates (von Humboldt 1805, p. 20)[6]; yet he is cautious, emphasising our ignorance of plant geography:

> We know so little of the produce of the interior of lands that we must abstain from any general conclusion; otherwise we risk falling into the same error as those geologists who constitute the entire globe on the basis of a few hills that surround them. (p. 22)

After having reviewed the present distribution of plants on earth, von Humboldt then asks himself how is it that fossils of palm trees, tree ferns, scitamineous plants, bamboo, all buried in the frozen lands of the north together with bones of elephants, tapirs, crocodiles, opossums, are found so far north? He considers several possibilities ending up with something that would not seem so outrageous to a geographer or a geologist of the late twentieth and early twenty-first century: had they been carried there by giant currents 'in a submerged world', or had the climate been different enabling these plants and animals to flourish in such high latitudes? He inclines to the second possibility, but then he says how could such a thing happen without reorientating the axis of the globe or a displacement of the stars,

[5] Moret et al. (2019) recently discovered that in this diagram von Humboldt did not everywhere use direct observations. As a result, he made errors as much as a kilometre concerning the altitudes at which certain plants occur. He later repeatedly revised his data. Therefore, Moret et al. (2019) emphasise that their 'findings reveal a generalized misinterpretation of Humboldt's most iconic work' and that their 'results show the cautious approach needed to interpret historical data and to use them as a resource for documenting environmental changes' (p. 12889).

[6] The French word 'germe' here used by von Humboldt does not mean the word germ in English in its medical meaning. His reference here is to germination, i.e., formation and development of a biological entity, especially of lower organisms. Some use spores, and others reproduce simply by cellular division.

which he says, astronomy assures us are improbable. He then considers that if the whole earth was once covered with water and all the rocks crystallised from it (at the time a viable suggestion by neptunists, in the most eminent school of whom he had been trained), that process would have released a lot of heat and thus warmed the entire globe. But then, he doubts whether that heat would have remained long without dissipating. He then thinks of changes in the intensity of the solar radiation. Was such a thing periodic or was it just a freak event, resulting from a perturbation in the planetary system? (pp. 23–24). It would be interesting to know whether Milutin Milanković (1879–1958) ever read or heard about this statement in his student days in Vienna.

These are not appropriate thoughts for a Baconian. Von Humboldt was weighing theories in the light of the available evidence. We shall see below that he did the same for geology. In the rest of his *Essai sur la Géographie des Plantes* he explicates in detail his *Tableau*. But he ends his introduction with one of the main conclusions of his book:

> The great height of some areas near the equator give their inhabitants the curious spectacle of the vegetation the forms of which are the same as those in Europe. (p. 33)

Contrary to common opinion, this observation was not original, having been first made by the French botanist and explorer Joseph Pitton de Tournefort (1656–1708) during his expedition from Trabzon along the Turkish Black Sea coast to the snow line of Mt. Ağrı (de Tournefort 1717), as already pointed out in von Humboldt's lifetime by Cotta (1848, p. 280). When von Linné postulated, instead of Noah's Ark, a very high mountain near the equator being better able to protect pairs of animals of all climes from the Biblical Flood, he was aware of Tournefort's observation (von Linné 1744). Von Humboldt's superiority was the precision and accuracy of his measurement of the elevations and the careful recording of the locations of his specimens (notwithstanding the valid point made by Moret et al. 2019). That is why the observation that as one ascends in the atmosphere one goes through analogues of the climate belts of the earth has so often been ascribed to him.

Von Humboldt opens the discussion of his *Tableau* by pointing out how vegetation changes with altitude. He then remarked that a similar change is observed in the geology, with rocks becoming progressively older as the altitude increases (a misconception that was a result of his neptunist training and the inability of dating the rocks he saw). This was followed by a comparison of different plant assemblages in different latitudes and their correlation with the altitude at the equator. He is careful to point out, however, that the change in plant communities as one goes from the equator northwards is not always what one expects. In Mexico, for instance, he noticed plants that cannot grow at corresponding altitudes at the equator. This, he says, is a function of climate influenced not only by the atmospheric circulation and precipitation, but also by the temperature of the oceanic currents along the shores of different lands. He ends up by pointing out that the culture of the soil is also dependent on climate, because climate changes with latitude (p. 141).

Von Humboldt's *Essai sur la Géographie des Plantes* thus created not only a new science, namely the geography of plants, but introduced a new way of looking at nature (as Darwin later explicitly acknowledged: Darwin 1903, p. 26). He showed that it was possible to be very eclectic in making observations without becoming a jack-of-all trades yet master of none. His interest was not diffuse, as he is often accused of, but pointed to one object: Nature; he showed that it was possible, even for one individual, to embrace the whole of Nature within the limits of contemporary science, and that any other way would result in a crippled understanding.

Von Humboldt knew, however, that climate was not simply a function of latitude. He emphasised that one had to make observations and measurements to understand the spatio-temporal distribution of factors that influence climate. He rightly thought that temperature of the atmosphere was by far the most important among all the factors affecting climate. To be able to see at a glance the distribution of temperature on the globe, he hit upon the idea of connecting points of equal mean annual temperature with continuous lines, as he had earlier devised in 1804, with the great French physicist Jean-Paptiste Biot (1774–1862), the *isodynamic lines* (from the Ancient Greek ἴσος (*isos*) meaning equal and δύναμις (*dynamis*) meaning power or strength; also called isogams) for connecting points of equal horizontal magnetic intensity (Beck 1961, pp. 3–5). He published the first map of lines of equal temperature of the world in 1817 and called the lines *isotherm* from *isos* and θέρμη (*therme*), i.e. warmth (de Humboldt 1817; Munzar 1967). Munzar (1967) also pointed out that von Humboldt's map included, in addition to the mean annual isotherms also the mean temperatures of the coldest and warmest months noted for some places. Despite the paucity of observations available to von Humboldt and the sources of error he discussed, his map showed, for the first time, the azonal distribution of temperature (and hence climate). The map also showed the systematic difference in the mean annual temperatures between the eastern and western coasts of continents. Von Humboldt thus became the founder of modern observational quantitative climatology. In fact, Munzar (1967, p. 361) says 'The determination of the azonal character of isotherms meant a drastic change in the view of the climate of our planet; the difference between the mathematical and real climate was demonstrated'. One wonders what Einstein would have said to this.

Von Humboldt recognised that factors other than climate also influenced the distribution of plants. Another factor he considered was geology. He had some ideas in geology that to us seem very odd today, yet they were hypotheses to be tested. In geology too, he was not just a collector of information, but a theoretician in his own right and also an astute critic of some of the very important geological theories of his time.

Between the month of February and 23 July 1800, von Humboldt and Bonpland explored much of Venezuela and found and mapped the Casiquiare canal. They made a number of smaller expeditions afterwards until November, when they left for Cuba. After all those expeditions, von Humboldt wrote a 'Geognostical sketch of South America' that was published in the *Annalen der Physik* in 1804. I here copy the second paragraph of that letter (the publication was in form of a letter) that outlines von Humboldt's hopes concerning his geological studies in South America:

> Should I be so lucky to be able to return to Europe and revise my geognostical manuscripts that I left in France and Germany, then I may be able to state something general about the *structure of the earth*. Then my earlier assertion will be seen to be confirmed, that the strike and dip of the layers of the primitive rocks, i.e., the angle they make with the meridian of the locality and with the axis of the earth are *independent* of the direction and slopes of the mountain ranges and rather follow laws and a general parallelism that can only be caused by attraction and the rotation of the earth. It will be then seen further, that the order of the *Flötz*[7] layers, believed to be peculiar in such highly deformed provinces such as Thuringia and Derbyshire, represents a general phenomenon (as [Johann Carl] Freisleben [1774–1846], von Buch and [Johann Samuel von] Gruner [1766–1824] already established) and that in these formations there is an *identity of layers* resulting from the deposition of the same sediments at the same times on the entire surface of the earth. These ideas are highly interesting not only for the physicist, but also for the miners, who have to evaluate things based on analogies and which would lead to a *reliable science* that would be entirely *descriptive* and a picture of the earth *as it is* and not according to its mode of origin. (von Humboldt 1804, pp. 401–402, italics von Humboldt's)

This is not a plan for a collector, but a research programme to establish a theory. The theory was almost entirely neptunistic, supplemented with von Humboldt's idea of the persistence of the loxodromic strike directions the world over supposedly resulting from gravity and the rotation of the globe, supported with a firm Baconian conviction that description alone would lead to knowledge and understanding, a faith which he had inherited from Werner (see his statement in von Humboldt 1823, pp. 1–2). Von Humboldt noticed that the general strike of the Coastal Cordillera of Venezuela is generally east-northeast and was delighted to realise that this strike was parallel with the strike of the basement fabric in the Erzgebirge in Germany (*Erzgebirgische Richtung* of the older German mining and geological literature), at the northeastern edge of which Freiberg is located.

By the time von Humboldt felt ready to present a synthesis of his geological observations, he had given up his loxodromic hypothesis, instead concentrating on the sequence of rocks seen in diverse parts of the globe in a small book entitled *Essai Géognostique sur le Gisement des Roches dans les deux Hémisphères* (von Humboldt 1823). His book is a monument to his knowledge, but not to his understanding, of geology, in which he was severely handicapped by his neptunistic training. Although he no longer subscribed to Werner's idea that rock type reflected time of origin, he still wanted to use rock type for correlation between different parts of the world. For example, he asked can 'the' (i.e. 'a particular') micaschist seen among 'primitive' rocks in one place be found among 'secondary' rocks in another. He stated that he had never seen such a case himself (von Humboldt 1823, p. 18), which is hard to believe bearing in mind the regions he wandered in, both in

[7] The German term *Flötz* is difficult to translate into other languages. It is an old miners' term meaning flat-lying or very gently dipping sedimentary layers, not very thick and usually containing economically valuable minerals or plant remains. *Flötz* is believed to stem from the Old High German (spoken roughly between the eighth and eleventh centuries) word *flezzi* meaning tabular.

the Americas and in Europe; but he was shackled by the general Wernerian stratigraphy of Primitive, Transition, Secondary and Tertiary rocks. Consequently, his *Essai Géognostique* fell flat, although it was immediately translated into English and German, but unlike his extremely influential geographical works, had negligible influence on the development of geology. This is a shame, however, because in this book there is a remarkable critique of biostratigraphy. Between pp. 34 and 46 von Humboldt first discusses the difficulties of identifying the fossils at the species level, but then says, this difficulty can be overcome if the fossils are sufficiently well-preserved. However, when he considers the present geography of the globe and the distribution of climates he points out that an animal and plant assemblage in one climatic zone may not have any member in a different climatic zone and thus difference in fossil content may not always mean difference in age. Von Humboldt argued that the same is true concerning differences between biotas on different continents. Neither is he entirely convinced that sameness of fossil content in rocks means sameness of age; he thinks of animal migrations, climate changes etc. that mobilise entire animal communities that thus may appear at different times in different places.

