2.0 Agricultural Landforms

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Abstract Indigenous agriculture of the Americas has a long history as a research topic in cultural geography, cultural anthropology, and archaeology. Native peoples developed a vast range of strategies from intensive agriculture (raised fields, terracing, irrigation) to agroforestry. Over time, human activities transformed much of the environment into highly productive anthropogenic landscapes. William Denevan dedicated his career to understanding indigenous knowledge through research on the complex agricultural landforms. Two early publications explore agricultural intensification, conversion of marginal wetlands and slopes into productive spaces, role of social organization in farming, human response to climate change, and abandonment of fields. In the process, Denevan presents methodological approaches to record, classify, date, and analyze field systems that continue to be relevant.

Keywords Agricultural intensification · Agricultural landforms · Human agency
Raised fields · Terraces

Introduction

Denevan's lifelong interest in everyday farmed landscapes and the people (individuals, families, and local communities) who built and used them have inspired countless scholars to follow in his path. Denevan's interdisciplinary approach provides a means to understand how rural peoples (those "people without history" as used by Eric Wolf 1982), lived, produced, and thrived in the Americas over hundreds and thousands of years in some areas. In his research on pre-European field systems, Denevan asks basic questions of what, where, when, who, how, and why. In many cases, his and that of his student's and colleagues' individual fieldwork on agricultural landscapes answered those questions. In most cases, archaeologists, soil scientists, historians, anthropologists, agronomists, geomorphologists, and hydraulic engineers took up the task of providing answers, often as collaborative teams.

The two publications discussed are *Aboriginal Drained-Field Cultivation in the Americas* (1970) and a chapter in Denevan's 2001 volume based on his 1987 report

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("the Science article" and "the Terrace chapter"). Each represents the conclusion of two important phases of Denevan's research career: his work on raised field agriculture and terrace agriculture. I will focus on a number of important methodological approaches and theoretical frameworks that Denevan introduces and applies in these articles.

Methodological Approaches

Agricultural Landforms

Denevan applies the conceptual framework common in geography of landforms during this period of research and publication. Landforms can be natural or cultural. Geographers use the term "agricultural landforms" to refer to the physical form, character, formation, and function of past or present farming and herding systems, the common categories [forms] of human-made landforms (Golomb and Eder 1964). Other geographers subsume agricultural landforms as examples of anthropomorphology, anthropic geomorphology, anthropogene, or anthropogenic geomorphology (Szabó et al. 2010). Formal imposed, relatively permanent structures such as ridges and furrows, terraces, raised fields, and field infrastructure (e.g., walls, canals, paths, and boundary markers) are the foci (Golomb and Eder 1964; Doolittle 2000, 5–6). Contemporary archaeologists and historical ecologists refer to these physical units as gardens and fields and other agricultural landscape features at the small scale of everyday life and cultural, cultivated, domesticated, anthropogenic, terraformed, engineered, and/or humanized landscapes at the larger, sometimes regional scale (Balée and Erickson 2006). In this chapter, I will use the more modern term "agricultural landscape" (a subset of cultural landscape) rather than agricultural landform.

Denevan's research at this time was influenced by a growing knowledge of the degree and scale of human impact and transformation of the Earth (e.g., Thomas Jr. 1956). Denevan demonstrated that "simple" farming communities, given enough time, were capable of regional-scale alteration of the surface, soils, and vegetation for productive purposes. Because of an interest in pre-European demography and carrying capacity, he also could show that most of the Americas were more densely populated in the past and that farming societies existing on landscapes for millennia provided evidence that what they were doing to the surface of the earth was successful (what we would call sustainable today).

Data Collection, Mapping, and Classification

As stated in the *Science* article, Denevan's goal of investigation of raised fields in the Bolivian Amazon was to determine "the nature, number, distribution, ecological situation, and probable function of the relic ridges, as well as revealing other, associated earthworks, including mounds, causeways, and canals" (1970, 648). As a cultural geographer of the "Berkeley School," Denevan used the approaches and techniques of his time but emphasized the use of aerial photographs in addition to traditional maps to understand raised field and terrace agriculture in the Americas within an integrated system of their specific environmental, geographical, temporal, historical, and cultural context. He learned to appreciate aerial photographs in his earlier raised field research in the Bolivian Amazon (Denevan 1966). Long before GIS was available, Denevan's approach to agricultural landscapes was to assemble, organize, and query past and present maps, cadastral survey, and aerial photographs; read relevant history, archaeology, ethnography, geology, and geography to understand temporal and spatial context; describe and classify forms; and conduct targeted "ground truthing" through repeated fieldwork, often for only short periods of time. The Terrace chapter concisely summarizes this strategy.