Because of such doubts, von Humboldt tries to use the mineralogical content of the rocks and their relations of superposition, considered generally constant, for correlation. He is not against biostratigraphy, but recommends caution. Regrettably, his concerns fell on deaf ears in the general euphoria of the immense success of biostratigraphy in identifying strata.

Asian studies: Von Humboldt's next, and last, great expedition was to Asia. After his return from America, he became convinced of the essential correctness of his friend Leopold von Buch's elevation hypothesis and became an early convert to Élie de Beaumont's ideas on mountain-building mainly on the basis of his personal observations, his own hypotheses on the Andes of South America and his later studies on the Cordilleran chains in general plus, of course, in the framework of his Wernerian schooling in the best miner's tradition in Europe. Two observations were critical for shaping von Humboldt's ideas in tectonics: one was that the Andean Cordillera was a volcanic mountain range par excellence. The other was that it was continuous along the trend, as the term 'cordillera' (= little ribbon!) so appositely expresses. Von Humboldt followed his friend Leopold von Buch's theory in postulating a fissure along the trend of every mountain range, along which the uplifting augite porphyry magma had welled up and raised the mountainous edifice (see von Buch 1827[1877], for example). In those days, most fissures (and faults) were drawn as broken straight lines (a leftover from the central European mining tradition that always drew mineralised veins and the faults that offset them as broken straight lines), and the assumption that mountain belts would have not only continuous, but also straight trends (a leftover from the straight mountain trends in Ptolemy's Γεωγραφιχή Υφήγησις: *Geographike Uphegesis*, i.e. Manual of Geography, second century CE), seemed very reasonable. Élie de Beaumont inherited this view and, true to his miner's training, assumed that any two parallel mountains (i.e. fractures in his mind) would be of the same age, as any two parallel veins would be in a mine.

All of this very strongly appealed to von Humboldt, but his ideas in tectonics were not the only, not even the main, reason why he wanted to go to Asia. Even before Élie de Beaumont's influential paper appeared, he had long wished to study the Himalaya. He wanted mainly to check the elevation of the snow line and compare it with his Andean observations. But the Napoleonic wars, his deteriorating financial situation, the repeated delays in the publication of his mammoth 14-book work (in 28 separate volumes) on the American expedition had not permitted him to realise this dream. A first opportunity had presented itself in 1811, when Russia organised an expedition to Tibet via Kashgar. Von Humboldt was invited and accepted enthusiastically, but Napoleon's invasion of Russia made the trip impractical.

A second opportunity had been created by the Prussian King Friedrich Wilhelm III (1770–1840) in 1816 to go to India, but could not come to fruition presumably because of the fears of the British, that a visit from a man of von Humboldt's great fame and convinced liberal stand in relation to colonialism might not be in the best interests of the Honourable East India Company's colonies in Asia (see Ette, in Knobloch et al. 2009, pp. 18–19).

These frustrated attempts at visiting Asia did at least one good, however. Von Humboldt kept his interest in Asian geology fresh, maintained close contact with noted oriental linguists. Especially fruitful was his contacts with his countryman, the polyglot scholar Heinrich Julius Klaproth (1783–1835), who at that time was working on a map of Central Asia upon the commission of the Prussian government. Klaproth had diligently studied all the Chinese and other Asian sources he could find in the rich libraries of Paris and out of these he constructed various maps of Asia including the famous four-sheet map of Central Asia (see Klaproth 1831, 1836). As recently as 1820, the French sinologist Jean-Pierre Abel-Rémusat (1788–1832), another acquaintance of von Humboldt, had written that, according to the tenth century CE Sung Dynasty Annals, Khotan is delimited to the south 'by the Blue Mountains and near the country of the Brahmins about 3000 li [one li, 里, is about half a kilometre]. To the east it is near the Tibetans. To the northwest one counts 2000 li to Kashgar. To the east of the town was the stream of the white *iu*, to the west green *iu*, more to the west the black *iu*. The source of these rivers was in the chain of mountains Kouen (Himalaya), to the 1300 li to the west of the royal town' (Abel Rémusat 1820, p. 84). Again on p. 137 we read '… Kuen-Lun mountains (the Himâlaya mountains) …'. In the preface to his book, he further underlined that the rivers emptying into the Tarim basin had their origin in the Himalaya (Abel Rémusat 1820, p. IV). Thus, after the Tien Shan had been recognised as a distinct range by von Strahlenberg (1730a, b), the Himalaya began to be confused with the Kuen-Lun, until Klaproth identified them as two separate ranges (see Päßler 2010, p. 39), where in his letter to Carl Ritter, dated to before 22 June 1832, von Humboldt wrote:

> From their works one sees how immensely Rémusat (alas! He died) and Klaproth influenced our knowledge of Asia. Without these two men, it would have never been moved forward and clarified.

His chance to check personally the tectonics of Asia finally appeared on 15 August 1827, when the conservative Russian finance minister, the German-born Egor Frantsevich Count Cancrin (1774–1845) wrote to von Humboldt to enquire whether the newly discovered platinum in the Urals (see Menschutkin 1934) might be used in coinage and the would-be relative value of platinum coins with respect to the gold and silver coins. The Minister added in a second letter dated 22 October 1827, answering von Humboldt's questions on the size of the platinum reserves and the projected yearly production, that 'the Ural would be well worth a visit for naturalistic purposes' (von Humboldt and von Cancrin 1869, p. 8). Von Humboldt answered on 19 November that platinum would be unlikely to maintain a stable value as against gold and silver as a monetary standard. He closed his letter by saying that it was his wish to pay a personal visit to the Minister in Russia:

> I picture to myself the Ural, the Ararat, which is soon to become Russian, and even the Lake Baykal, as lovely vignettes. (von Humboldt and von Cancrin 1869, p.18; Bruhns 1872, p. 435)

The Count grabbed the opportunity to invite the great geographer to Russia and the resulting trip lasted from 12 April to 28 December 1829. Von Humboldt was accompanied by two professors of the University of Berlin, the mineralogist Gustav Rose (1798–1873) and the zoologist Christian Gottfried Ehrenberg (1795–1876). The main purpose of the Russian government was 'to further science' and, as far as compatible with scientific interests, to help the Russian industry and especially mining interests (Bruhns 1872, p. 438). By river transport on the Volga, the travellers went from Nijni Novgorod to Kazan to see the Tartar ruins of Bulgari, where they collected coins of Timur and Batu Khan (Knobloch et al. 2009, p. 151). Then via Perm to Yekaterinburg on the Asiatic side of the Ural (in the vicinity of which the first platinum discoveries had been made). In one month, von Humboldt visited the central and the northern parts of the range and studied its rich mineral deposits. From Yekaterinburg they went via Tumen to Tobolsk on the Irtysh and then through the Barabansk steppes to Barnaul north of the Altay. After studying the southwestern slopes of the Altay, they continued to Ust-Kamenogorsk and, via Bukhtarminsk, they reached the Sino-Russian frontier in the Junggar basin. They even received permission to cross the frontier and visited the Mongolian border station of Baty. Von Humboldt used the opportunity to acquire some Chinese novels from the commander of the frontier station for his brother (Beck 1959, p. 107).

On the way back to Ust-Kamenogorsk the travellers saw the locality just below the confluence of the Irtysh and the Narym, between rivers Bareshnikov and Kozlovka (Hermann 1801, pp. 108–113 and Fig. 14 between pp. 108 and 109; see Rose 1837, pp. 610–613; von Humboldt 1843b, p. 306; Suess 1901, p. 205), previously described by the Austrian mining expert and geologist Benedikt F. Hermann (in Russian Ivan Filippovich German, 1755–1815), where for a distance of more than 5 km, granite overlay schists (Fig. 3).

Hermann had correctly interpreted this distribution as resulting from thrusting, but he had remained deeply puzzled by the unusual phenomenon (the existence of thrusts was unknown in those days). Von Humboldt wrote in his notebook that 'this

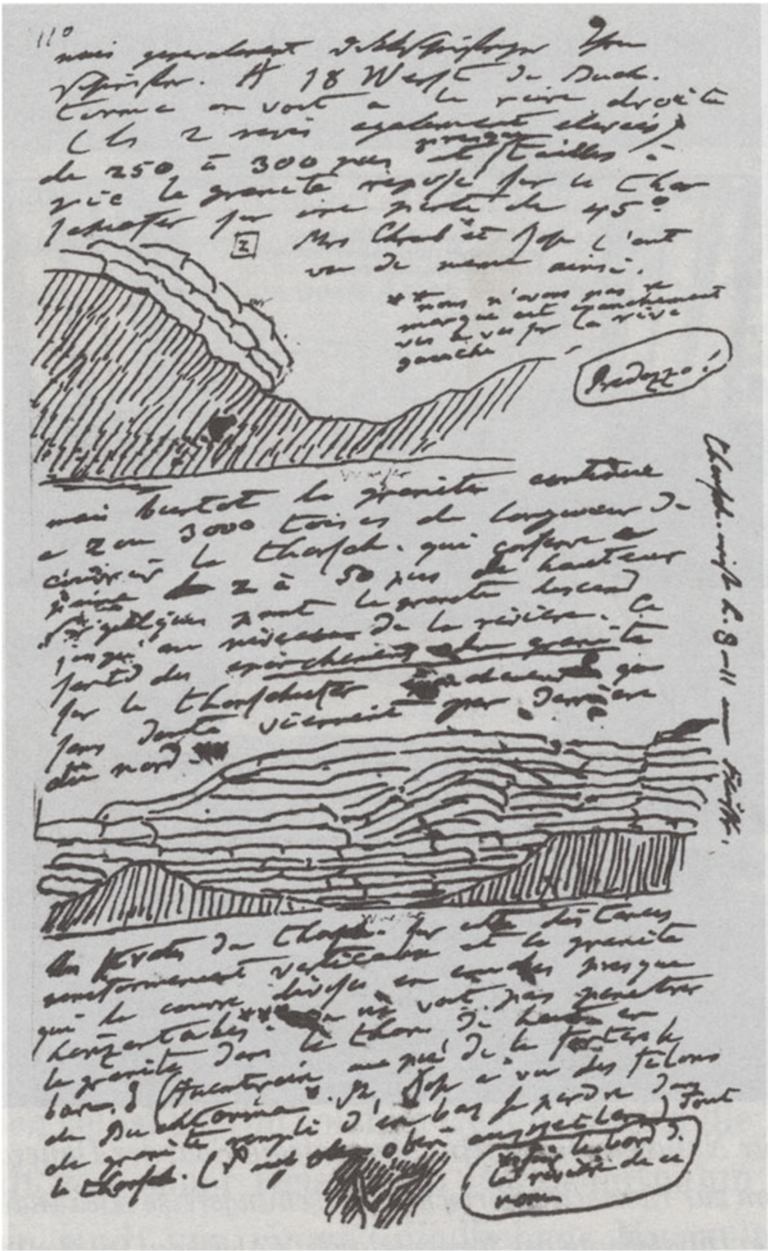


Fig. 3 A page from von Humboldt's field notebook of the Asian expedition, p. 56R (from Lubrich 2009, p. 837) showing the famous thrust fault locality along the Irtysh. In his barely legible handwriting, von Humboldt noted that 'quelques écailles (illegible) granite repose sur le (illegible) schistes sur une pente de 45° …'. Judging from his sketches and my own personal observations in the same locality, it is hardly surprising that von Humboldt missed the thrust fault and interpreted the contact as igneous

superposition of the slates by the granite, already noted by Hermann, is indubitable' (von Humboldt 1843b, p. 306). But he interpreted the contact as representing the spreading of igneous rocks over bedded sediments in an igneous relationship (von Humboldt 1843b, p. 307). I think von Humboldt's misinterpretation must have been influenced by the similar misinterpretation by Élie de Beaumont (1829) of a tectonically comparable occurrence near Dresden, where Hercynian (Palaeozoic) granite overlies across the Lausitz Overthrust, Upper Cretaceous Pläner and Quadersandstein units (Wagenbreth 1966, 1967).

From this remarkable locality, the travellers went via Semipalatinsk and Omsk to the river Ishim and thence to the southern Ural. They traversed the chain near Orsk where pretty green jasper was quarried and went to Astrakhan to collect water samples from the Caspian Sea, undertaken by Gustav Rose. From Astrakhan the travellers went back to Moscow and then to St. Petersburg (Cuvier in von Humboldt 1832, pp. 1–5), where von Humboldt was asked to give a lecture in an extraordinary session of the Academy of Sciences of St. Petersburg, on 28th (16th Old Style) November 1829, in which, after much flattery about the support the Russian Emperor had given to science and expressing his gratitude for the opportunity he was given to see first-hand a good part of the Empire, he mainly talked about the importance of the measurements of the earth's magnetism and climate parameters and mentioned the importance of setting up stations for measuring their variations in time across the vast domains of the Russian Empire (which, in those days, included Alaska), the lateral extent of which was more than the maximum width of the visible surface of the Moon (de Humboldt 1829[8]). The Czar kindly obliged!

Von Humboldt published two books on Asia; one came out shortly after he returned home and the other some 14 years later. Both were much enriched by his study of the available literature and especially by what he learnt from his orientalist colleagues in Paris. As they give the same message regarding the tectonics of Asia, I shall deal with them here together (for a modern edition of the second book plus an introduction and supporting documents, see Lubrich 2009).

The first was his *Fragmens de Géologie et de Climatologie Asiatiques*, published in two volumes in Paris in 1831 with one map at the end of volume one. That is the only one of the two books I cite here. The second was the three-volume *Asie Centrale—Recherches sur les Chaînes des Montagnes et la Climatologie Comparée* published in 1843 with an improved map at the end of v. 3. In these volumes, von Humboldt summarised his views of the structure of Asia and added a number of geologically and climatologically important observations he and others had made. He argued that four major mountain ranges of east–west trend dominate the structure of Asia (e.g. von Humboldt 1831, pp. 85, 86).

The northernmost was the Altay Mountains and as a system of mountains it extended from China to the middle of the present-day Kazakhstan ('up to the Kirgiz Steppe [of the Middle Horde]': von Humboldt 1831, p. 36). Von Humboldt pointed

[8] The text of this important address was reprinted both in Knobloch et al. (2009, pp. 267–285) and in Lubrich (2009, pp. 769–786).

out that the Altay proper had a northwest–southeast trend, but across the Irtysh it continued west in the form of unimpressive hilly country along roughly the 50° N latitude. He thought this to be of 'great interest for geognosy. There is no continuous Kirgiz mountains connecting the Altay with the Ural, which the maps indicate under the vague names of *Algydin tsano* or even *Algydin shamo*' (von Humboldt 1831, pp. 36–38; italics his; for a map of the imaginary Monts Algydim, see Huot 1837, plate 66, entitled *Sibérie ou Russie d'Asie septentrionale*). Von Humboldt's particular interest was related to the mode of formation of these mountains. Similar to Élie de Beaumont's views, he thought that parallel-trending mountain ranges must be of the same age. An east–west mountain range being a part of a north–south range would have been difficult to account for: 'We confine ourselves here to comment, on the basis of Mr. Élie de Beaumont's apposite ideas which he recently developed on the age of mountain ranges and their parallelism, that also in Inner Asia the four large east–west ranges have an entirely different origin from the northeasterners or the N30° W–S30° E trending ones. The Ural belt, the Bolor (Belur) Tagh [the reference here is to the eastern Pamirs, particularly to Muztagh Ata] the Malabrian Gates [i.e., the Western Ghats in India around the so-called 'Goa Gap'] and the Hinggan [in northeastern China] are probably younger than the Himalaya range and the Heaven-Mountains' (von Humboldt 1831, pp. 140f.). The mode of origin of the Altay system was related in terms of the elevation theory of Leopold von Buch, to which von Humboldt himself had contributed, and which had been also adopted by Élie de Beaumont.

To the south of the Altay Mountains, the great mountain range of Tien Shan, which von Humboldt thought continued eastwards into Yin Shan (which he spelled as 'In Shan') and beyond all the way to the Sino-Korean frontier, and westwards into the Caucasus, all assumed to be located on the same fissure or fault system. Von Humboldt followed the ancient Chinese geographers in assuming a meridional range, the fictitious Bolor-Tagh[9] connecting the Tien Shan with the Kuen-Lun.

[9] The Kashgar Chain, the northwestern extremity of the Kuen-Lun, is now considered to have given rise to the image of a fictitious, north–south trending Bolor Range, a name known to Europeans since Marco Polo (supposedly equivalent to the Tsung-Ling, i.e. the onion mountains or the blue mountains of the Chinese). For the etymology, see Abel-Rémusat (1820, pp. VI–VIII). Although it first appears in the western literature in Marco Polo's account (Yule 1903 {1929}, v. 1, pp. 172, 178–179; Moule and Pelliot 1938, p. 143; the latter authors spell it as Belor and Pelliot 1959, pp. 91f. says that the form Bolor is 'without authority'), Yule (1903 {1929}, pp. 178–179 and the map entitled Marco Polo's itineraries, no. III) pointed out that the name Bolor is very old, occurring already in the Buddhist monk and translator Hwen Thsang's (in Pinyin Xuan Zang) account of his pilgrimage from China to India and back in the seventh century AD (see also Cordier 1920, pp. 42–43; Pelliot 1959, pp. 91–92). Von Strahlenberg (1730b) first depicted it as a roughly north–south mountain range delimiting in the west both the Tien Shan (his Mussart) and the Himalaya. Abel-Rémusat (1820, pp. 108, n. 1, and pp. 151–152) argued that the Belur (as he wrote it) was nothing more than the western Kuen-Lun, called Karangoui Tagh (= Tenebrous Mountain in Turkish). Von Humboldt (1831) adopted von Strahlenberg's position and regarded the Bolor as one of the most important north–south orographic elements of Asia together with the Ural, the Khingan and even Kamchatka. These north–south mountain ranges supposedly housed much of Asia's mineral wealth. In his great *Asie Centrale* (1843), von Humboldt retained the interpretation of the

Indeed, he thought that the meridional ranges such as the Ural, the Bolor and the Kuznetsk Alatau carried much of the ore richness of Asia. Von Humboldt returned to the Chinese sources with the help of his sinologist friends to document that Tien Shan was an active volcanic range similar to the Andes. He thought he could unhesitatingly identify the following volcanoes, all believed active in historic times. From east to west: the volcano of Hotscheu (or Turfan), the Solfatara of Urumqi, the volcano of Aral-tubé, and the volcano of Pe Shan. These assumed volcanoes (which in reality are all coal and methane fires with typical mud volcanoes, gryphons and salses associated with paralavas and pyrometamorphic rocks) allowed him to strengthen his argument that magmatic uplift had been the chief factor in the formation of these mountains and that volcanoes did not need to be confined to seashores as some had claimed. When later observations around the western Tien Shan failed to find recent volcanic rocks, von Humboldt proved unwilling to let his favoured hypothesis die. In a letter to Sir Roderick Impey Murchison (1792–1871), then the president of the Royal Geographical Society, the ageing geographer wrote: ‘On the northern side of the great volcanic chain of Tien-Shan, they have, it is true, discovered plutonic rocks only, such as granite and gneiss, and along the edges of the great bitter lake of Central Asia (Issingul [i.e., Issik Kol, ‘warm lake’]) no trachytes (volcanic rocks) have been seen; but it must not be forgotten, that from the eastern shore of that lake to the Volcano of Peschan (the most western of the volcanoes of Tien-Shan, or The Celestial [or Heaven] Mountains) the distance, in a straight line, is not less than 250 English miles’ (Murchison 1857, p. 71).

Farther south the Kuen-Lun (or Kulkun: see von Humboldt 1831, p. 69) and the Himalaya are described to belong to two fissure systems that diverged eastwards from a single stem between the Hindu Kush and the Anatolian Taurus. Here, von Humboldt pointed out that the main easterly continuation of the Hindu Kush was not, as until then assumed, the Himalaya, but the Kuen-Lun and the Himalaya appeared as a side branch that joined the main generative fissure somewhere in the Pamir. He thus returned to the idea of a grand transcontinental Taurus of Eratosthenes, a straight mountain range that followed faithfully the 36th north parallel. Von Humboldt argued that these four east–west axes of elevation in the structure of Asia became progressively longer and better developed from north to south.