A basic approach used in agricultural landform analysis is the mapping and classification of field forms across the landscape, sometimes at the regional scale. Denevan used classification as an initial step of analysis in the *Science* article and the Terrace chapter. Once the types are established, Denevan examines their distribution, context (topographic, ecological, and environmental), and scale to draw inferences about function and sometimes chronology. In the *Science* article, Denevan uses his and colleagues' fieldwork combined with mapping and classification to document the similarities in form and environmental context of "drained" or raised fields in wetlands and highland savannas across Latin America. In the process, he points out significant differences between and within raised field systems that relate to chronology, environmental contexts, and functions. At the same time, Denevan also distinguishes wetland raised fields from the more widespread mounding strategies used by farmers throughout the world. In the Terrace chapter, Denevan emphasizes that we must move beyond the scores of classifications proposed by previous scholars to address "ecology, functions, management, and productivity" of local terracing (Denevan 1987, 2).

Modern landscape archaeologists refer to this approach as "reading" the landscape in terms of palimpsest, associations, disjuncture, integration, boundaries, hierarchy, style, community, and territories in addressing social organization, labor, settlement, land tenure, intensification, expansion, and taskscapes (e.g., Erickson 1993; Miller and Gleason 1994; Walker 2011).

Dating and Chronology

In early research on agricultural landscapes, scholars assumed that fields could not be accurately dated; thus many "big questions" about terraces and raised fields could not be addressed. In the *Science* article, Denevan and colleagues relied on associations with dated archaeological settlements (often diagnostic pottery from the surface), now known to be less reliable than direct dating of fields. Denevan combed literature by chroniclers, explorers, missionaries, historians, and ethnographers for mention of fields to demonstrate their construction and use (and in some cases, abandonment) before the arrival of Europeans. Denevan also reasoned that the recorded colonial and present-day populations of many areas with abandoned fields would not be sufficient in number to create and manage intensive agriculture at the scale of the remains nor require such high production of food. In the Colca Valley research, Denevan and colleagues excavated trenches in abandoned terraces for recovery of stratigraphy and charcoal samples to demonstrate that direct dates of fields could be obtained through radiocarbon dating and associations with diagnostic pottery. The documentation of periods of construction, use, and abandonment were critical for addressing farmer's responses to climate change in late prehistory.

Ethnographic, Historical, and Experimental Analogy

In the *Science* article, Denevan turns to his vast knowledge of the historical, ethnographic, and agronomic literature on *chinampas*, a living although degraded example of indigenous raised field agriculture practiced by the Aztecs in late prehistory and continuing until the present, sweet potato raised fields in Baliem Valley of New Guinea, Sibundoy drained fields in Colombia, Andean lazybeds, Tlaxcala drained fields, Guató mounds in the Pantanal, and traditional mound fields in Amazonia and Africa. In later research on swidden fallow, Denevan and colleagues increasingly turned to ethnography of living farmers in the Amazon (Denevan and Padoch 1988). He also wrote about small-scale contemporary farmers that were still practicing small-scale wetland raised field agriculture (Denevan and Bergman 1975).

Because many systems of raised fields and terracing are abandoned and unused, Denevan encouraged colleagues to use experimental and applied archaeology to understand field function, energetics, and sustainability (e.g., Coolman 1986; Earls 1989; Erickson 1985; Garaycochea 1987; Gómez-Pompa et al. 1983; Puleston 1977; Ramos Vera 1986a, b; Canahua Murillo and Larico Mamani 1992; Kolata 1996; Stab and Arce 2000). Denevan argued that these experimental studies, in addition to understanding abandonment, were critical first steps in evaluating the contemporary and future use of these field systems.

Photography

Although publication at the time limited the inclusion of figures, Denevan effectively used his oblique photographs showing details of continuous raised fields in the foreground with identifiable isolated trees for scale and extending to local horizon taken from low-flying aircraft in addition to maps and aerial photographs to convince readers of the massive scale of landscape transformation. For his Colca Valley Project, Denevan obtained access to the high-resolution aerial photographs of entire valleys filled with terraces, irrigation infrastructure, and terraces from the Shippee-Johnson Expedition in 1931, in addition to later photographs. The aesthetics of highly patterned raised field and terraced landscapes as a human imposition of rigid structure on disorderly nature could easily be grasped by his audience.

Theoretical Frameworks

Political Economy and Social Organization

The level of organization required for the planning, construction, engineering, and maintenance of intensive agriculture at a large scale has long been of interest to scholars. Denevan addressed the social organization of raised fields and terracing in early articles but considered any interpretations as premature based on the information available. In later works, he stressed the agency of the farmers and their farming communities as capable of working and coordinating across generations over long periods of time.