Another major structure in Asia that drew von Humboldt’s attention was the vast West Siberian Depression, which he compared with the giant craters on the Moon (von Humboldt 1831, pp. 137f.). Von Humboldt interpreted it as a counterpart of the equally impressive highland that stretched from Iran via Tibet to Mongolia and regarded the depression to be coeval with the uplift of that immense and topographically much differentiated plateau. The Ural chain he thought had to be

Bolor. Yule, among others, later pointed out, however, that the name Bolor (or Balor, Belor, Palur, Bilaur or even Malaur; for other appellations, see von Humboldt 1832, p. 32, note 2, and p. 36, note 1) really applied to a high country immediately adjoining the Pamirs to the south and that there was no independent, north–south trending Bolor as von Humboldt had imagined.

younger, for had it been older the subsidence would have long erased any expression of that low mountain range.

Von Humboldt was therefore the last great representative of what he himself called orometric geology, i.e., the inference of tectonics from the topography of a continent. Although he paid much lip service to Elie de Beaumont's stratigraphic method of dating mountain chains, he himself hardly used it. His friend Carl Ritter (1779–1859) very much followed his lead in his monumental *Erdkunde von Asien* (e.g. Ritter 1832, pp. 43–48) and von Humboldt's own *Asie Centrale* (e.g. 1843b, pp. 125 ff.) basically added nothing new to what he published in 1831.

Geology was not von Humboldt's forté. The reason for what Darwin called his 'funny' geology that 'was not in advance of his times' (Darwin 1887, p. 247) is, I think, to be looked for (1) in his training under Werner and (2) in his 'advisors' in geology later on, such as Leopold von Buch and Élie de Beaumont, two very dogmatic individuals who were not very tolerant of criticism. It is unlikely that the diplomatic von Humboldt would have wanted to cross these friends of his (note his gentle reminders to Ritter not to upset the rather volatile Klaproth: Päßler 2010, pp. 42, 48). Both of these geologists were extremely highly regarded during their lifetimes, especially in continental Europe, but not much remained of their efforts after their life was over, largely because they did not keep pace with the developments in geology after about 1830. Some of Élie de Beaumont's ideas such as the key-stone-drop origin of rifts and his method of dating of orogenies have survived well into the twentieth century, but not necessarily in circles now considered particularly progressive. It is quite extraordinary, for example, that not a single reference to James Hutton (1726–1797) is found in any of von Humboldt's writings. That Hutton was not read carefully in his immediate circle is perhaps attested by Carl Ritter's rather bungled reference to him in his *Erdkunde* (Ritter 1817, pp. 46–47; 1822, pp. 46–47) strongly suggesting second-hand knowledge, although it is hard to imagine that von Humboldt and Ritter did not discuss geology; Ritter's description of the Asian mountain ranges, for instance, is extremely Humboldtian, as mentioned above. This is very surprising indeed, because Hutton's ideas were favourably received in German geological circles in von Humboldt's time, even in Berlin (e.g. Hoffmann 1838, pp. 208–210), even in the writings of the man who made the authorised translation of von Humboldt's *Relation Historique* into German (Hauff 1840, pp. 410, 469–470).

Einstein

Albert Einstein (1879–1955) hardly needs an introduction. He is one of the greatest and without doubt one of the most famous scientists in the history of mankind and is responsible for changing our conception of the universe. He was a theoretical physicist and his approach to science has long been considered to be very different from Humboldt's approach. In order to see whether that is really so, I review below his most important contributions that inaugurated modern physics. It was in 1905, later called his *annus mirabilis*, that he published four papers that changed the face of physics and catapulted him to the position of one of the best-known scientists among physicists (Einstein 1905a, b, c, d). His very great public fame was to come later in 1919, when the prediction of his general theory of relativity (Einstein 1916), that space is deformed around a heavy object, was corroborated by showing that light bends near a massive star during the solar eclipse experiment on 29 May 1919 exactly by the amount predicted by Einstein's theory by a group led by Sir Arthur Eddington (1882–1944).

Einstein's contributions are both very easy and very difficult to explain. Easy if one states simply what he did. Extremely difficult if one tries to explain why and how he did what he did. His first paper of the *annus mirabilis* (Einstein 1905a) was simply an attempt to resolve a contradiction. He wrote:

> Whereas we consider the state of a body to be completely determined by the positions and velocities of a very large yet finite number of atoms and electrons, we make use of continuous spatial functions to determine the electromagnetic state of a volume of space, so that a finite number of quantities cannot be considered as sufficient for the complete determination of the electromagnetic state of space. According to Maxwell's theory, in all purely electromagnetic phenomena, and also in case of light, the energy is to be taken as a continuous space function, yet the energy of a ponderable substance, according to the view of the physicists today, is expressed as a sum distributed to atoms and electrons. The energy of a ponderable substance cannot be divided into an arbitrary number of pieces, yet, according to Maxwell's theory (or, more generally, according to any undulation theory) the energy of a light ray sent from a point-shaped source is distributed continuously in an expanding volume. (Einstein 1905a, p. 132)

While the wave theory, (i.e. Einstein's 'Undulationstheorie') explained optical phenomena over finite periods of time, it did not relate to instantaneous phenomena and thus may lead to discrepancies when used on light-generating or light-altering phenomena. Einstein thought that these discrepancies could be resolved if one assumed that light is not emitted in continuous waves, but in packages carrying a finite amount of energy, called 'light quanta'. This idea made use of Planck's equation $E = hv$, where E is energy, v is frequency of light waves and h is Planck's constant and showed that light energy is dependent on frequency and not on intensity. Only above a certain frequency light is capable of dislodging electrons from a surface to produce the photoelectric effect. This was another step (after Planck's) to Duke Louis Victor Pierre Raymond de Broglie's (1892–1987) thesis (de Broglie 1924) that matter could also be described as a wave and to Einstein's famous equation $E = mc^2$, published in the last of the four papers of the *annus mirabilis* (Einstein 1905d). The idea expressed in this paper, led eventually to the theory of quantum mechanics.

The difficulty in any further account of the first paper of the *annus mirabilis* concerns the explanation of the black body radiation and how it led to Planck's formulation of energy quanta in Planck's Law and the derivation of his formula $E = hv$. But the point to be made here is that Einstein's paper was written to explain certain observations, such as the photoelectric effect, for which he was awarded the Nobel Prize in physics for 1921. To come up with his explanation all the necessary observations already had been made, because the photoelectric effect is the same wherever it appears, unlike observations in biology or geology which pertain to contingent events albeit obeying general natural laws. Einstein was not trying to corroborate any law by collecting further observations; *his aim was rather to change the law* to fit the existing observations better, which, albeit eventually accepted by physicists, was not an immediate success.

In order not to lengthen this paper any more I shall not discuss Einstein's other contributions that changed the face of physics, but summarise their general character: Einstein was always interested in pursuing contradictions in current explanations that are believed to represent natural laws, i.e. those statements that are assumed true everywhere and all the time. His assumption that light is radiated not as ordinary continuous waves as the classical physics formulated it, but in funny sort of waves that can only have a certain amount of energy controlled by frequency, resulted in changing a law. Similarly, in his theory of special relativity, his assumption that the speed of light was independent of frame of reference violated a natural law (Newton's law of addition of velocities) and replaced it with a new one to explain observations classical physics could not. The same is true for his theory of general relativity (Einstein 1916) which replaced Newton's theory of gravitation with a new, much more general one to be able to explain observations that Newton's theory could not, such as the deflection of light rays in a gravitational field or the deviation from the expected precession of the perihelion of the planet Mercury (and of the other planets as well, but at the time they could not be observed). Newton's 'absolute space' and 'absolute time' could not explain either of these effects, but if one assumed space (or, rather, space–time) to be deformable, then the difficulties would vanish ('deformable space' is an extremely weird concept in itself, because, when Einstein proposed it, it literally meant the deformation of the void and interference with the flow of time). Yet this weird concept has so far stood the test of time (no pun intended).

Einstein's work was thus aimed at changing general laws that have already proved inadequate in explaining the existing observations, not collecting new observations to test the existing laws. He was not always successful in his attempts and made mistakes on the way. For example, he had to publish a correction to his first paper of the *annus mirabilis*, already the next year (Einstein 1906). Although he never liked the theory of quantum mechanics, he was unable to find an alternative (see Einstein et al. 1935).

Humboldt's approach to science can now be compared with Einstein's approach:

Discussion and Conclusions: Are There Two Kinds of Science?

Let us quote first the two ways of doing science expressed by von Humboldt and by Einstein. As already quoted above, 'von Humboldt's main objective is the physics of the world, the composition of the globe, analysis of the air, physiology of plants and animals, finally the general relations that exist between the organisms and the inanimate Nature, …' (von Humboldt 1799, p. 378). He wished to create 'a *reliable science* that would be entirely *descriptive* and a picture of the earth *as it is* and not according to its mode of origin' (von Humboldt 1804, p. 402, italics his). Is this a Baconian programme that Einstein always deprecated? Let us see what von Humboldt wrote in his only geological book: 'It is to demean the sciences to make their progress depend solely on the accumulation and study of particular phenomena' (von Humboldt 1823, p. vj). We have seen above that every time he collected data, he always had a hypothesis in mind, whether his own or somebody else's. His data were for testing them with the hope of finding better ones for a 'reliable science'. His ultimate goal was to understand Nature as a whole, to see how its various parts function and how, and to what extent, those functions depend on one another. To accomplish that task, the requisite data had not yet been collected:

> We are still a long way away from the point in time at which it might be possible to concentrate all our sensory perceptions on the unity of the concept of Nature. It may be doubtful whether this point will ever get nearer. The complexity of the problem and the immensity of the *cosmos* almost leads one to despair. But even if the whole is inaccessible to us, the partial solution to the problem, the striving to *understand* the phenomena of the world, remains the highest and eternal purpose of all natural research. (von Humboldt 1845, pp. 67–68, emphasis von Humboldt's)

That is therefore the reason that von Humboldt took it upon himself to collect as many observations as he could and encouraged others to do so with a view to improving the existing interpretations of the nature of our planet.

In his inaugural lecture before the Royal Prussian Academy of Sciences on 2 July 1914 in Berlin, Einstein outlined how he thought science is done:

> The method of the theoretician requires that as a foundation he needs general conditions, so-called principles, from which he can deduce inferences. His activity is therefore divided into two parts. First, he has to find those principles and, secondly, to develop the implications derived from the principles. For the fulfillment of the second task, he receives at school excellent tools. So, if the first of his tasks is already accomplished in a field or a complex of contexts, he will not lack success if he has sufficient diligence and understanding. The first of these tasks, namely the setting up of the principles that are to serve as a basis for deduction, is of a completely different kind. There is no learnable, systematically applicable method that leads to the goal. Rather, the researcher must, so to speak, somehow discern from Nature those principles by considering larger complexes of empirical facts with a view to finding general features that can be formulated sharply.
>
> Once this formulation is achieved, a development of inferences commences, which often yields previously unsuspected connexions, reaching well beyond the facts, on the basis of

> which the principle had been developed. As long as a principle to function as a basis of deduction is not found, the individual observations would be of no use to the theoretician. He cannot even make use of the empirically established general laws. He must stand helpless in front of the individual results of empirical research until principles are found that can serve as a basis of deductive developments. (Einstein 1914, p. 740)

Let us now ask ourselves in the light of what is said in the body of this paper: is this not precisely what von Humboldt was trying to do? Was he not trying 'somehow [to] discern from Nature those principles by considering larger complexes of empirical facts with a view to finding general features that can be formulated sharply'? So what is the difference between von Humboldt's approach and Einstein's approach? It is nothing more than the generality of the problems tackled. Einstein was able to tackle what is, as far as is now known, universal problems, because they were of a kind tractable with the available observations. Von Humboldt was after a much smaller subset of the realm Einstein considered, but the available observations were not sufficient to constrain, in David Deutsch's words, 'hard to vary' hypotheses within that subset. Von Humboldt emphasised this with the following words:

> The empirical sciences are never completed, the abundance of sensual perceptions cannot be exhausted; no generation can boast of overseeing the totality of the phenomena. Only where the phenomena are separated into groups can one recognize the rule of great and simple natural laws *in individual groups* of the same kind. The more the physical sciences develop, the more the circles of this rule expand. (von Humboldt 1845, p. 65, emphasis von Humboldt's)

Einstein's solutions could not give us a clue about how our planet functioned, because, as the great German theoretical physicist and Nobel laureate Werner Karl Heisenberg (1901–1976) very astutely observed, the more we understand general processes of Nature, the more we have to sacrifice our knowledge of the particulars (Heisenberg 1948, p. 12), i. e., as we generalise, we are prohibited, ironically, from 'overseeing the totality of the phenomena'. Einstein, with his approach, could not have dealt with the multitude of the multifarious particulars that seemed relevant to von Humboldt.

The importance of such particulars is perhaps best seen in the development of plate tectonics, a theory of the earth that now seems very unlikely to change in any drastic way in the future. In the fifties and early sixties of the twentieth century, people such as William Maurice 'Doc' Ewing (1906–1974), Sir Edward Crisp Bullard (1907–1980) and Henry William Menard (1920–1986) spearheaded campaigns of data collecting from ocean floors using decommissioned navy equipment. In the Lamont-Doherty Geological Observatory (now 'Earth Observatory') of the Columbia University in New York it was common knowledge that every time their research vessel *Vema* went out for a specific mission, Ewing insisted that it collect data on bathymetry, gravity, magnetics, cores from the sea-floor in addition to whatever the specific mission required and this 'Baconian' approach was emulated by other great marine institutions. As a consequence, especially in the United States, a vast store of ocean floor data accumulated. Additionally, in the early sixties, the United States instituted the World Wide

Standardized Seismograph Network (WWSSN) to be able to monitor Soviet nuclear tests (89 instruments by 1963 and 120 by 1967). But this network also enabled seismologists to locate and study earthquakes in the whole world with an hitherto unimaginable precision and accuracy. While this activity was going on, the American petrologist Harry Hammond Hess (1906–1963) came up in 1959 with the idea of sea-floor spreading (he was unaware of the earlier similar suggestions by the Dutch geologist Gustaaf Adolf Frederik Molengraaf 1916, 1928, and the Austrian geologist Otto Ampferer 1941) and coupled it with the previous knowledge that deep-sea trenches were surface expressions of giant thrust faults along which ocean floors descended along inclined seismic surfaces beneath magmatic arcs (e.g. Benioff 1949, 1954; Benioff in turn remained ignorant of the Dutch papers describing the inclined seismic surfaces with their isobath representations under the magmatic arcs in the Netherlands East Indies {present-day Indonesia} interpreted as giant thrust faults by Hendrik Petrus Berlage Jr. 1937 and Gerard Leonard Smit Sibinga 1937) to be able to reconcile Wegener's continental drift (Wegener 1915) with Sir Harold Jeffrey's (1891–1989) demonstration in 1924 that the strength of ocean floors would not allow continental rafts to plough through them (Hess 1962). Hess thus postulated that the ocean floors were moving with the continents. This hypothesis could be tested by using the magnetic observations so far collected because it had already been established earlier that the earth's magnetic field had flipped repeatedly and irregularly in the past and that a record of this ought to be seen on the ocean floor if it is really generated by igneous processes involving basaltic extrusion at mid-ocean ridges (Vine and Matthews 1963).

Amidst all of this activity it was not realised that Hess' hypothesis was incomplete, in that just sea-floor spreading and subduction could only generate copolar spherical gores delimited by spreading centres and subduction zones. Such spherical gores are, however, not observed. The dilemma was finally solved when Wilson pointed out in 1965 that the earth's surface was divided into a finite number of spherical caps (he called them plates) bounded by extensional ('constructive'), shortening ('destructive') and strike-slip ('conservative') boundaries. Had it not been the earlier Humboldtian style data collecting activity in the oceans and in seismology, it would have been impossible to test Wilson's hypothesis. Yet, because the data were available, it was tested and repeatedly corroborated and plate tectonics rapidly developed into the central theory of the earth sciences with implications reaching from geophysics and climatology to palaeontology and biogeography, in a way that von Humboldt could only dream of. But it did so, because of the Humboldtian style data collecting that preceded Wilson's Einsteinian creative model of plate tectonics that could thus be easily tested.

I hope that the rather long-winded discussion in this paper has made it clear that the distinction between 'observational' and 'theoretical' sciences is based on a faulty understanding of how science generally operates. There is only one kind of science and its *modus operandi* is simply generating bold hypotheses and testing them with observation reports. Hypotheses cannot be generated without audacity and creativity and they cannot be tested without diligent collection of data. As hypotheses cannot be improved without data, data cannot be gathered without hypotheses. The German physical geographer Supan (1903, p. 40) wrote that 'nothing becomes clearer when hypotheses are piled upon hypotheses' and Darwin wrote to Wallace on 22 December 1857 'I am a firm believer, that without speculation there is no good & original observation' (Burkhardt and Smith 1990, p. 35). If we reduce the above statements in reference to the two scientists discussed in this paper, we would say 'science needs both a von Humboldt and an Einstein' and, as von Humboldt pointed out, right at the beginning of the birth of science among Greek speaking peoples during the sixth and fifth centuries BCE, this duality of approach to Nature had already crystallised:

> More indifferent to the specific nature of the space-filling objects, to the qualitative difference between materials, the sense of the Italian school [he means the 'Eleatics' in Magna Graecia in southern Italy], with Doric earnestness, was directed solely to regulated design, to form and measure, while the Ionian physiologists were directed to material itself, its anticipated transformations and genetic conditions that remained the preferred subjects of research among them. (von Humboldt 1845, p. 59)

It is not for nothing that Popper once called Einstein 'Parmenides' during a discussion on determinism they had in Princeton in 1950, as he relates in his autobiography (Popper 1974, p. 102)! Charles Darwin represents the Einsteinian approach in the historical sciences. Therefore, the existence of this duality of approach is as true for theoretical physics as history. If science is to remain science, a choice between them is not possible. The bias of thinking theoretical sciences somehow 'above' the observational sciences (e.g., Comte 1830, p. 70) is in a large part due to the languages they use: the theoretical sciences use mainly the more rigorous 'formal' languages (e.g., mathematics) making their statements more precise (but not necessarily more accurate), whereas the observational sciences use mainly the looser 'natural' languages, in which the same kind of precision as in the formalised languages cannot always be expected, but that does not mean they cannot express accurate statements (see Beth 1963). When hypotheses conflict with one another in either group, *experimenta criticae* can decide which one conforms better with observations, whether it is a hypothesis in physics or in history. The immense progress that occurred in our understanding of dinosaurs and birds in the last half century is a glorious example of the latter case.

This is also an important lesson for organisations that fund scientific research in our days, many of which in the western world seem to consider field work in such areas as geology and biology 'passé' and not necessarily priority subjects for support. It is further a lesson for scientific journals that spurn 'Humboldtian' papers in favour of 'black box research'. Such attitudes are not only against the spirit of science, but may even be dangerous for the future of mankind. Recently, the German geologist Baron von Blanckenburg said in an interview concerning the global emergencies such as the CO_2 budget of the atmosphere, climate change and erosion:

> What we very generally need are much more powerful monitoring systems in which all components of the earth system would be measured with high global resolution. (von Blanckenburg and Schmidt 2020, p. 56)

One would think that he were quoting from von Humboldt's *Kosmos*!

Finally, labelling von Humboldt as a dilettante, or a 'β', in the sense his great predecessor, the man who created the term geography, Eratosthenes of Cyrene (276–194 BCE), had been called, because of his very wide-ranging interests without a specialty that allegedly would have made him appear as an 'α' in that particular field, can only be a consequence of a profound misunderstanding of the aims of science and how it operates. Von Humboldt's great genius was to recognise the interrelatedness of all terrestrial phenomena and that there were no shortcuts for reaching an understanding of these relationships; that one could not simply consider a spherical cow (cf. Harte 1988) *if understanding the cow as a cow* was one's aim; one had to study a real cow with all her environment. Hence the very great importance of Andrea Wulf's Humboldt book (2015), not only for Humbodt aficionados, but especially for everyone who has a say in the governing of the human society today.

Acknowledgements I am very grateful to Manfred Strecker, Simon Schneider and Gregor Falk for inviting this contribution as the Epilogue in this celebration of Baron Alexander von Humboldt and their understanding that a much shorter text would not have been able to emphasise and document the points I try to make. Mr. Edward Manning carefully read the entire typescript and offered useful linguistic advice.

Appendix

Complete copies of von Humboldt and Bonpland's immense expedition report to Latin America are exceedingly rare even in the best libraries. I give below a detailed citation of one of the few known complete copies, preserved in their original colours and with their original covers (10 volumes in quarto and 18 volumes in folio), from the library of Princess Louise of The Netherlands (born: Princess of Prussia: Luise Auguste Wilhelmine Amalie von Hohenzollern; 1808–1870) published by Joseph Baer & Co., antiquarian book dealers in Frankfurt am Main, in the early part of the twentieth century. Princess Luise was the daughter of the Prussian King Friedrich Wilhelm III, von Humboldt's later employer and admirer:

First Part

I. *Relation Historique*:

v. I, 1814, F. Schoell, Paris, 5 ff., 643 pp. + 1 plate

v. II, 1819, N. Maze, Paris, 4 ff and 722 pp.

v. III, 1825, J. Smith et Gide fils, 4 ff. 632 pp. + 4 plates

v. IV never published

II. *Vues des Cordillères et Monumens des Peuples Indigènes de l'Amérique (Atlas Pittoresque)*: F. Schoell, Paris, 4 11, XVI + 350 pp. + 1 f + 69 plates (21 of them coloured).

III. *Atlas Géographique et Physique des Régions Équinoxiales du Nouveau Continent, fondé sur les observations astronomiques, des mesures trigonométriques et des nivellements barométriques*: 1814–1834, Gide, Paris, 4ff, 3 and 2 ff, and 39 maps. (Published in instalments and each instalment is here preserved in its original folder).

IV. *Examen Critique de l'Histoire de la Géographie du Nouveau Continent, et des progrès de l'astronomie nautique aux quinzième et seizième siècles*: 1814–1834, Gide, Paris, 2 ff, III–IVI + 562 pp. (Published in instalments and each instalment is here preserved in its original folder).

Second Part

V. *Recueil d'observations de Zoologie et d'Anatomie Comparée Faites dans l'Océan Atlantique, dans l'Intérieur du Nouveau Continent et dans la Mer du Sud Pendant les Années 1799, 1800, 1801, 1802 et 1803*:

v. I, 1811, Schoell et Dufour, Paris, 2 ff, VIII + 368 pp. + 30 plates (of which 17 are coloured).
v. II, 1833, Smith et Gide, Paris, 2 ff, 352 pp. + plates 31–48 and 48 to 57 (of which 21 are coloured).

Third Part

VI. *Essai Politique sur le Royaume de la Nouvelle-Espagne*:

v. I, 1811, F. Schoell, Paris, 5 ff, IV, XCII pp. + pp 1–350, 3 ff.
v. II, 1811, F. schoell, Paris, 2 ff, pp. 351–904, 861bis—867 and 1f Atlas 2ff, 4 pp. + 20 maps.

Fourth Part

VII. *Recueil d'Observations Astronomiques, d'Opérations Trigonométriques et de Mesures Barométriques, Faites Pendant le Cours d'un Voyage aux Régions Équinoxiales du Nouveau Continent, depuis 1799, jusqu'en 1803—Rédigées et Calculées, d'aprés les Tables les plus exactes par Jabbo Oltmann. Ouvrage auquel on a joint des recherches historiques sur la position de plusieurs points importans pour les navigateurs et pour les géographes*, 1808–1810:

v. I., 5ff. LXXVI + 138 + 52 pp. 1f + 382 pp., 1f, + 1 plate.
v.II, 2ff, 629 pp., 1f and 1 plate.

Fifth Part

VIII. *Conspectus Longitudinum Geographicarum, per Decursum Annorum 1799 ad 1804 in Plaga Acquinoctiali ab Alexandro de Humboldt Astronomice*

Observatarum. Calculo Subjecit Jabbo Oltmanns: 1808, F. Schoell, Lutetiae Paris et Tubingae Cotta, 2 ff (16) pp. + 1 Cart.

IX. *Essai sur la Géographie des Plantes, accompagné d'un tableau physique des régions équinoxiales, fondé sur les mesures exécutées depuis le dixième degré de latitude boréale jusqu'au dixième degré de latitude australe, pendant les années 1799, 1800, 1801, 1802 et 1803*: 1807, Fr. Schoell, Paris et Tubingue, J. G. Cotta, 3ff, 155 pp. + 1 coloured plate.

Sixth Part: Botany

X. *Plantes Équinoxiales, recueilles au Mexique; dans l'île de Cuba, dans les provinces de Caracas, de Cumana et de Barcelonne, aux Andes de la Nouvelle-Grenade, de Quito et du Pérou, et sur les bords du Rio-Negro, del'Orénoque et de la rivière des Amazonas*: 1808–1809, F. Schoell, Paris et J. G. Cotta, Tubingue

v. I, 4ff, VII + 234 pp. + 68 plates
v. II, 4ff, 191 pp. + 76 plates

XI. *Monographie des Melastomacées, comprenant toute les plantes de cet ordre recueilles jusqu'à ce jour, et nottement au Mexique; dans l'île de Cuba, dans les provinces de Caracas, de Cumana et de Barcelonne, aux Andes de la Nouvelle-Grenade, de Quito et du Pérou, et sur les bords du Rio-Negro, del'Orénoque et de la rivière des Amazonas*:

v. I, 1816, *Melastomes*: Librairie Grecque-Latine-Allemande, 8ff, VI + 142 pp. + 60 coloured plates
vII, 1823, *Rhexies*: Gide fils, Paris, 4ff, II + 158 pp. + 1 l., 60 coloured plates

XII. *Nova Genera et Species Plantarum quas in peregrinatione orbis novi collegerunt, descripserunt, partim adumbraverunt Amat. Bonpyland et Alex. De Humbldt. Ex schedis autographis Amati Bonplandi in ordinem digessit Carol Sigismund Kunth. Accedunt tabulae aeri incisae, et Alexandri de Humboldt notationes ad geographiam plantarum spectantes*:

(volumes published by Librairie Grecque-Latine-Allemande):
v. I, 1815, 4ff, XLVI + 1f + 302 pp. + 97 coloured plates
v. II, 1817, 4ff, 324 pp + 96 coloured plates
v. III, 1818, 4ff, 356 pp + 133 coloured plates
(volumes published by N. Maze):
v. IV, 1820, 4ff, 247 pp + 88 coloured plates
v. V, 1821, 4ff, 338 pp + 105 coloured plates
(volumes published by Gide et fils):
v. VI, 1823, 4ff, 422 pp + 113 coloured plates
v. VII, 1825, 4ff, 399 pp + 85 coloured plates

XIII. *Mimoses et autres plantes légumineuses du nouveau continent, recueilles par MM. de Humboldt et Bonpland, décrites et publiées par Charles-Sigismond Kunth*: 1819–1824, Librairie Grecque-Latine-Allemande, Paris, 5ff, 223 pp. + 60 coloured plates.

XIV. *Révision des Graminées publiées dans la nova gnerea et species plantarum de Humboldt et Bonpland; précédée d'un travail géneral sur la famille de graminées: par Charles-Sigismond Kunth*: 1829, Gide Fils, Paris.

v. I, 4ff, 374 pp. + 100 coloured plates
Supplement, 4ff, pp. 375–666 + 1 folio table + plates 101–220.

The unfortunately undated sale catalogue of Joseph Baer & Co. (*Katalog Nr. 601*) contains also a full list of octavo-size publications pertaining to the different parts of the voyage. The famous Cuba book is among those. The entire catalogue is devoted to Alexander von Humboldt and constitutes a most valuable bibliography of publications by and on von Humboldt and a list of his portraits.

References

Abel Rémusat, [J.-P.], 1820, Histoire de la Ville de Khotan, tirée des annales de la Chine et traduite du Chinois; Suivie de Recherches sur la substance minérale appelée par les Chinois PIERRE DU IU et sur le JASPE des anciens: Imprimerie de Doublet, Paris, XVI + 240 pp.

Ampferer, O., 1941, Gedanken über das Bewegungsbild des atlantischen Raumes: Sitzungsberichte der Akademie der Wissenschaften Wien, mathematischnaturwissenschaftliche Klasse, v. 150, pp. 19–35.

Beck, H., editor, 1959, Gespräche Alexander von Humboldts: Akademie-Verlag, Berlin, 492 pp.

Beck, H., 1961, Alexander von Humboldt, v. 2 Vom Reisewerk zum "Kosmos" 1804–1859: Franz Steiner, Wiesbaden, XII+439 pp.+2 plates+1 foldout map.

Benioff, H., 1949, Seismic evidence for the fault origin of oceanic deeps: Bulletin of the Geological Society of America, v. 60, pp. 1837–1866.

Benioff, H., 1954, Orogenesis and deep crustal structure—additional evidence from seismology: Bulletin of the Geological Society of America, v. 65, pp. 385–400.

Berlage, H. P., jun., 1937, A provisional catalogue of deep-focus earthquakes in the Netherlands East Indies 1918–1936: Gerlands Beiträge zu Geophysik, v. 50, pp. 7–17

Beth, E. W., 1963, The relationship between formalised languages and natural language: Synthese, v. 15, pp. 1–16.

Biedermann, G., 1849, Die Speculative Idee in Humboldt's Kosmos—Ein Beitrag zur Vermittlung der Philosophie und der Naturforschung: I. G. Calve'sche Buchhandlung. Friedrich Tempsky, Prag, 142 pp.

von Blanckenburg, F. (Baron) and Schmidt, A., 2020, "Ohne Beispiel in der Erdgeschichte" über Geochemie, Erosion und den Klimawandel: Jahresmagazin 2020 der Berlin-Brandenburgischen Akademie der Wissenschaften, Berlin, pp. 52–59.

de Broglie, L. (Duke), 1924, A tentative theory of light quanta: Philosophical Magazine, v. 47, pp. 446–458.
Bruhns, K., editor, 1872, Alexander von Humboldt—Eine Wissenschaftliche Biographie: F. A. Brockhaus, Leipzig, v. 1, XX+480 pp.+1 frontispiece
von Buch, L. (Baron), 1827[1877], Ueber die Verbreitung grosser Alpengeschiebe: Poggendorff's Annalen der Physik und Chemie, v. 9, pp. 575–588 (reprinted in Ewald, J., Roth, J., and Dames, W. editors, Leopold von Buch's Gesammelte Schriften, v. III: G. Reimer, Berlin, pp. 659–668.)
Bunge, M., 1969, Alexander von Humboldt und die Philosophie: in Pfeiffer, H., editor, Alexander von Humboldt—Werk und Weltgeltung, R. Piper & Co., München, pp. 17–30
Burkhardt, F. and Smith, S., 1990, The Correspandence of Charles Darwin, v. 6, 1856-1857: Cambridge UniversityPress, Cambridge, xxix+[iii]+673 pp.
Cotta, B., 1848, Briefe über Alexander von Humboldt's Kosmos—Ein Commentar zu diesem Werke für Gebildete Laien: T. O. Weigel, Leipzig, X+356 pp.+1 p. errata.
Comte, A., 1830, Cours de Philosophie Positive, v. 1, Les Préliminaires Généraux et la Philosophie Mathématique: Rouen Frères, Paris, VIII+739 pp+[II]
Cordier, H., 1920, Ser Marco Polo—Notes and Addenda to Sir Henry Yule's Edition, Containing the Results of Recent Research and Discovery: John Murray, London, x+161 pp.+frontispiece
Corsi, P., 1988, The Age of Lamarck—Evolutionary Theories in France 1790–1830, revised and updated, translated by Jonathan Mandelbaum: University of California Press, Berkeley, xiii +360 pp.
Darwin, F., editor, 1887, The Life and Letters of Charles Darwin Including an Autobiographical Chapter: John Murray, London, v. 3, iv+418 pp.+ 1 frontispiece.
Darwin, F., editor, 1903, More Letters of Charles Darwin—A Record of His Work in a Series of Hitherto Unpublished Letters: John Murray, London, v. 2, viii+508 pp.+ 1 frontispiece+ 1 slip of errata.
Deutsch, D., 2011, The Beginning of Infinity—Explanations that Transform the World: Penguin, New York, [iv]+487 pp.
Einstein, A., 1905a, Über einen die Erzeugung und Verwandlung des Lichtes betreffenden heuristischen Gesichtspunkt: Annalen der Physik, v. 17, pp. 132–148.
Einstein, A., 1905b, Über die von der molekularkinetischen Theorie der Wärme geforderte Bewegung von in ruhenden Flüssigkeiten suspendierten Teilchen: Annalen der Physik, v. 17, pp. 549–560.
Einstein, A., 1905c, Zur Elektrodynamik bewegter Körper: Annalen der Physik, v. 17, pp. 26–50.
Einstein, A., 1905d, Ist die Trägheit eines Körpers von seinem Energieinhalt abhängig? Annalen der Physik, v. 17, pp. 639–641.
Einstein, A., 1906, Theorie der Lichterzeugung und Lichtabsorption: Annalen der Physik, v. 20, pp. 199–206.
Einstein, A., 1914, Antrittsrede: Sitzungsberichte der Königlich Preußischen Akademie der Wissenschaften, Jahrgang 1914, zweiter Halbband, pp. 739–742.
Einstein, A., 1916, Grundlage der allgemeinen Relativitätstheorie: Annalen der Physik, v. 49, pp. 769–822.
Einstein, A., Podolsky, B. and Rosen, N., 1935, Can quantum-mechanical description of physical reality be considered complete?: Physical Review, v. 47, pp. 777–780.
Élie de Beaumont, L., 1829, Recherches sur quelques-unes des Révolutions de la surface du globe, présentant différens exemples de coïncidence entre le redressement des couches de certains systèmes de montagnes, et les changements soudains qui ont produit les lignes de démarcation qu'on observe entre certains étages consécutifs des terrains de sédiment: Annales des Sciences Naturelles, v. 18, p. 5–25, 284–417.
Gascoigne, J., 2003, Ideas of Nature—Natural Philosophy: in, Porter, R., editor, The Cambridge History of Science, v. 4, Eighteenth-Century Science, Cambridge University Press, Cambridge, pp. 285–304.
Gebauer, A., 2017, Alexander von Humboldt, seine Woche auf Teneriffa 1799: Zech, Santa Ursula, Tenerife, 208 pp.

Grice, I. G. R., 1970, Hume's law: The Aristotelian Society, Supplementary Volume XLIV, The Symposia Read at the Joint Session of the Aristotelian Society and the Mind Association at the University of Aberdeen, 10–12 July, 1970, pp. 89–103.

Harte, J., 1988, Consider a Spherical Cow—A Course in Environmental Problem Solving: University Science Books, Mill Valley, xvi+283 pp.

Hauff, H., 1840, Skizzen aus dem Leben und der Natur. Vermischte Schriften, v. 2: J. G. Cotta, Stuttgart und Tübingen, [II]+499 pp.

Heisenberg, W., 1948, Wandlungen in den Grundlagen der Naturwissenschaft, 8. Auflage: S. Hirzel, Zürich, 112 pp.

Hermann, B. F., 1801, Mineralogische Reisen in Sibirien. Vom Jahr 1783 bis 1796. Dritter Theil: Bei der kaiserlichen Akademie der Wissenschaften, St. Petersburg, [4] + 312 pp. + 6 copper-plates and foldout tables VIII through XIV.

Hess, H. H., 1962, History of ocean basins. In Engel, A. E. J., James, H. L. and Leonard, B. F., editors, Petrologic Studies: A Volume in Honor of A. F. Buddington, Geological Society of America, New York, pp. 599–620.

Hoffmann, F., 1838, Geschichte der Geognosie und Schildering der Vulkanischen Erscheinungen —Vorlesungen gehalten an der Universität zu Berlin in den Jahren 1834 und 1835: Hinterlassene Werke von Friedrich Hoffmann, v. 2, Nicolaische Buchhandlung, Berlin, VIII +596 pp.

Hume, D., 1739[1978], A Treatise of Human Nature: Oxford, At the Clarendon Press, xix+ 743 pp. (Second ed. with text revised and notes by P. H. Nidditch)

Hume, D., 1777[1902], Enquiries concerning Human Understanding and Concerning the Principles of Morals, edited by L. A. Selby-Bigge, 2nd edition: Clarendon Press, Oxford, xl +371 pp.

de Humboldt, A. (Baron), An VIII (1799), Lettre du baron de Humboldt (de Berlin), å Jérôme Lalande: Magasin Encyclopédique ou Journal des Sciences et Lettres et des Artes, v. année, v. 6, pp. 376–391

de Humboldt, A. (Baron), 1805, Essai sur la Géographie des Plantes; Accompagné d'un Tableau Physique des Régions Équinoxiales, Fondésur des mesures exécutée, depuis le dixième degré de latitude boréale jusqu'au dixième degré de latitude australe, pendant les années 1799, 1800, 1801, 1802 et 1803: Levrault, Schoell et Compagnie, Paris, XII+155 pp.+ 1 foldout plate.

de Humboldt, A., (Baron), 1811, Atlas Géographique et Physique du Royaume de la Nouvelle-Espagne, fondé sur des observations astronomiques, des mesures trigonométriques et des nivellemens barométriques: F. Schoell, Paris,

de Humboldt, A. (Baron), 1817, Des lignes isothermes et la distribution de chaleur ser le globe: Mémoires de Physique et de Chimie de la Société d'Arcueil, v. 3, pp. 462–602.

de Humboldt, A., (Baron),1823, Essai Géognostique sur le Gisement des Roches dans les Deux Hémisphères: F. G. Levrault, Paris, viij + 379 pp.

de Humboldt, A. (Baron), 1829, Discours prononcé par M. Alexandre de Humboldt à la Séance extraordinaire de l'Académie Impériale des Sciences de St.-Pétersbourg tenue le 16/28. Novembre 1829: publié par l'Académie des Sciences, P. H. Fuss, Secrétaire perpétuel, [St.-Pétersbourg], 18 pp.

de Humboldt, A. (Baron), 1831, Fragmens de Géologie et de Climatologie Asiatiques, tome premier: Gide, A. Pihan Delaforest, Delaunay, Paris, 309 pp.

de Humboldt, A. (Baron), 1843a, Asie Centrale—Recherches sur les Chaines de Montagnes et la Climatologie Comparée, v. 3: Gide, Paris, 614 pp.+1 p. of errata+14 unnumbered plates and tables.

Huot, J.-J.-N., 1837, Atlas Complet du Précis de la Géographie Universelle de Malte-Brun, dressé conformement au texte de cet ouvrage et entièrement revu et corrigé: Aimé André, Ve le Normant, Paris, 72 maps + 16 pp. text.

von Humboldt, A. (Baron), 1790, Mineralogische Beobachtungen über einige Basalte am Rhein mit vorangeschickten, zerstreuten Bemerkungen über den Basalt der älteren und neueren Schriftsteller: Schulbuchhandlung, Braunschweig, 126 pp.

von Humboldt, A. (Baron), 1793, Florae Fribergensis Specimen Plantas Cryptogramicus Praesertim Subterraneas Exhibens: Heinrich August Rottmann, Berlin, XIV+189 pp.+1 page of addenda and corrigenda+3 plates

von Humboldt, F. A. (Baron), 1797a, Versuche über die Gereizte Muskel- und Nervenfaser nebst Vermutungen über den Chemischen Prozess des Lebens in der Thier- und Pflanzenwelt: Decker und Compagnie, Posen; H. A. Rottmann, Berlin, v. 1, 495 pp.

von Humboldt, F. A. (Baron), 1797b, Versuche über die Gereizte Muskel- und Nervenfaser nebst Vermutungen über den Chemischen Prozess des Lebens in der Thier- und Pflanzenwelt: Decker und Compagnie, Posen; H. A. Rottmann, Berlin, v. 2, 468 pp.

von Humboldt, A. (Baron), 1804, Geognostische Skizze von Südamerika: Annalen der Physik, v. 16, pp. 394–493.

von Humboldt, A. (Baron), 1832, A. v. Humboldt's Fragmente einer Geologie und Klimatologie Asiens aus dem Französischen mit Anmerkungen, einer Karte und einer Tabelle vermehrt von Julius Loewenberg: J. A. List, Berlin, 272 pp.

von Humboldt, A., (Baron), 1843b, Asie Centrale—Recherches sur les Chaînes des Montagnes et la Climatologie Comparée, tome premier: Gide, Paris, 571 pp.

von Humboldt, A., (Baron), 1843c, Asie Centrale—Recherches sur les Chaînes des Montagnes et la Climatologie Comparée, tome deuxiéme: Gide, Paris, 558 pp.

von Humboldt, A. (Baron), 1845, Kosmos. Entwurf einer Physischen Weltbeschreibung, erster Band: J. G. Cotta, Stuttgart und Tübingen, XVI+493 pp.

von Humboldt, A. (Baron), 1858, Kosmos, Entwurf einer Physischen Weltbeschreibung, vierter Band. J.G. Cotta'scher Verlag, Stuttgart und Tübingen, 649 pp.+ 1 page of errata.

von Humboldt, A., and von Cancrin, G., 1869, Im Ural und Altai—Briefwechsel zwischen Alexander von Humboldt und Graf Georg von Cancrin: F. A. Brockhaus, Leipzig, XV + 170 pp.

Jeffreys, H. (Sir), 1924, The Earth—Its Origin, History and Physical Constitution: At the University Press, cambridge, ix+[i]+278 pp.

Klaproth, J., 1831, Asia Polyglotta, zweite Auflage: Heideloff & Campe, Paris, XV + [1] + 144 + 8 pp. and Asia Polyglotta—Sprachatlas, LIX pp. of tables + 1 coloured map of Asia (dated 1923).

Klaproth, J., 1836, Carte de l'Asie Centrale Dressée d'après les cartes levées par ordre de l'Empereur Khian Loung par les Missionaires de Peking, et d'après un grand nombre de notions extraites de livres chinois par M. Jules Klaproth, 4 sheets, scale 1/2,664,000: L. Berthe, Paris.

Klein, U., 2012, The Prussian Mining Official Alexander von Humboldt: Annals of Science, v. 69, pp. 27–68.

Knobloch, E., Schwarz, I. and Suckow, C., editors, 2009, Alexander von Humboldt—Briefe aus Russland, mit einem einleitenden Essay von Ottmar Ette: Beiträge zur Alexander-von-Humboldt-Forschung, 30, Akademie Verlag, Berlin, 329+[1 pp.]

von Linné, C., 1744, Oratio de Telluris Habitabilis Incremento. Et Andreae Celsii … Oratio de Mutationibus Generalioribus quae in superficie corporum coelestium contingunt: Cornelium Haak, Lugduni Batavorum, pp 17–84.

Lubrich, O., editor, 2009, Alexander von Humboldt Zentral-Asien—Das Reisewerk zur Expedition von 1829: S. Fischer, Frankfurt am Main, CCVIII+923pp+48 pp. of documents+2 foldout maps

Lubrich, O. and Ette, O., 2006, Alexander von Humboldt—Über einen Versuch den Gipfel des Chimborazo zu ersteigen: Eichborn, Berlin, 196 pp.

Menschutkin, B. N., 1934, Discovery and early history of platinum in Russia: Journal of Chemical Education, v. 11, pp. 226–229.

Molengraaf, G. A. P., 1916, On the coral reef problem and isostasy: Proceedings of the Royal Academy at Amsterdam, v. 19, pp. 610–627.

Molengraaf, G. A. F., 1928, Wegener's continental drift: in Theory of Continental Drift—A Symposium on the Origin and Movement of Land Masses both Inter-Continental and

Intra-Continental, as Proposed by Alfred Wegener: The American Association of Petroleum Geologists, Tulsa, pp. 90–92.
Moret, P., Muriel, P., Jaramillo, R. and Dangles, O., 2019, Humboldt's Tableau Physique revisited: Proceedings of the National Academy of Sciences of the United States of America, v. 116, pp. 12889–12894.
Moule, A. C. And Pelliot, P., 1938, Marco Polo The Description of the World, v. I: Georg Routledge & Sons Limited, London, 595 pp.+ 1 colured frontispiece + 1 foldout table +1 errata slip.
Mozskowski, A., 1921, Einstein—Einblicke in Seine Gedankenwelt—Gemeinverständliche Betrachtungen über die Relativitäts-Theorie und ein Neues Welt-System Entwickelt aus Gesprächen mit Einstein: Hofmann und Campe, Hamburg/F. Fontane & Co., Berlin, 240 pp.
Munzar, J., 1967, Alexander von Humboldt and his isotherms—on the occasion of the 150th anniversary of the first map of isotherms: Weather, v. 22, pp. 360–363.
Murchison, R. I. (Sir), 1857, Address to the Royal Geographical Society of London; delivered at the anniversary meeting on the 25th May, 1857: W. Clowes and Sons, London, 116 pp.
Päßler, U., editor, 2010, Alexander von Humboldt Carl Ritter Briefwechsel: Beiträge zur Alexander-von-Humboldt-Forschung, Akademie Verlag, Berlin, 311 pp. + 2 maps hors-texte.
Pelliot, P., 1959, Notes on Marco Polo, v. I: Imprimerie Nationale, Librairie Adrien-Maisonneuve, Paris, XII+611 pp.
Popper, K. R. 1933: Ein Kriterium des empirischen Charakters theoretischer systeme (Vorläufige Mitteilung): Erkenntnis, v. 3 (Annalen der Philosophie, v. 11), pp. 426–427.
Popper, K. R., 1935, Logik der Forschung: Springer Verlag, Wien, vi + 248 pp.
Popper, K. R., 1966, The Open Society and Its Enemies, v. 2, The High Tide of Prophecy: Hegel, Marx, and the Aftermath, fifth, revised edition: Princeton University Press, Princeton, v+[i] +420 pp.
Popper, K. R., 1974, Autobiograpy: in, Schilpp, P. A., editor, The Philosophy of Karl Popper, v. I (The Library of Living Philosophers, v. 14, book I), Open Court, La Salle, Illinois, pp. 1–181.
Popper, K. R., 1980, The Logic of Scientific Discovery, tenth impression (revised): Unwin Hyman, London, 480 pp.
Rey de Morande, A.-J., 1846, Examen Critique du Cosmos de Humboldt. Avec l'Exposé d'un Nouveau Système de l'Univers Basé sur une Loi Unique et Donnant l'Explication Physique Rationelle des Principes Newtoniens: M^{me} V^{e} Bouchard-Huzard, Paris, 40 pp.
Ritter, C., 1817, Erdkunde im Verhältnis zur Natur und zur Geschichte des Menschen oder allgemeine, vergleichende Geographie, als sichere Grundlage des Studiums und Unterrichts in physicalischen und historischen Wissenschaften, erster Theil: G. Reimer, Berlin, XX+832 pp.
Ritter, C., 1822, Erdkunde im Verhältnis zur Natur und zur Geschichte des Menschen oder allgemeine, vergleichende Geographie, als sichere Grundlage des Studiums und Unterrichts in physicalischen und historischen Wissenschaften, erster Theil, erstes Buch. Afrika, zweite stark vermehrte und verbesserte Ausgabe: G. Reimer, Berlin, XXVII+1 page of errata+1084 pp.
Ritter, C., 1832, Erdkunde im Verhältnis zur Natur und zur Geschichte des Menschen oder allgemeine, vergleichende Geographie, als sichere Grundlage des Studiums und Unterrichts in physicalischen und historischen Wissenschaften, zweiter Theil, zweites Buch. Asien, v. I Der Norden und Nord-Osten von Hoch-Asien, zweite stark vermehrte und umgearbeitete Ausgabe: G. Reimer, Berlin, XXX+1143 pp.
Rose, G., 1837, Mineralogisch-Geognostische Reise nach dem Ural, dem Altai und dem Kaspischen Meere, erster Band, Reise nach dem nördlichen Ural und dem Altai: Verlag der Sanderschen Buchhandlung (C. W. Eichhoff), Berlin, XXX+641pp. + 11 plates.
Şengör, A. M. C., 2001, Is the Present the Key to the Past or the Past the Key to the Present? James Hutton and Adam Smith versus Abraham Gottlob Werner and Karl Marx in Interpreting History: Geological Society of America Special Paper 355, x+51 pp.
Smit Sibinga, G.L., 1937, On the relation between deep-focus earthquakes, gravity and morphology in the Netherlands East Indies: Gerlands Beiträge zu Geophysik, v. 51, pp. 402–409.

von Strahlenberg, J. P., 1730a, Das Nord und Östliche Theil von Europa und Asia, In so weit solches Das gantze Rußische Reich mit Siberien und der grossen Tatarey in sich begreiffet, In einer Historisch-Geographischen Beschreibung der alten und neuern Zeiten, und vielen andern unbekannten Nachrichten vorgestellet, Nebst einer noch niemahls ans Licht gegebenen Tabula polyglotta von zwey und dreißigerley Arten Tatarischer Völcker Sprachen und einem Kalmuckischen Vocabulario, Sonderlich aber Einer grossen richtigen Land-Charte von den benannten Ländern und andern verschiedenen Kupfferstichen, so die Asiatisch-Scythische Antiquität betreffen; Bey Gelegenheit der Schwedischen Kriegs-Gefangenschaft in Rußland, aus eigener sorgfältigen Erkundung, auf denen verstatteten weiten Reisen zusammen gebracht und ausgefertiget: in Verlegung des Autoris, Stockholm, 438 pp.

von Strahlenberg, J. P., 1730b[1991], Nova Descriptio Geographica Tattariae Magnae tam orientalis quam occidentalis in particularibus et generalibus Territoriis una cum Delineatione totius Imperii Russici imprimis Siberia accurate ostensa, one sheet (reprinted in 1991 in Stockholm at Gotab).

Suess, E., 1901, Das Antlitz der Erde, v. III1 (Dritter Band. Erste Hälfte): F. Tempsky, Prag and Wien, and G. Freytag, Leipzig, IV + 508 pp.

Supan, A., 1903, Grundzüge der Physischen Erdkunde, dritte, umgearbeitete und verbesserte Auflage: Veit & Comp., Leipzig, IX+I+852 pp.+ 20 maps (one fold-out).

de Tournefort, [J.], P., 1717, Relation d'un Voyage du Levant fait par ordre du Roy, tome second: Imprimerie Royale, Paris, [I]+526+unpaginated analytical contents.

Vine F. and Matthews, D. H., 1963, Magnetic anomalies over ocean ridges: Nature, v. 199, pp. 947–949.

Wagenbreth, O., 1966, Die Lausitzer Überschiebung und die Geschichte ihrer geologischen Erforschung—Teil I: Abhandlungen des Staatlichen Museums für Mineralogie und Geologie, v. 11, pp. 163–279.

Wagenbreth, O., 1967, Die Lausitzer Überschiebung und die Geschichte ihrer geologischen Erforschung—II. Teil: Abhandlungen des Staatlichen Museums für Mineralogie und Geologie, v. 12, 279–368.

Wegener, A., 1915, Die Entstehung der Kontinente und Ozeane: Friedrich Vieweg und Sohn, Braunschweig, V + 94 pp.

Whymper, E., 1891–1892, Travels Amongst the Great Andes of the Equator: John Murray, London, v. 1, xxiv+456 pp.

Wilson J. T., 1965, A new class of faults and their bearing on continental drift: Nature, v. 207, pp. 343–347.

Wulf, A., 2015, The Invention of Nature—Alexander von Humboldt's New World: Alfred A. Knopf, New York, xix+473 pp.

Yule, H. (Sir), 1903 (1929), The Book of Marco Polo the Venetian Concerning the Kingdoms and Marvels of the East, third edition, revised by H. Cordier, v I: John Murray, London, cii+462 pp. + 35 plates (some foldout)

Ali Mehmet Celâl Şengör is a retired member of the Faculty of Mines and the Eurasia Institute of Earth Sciences in the Istanbul Technical University, Department of Geology. In addition to his respected and extensive research work, for 15 years he wrote a weekly popular science column in the Turkish newspaper *Cumhuriyet* (now he writes there on a much less regular basis). Şengör is a member of the German Leopoldina—National Academy of Sciences, the Russian Academy of Sciences and the American Philosophical Society. These memberships he shares with Alexander von Humboldt. Şengör is also a member of the United States National Academy of Sciences, Academia Europaea, Austrian Academy of Sciences and the Serbian Academy of Sciences and Arts.