In the *Science* article, Denevan shows that raised fields and their associated societies in the Americas are diverse. He suggests that a variety of relationships may have existed by stating:

> The aboriginal cultures responsible for drainage ranged from the seminomadic Guató, to farm villages and chiefdoms, to the high civilizations. The ridged-field farmers of the savannas were capable people but certainly not comparable to the farmers of the efficient and sophisticated states of the Andes and Mexico. Most of the drained-field systems could have been constructed and managed through small-scale family and community cooperation, as in New Guinea, rather than through central political control. On the other hand, there does seem to be a frequent relationship between degree of agricultural intensification, population size, and complexity of social organization. (Denevan 1970, 653)

Denevan avoids interpreting the mere coexistence of field systems and state societies as evidence of a direct association in terms of social organization of labor and political economy. Although recognizing the deep time and large scale of raised field and terrace agriculture, Denevan never fell into the trap of automatically assuming that the elite planned, implemented, administered, and maintained regional-scale raised fields and terraces as "top-down" state projects controlling the labor of their peasants. Denevan recognized that the periods of field use often overlapped with the presence of powerful states *and* periods after state collapse or absence of state. In the two articles, analogy is drawn from cross-cultural and local case studies to argue that small-scale societies are capable of intensive agriculture. These debates drove much of raised field research (e.g., Graffam 1990; Erickson 1993; Janusek and Kolata 2004; Bandy 2005).

Intensification

Although rarely discussed in his early work, Denevan's *Science* article concludes with a discussion of Boserup's theory of intensification that intensive agriculture is the result of increasing demographic pressure rather than the reverse causation (1965). Agreeing with the prevailing scholarly assumptions of the time, Denevan argued that marginal areas such as wetlands that require increasing labor inputs to raise production were adopted through necessity after available well-drained forest lands were filled by farmers because of higher labor costs for construction and maintenance. He also reasoned that marginal areas such as wetlands with raised fields would be the first to be abandoned with population collapse after European conquest, the condition in which they are most often found today. On the other hand, Denevan noted that land tenure changes imposed by Europeans denied indigenous farmers access to many areas where raised fields and terraces are found and cultivated by their ancestors. He also points out in the *Science* article that wetlands are attractive to early pioneering farmers as a rich source of aquatic protein, irrigation water, level surfaces, and efficient water transportation that may have trumped wetland marginality in the Boserup sense.

Denevan and colleagues realized that data about labor requirements, efficiency, production, carrying capacity, and cultivation intensity for specific field systems were necessary to test Boserup's agricultural intensification theory. Although most case studies showed evidence of large populations during periods of use, he discusses the potential problems in extrapolating population size and density based on the carrying capacity of raised fields.

Denevan explicitly addresses intensification theory in the Terrace chapter. Rather than assume that terrace abandonment means disintensification due to removal of population pressure, Denevan and colleagues' dating of the construction, use, and abandonment of terraces showed that terrace farming (a recognized form of intensive agriculture) practiced in the Middle Horizon was further intensified by retraction of cultivation to lower slopes that could be more efficiently irrigated to raise production than upper slopes as drought conditions increased in the Late Intermediate Period. This fascinating interpretation is a continuing research topic by other scholars (Treacy 1994; Guillet 1987, 1992; Trawick 2003; Gelles 2000; Wernke 2013).

Inspired by Denevan, archaeologists began to question Boserup's assumptions in later research involving experimental archaeology applied to raised fields and terraces. In the early 1990s, Denevan undermined assumptions about the intensification process from extensive to intensive agriculture in arguing that shifting cultivation in tropical forests could only be a widespread productive practice after the European introduction of iron and steel axes to the Americas (Denevan 1993, 2001). Before that, farmers emphasized more permanent field systems with labor and nutrient inputs.

Environmental Determinism vs Farmer Agency

In the 1954, Betty Meggers (1954, 1971) proposed that complex societies did not and could not have developed in the pre-European Amazon or broader Neotropics due to poor soil that limited production to extensive agriculture that could only support low population densities and primitive technology. She and colleagues later added lack of protein resources, tribal warfare, and climate change (regular "mega-el Niños") to the list of limitations. Denevan's early research in the Bolivian Amazon and that of colleagues Donald Lathrap and Robert Carneiro questioned these assumptions. Denevan's documentation in the *Science* article of "at least 170,000 ha

(1700 km^2) of ridged field remnants in Surinam, Venezuela, Colombia, Ecuador, Peru, and Bolivia" (a conservative figure in today's scholarship) helped undermine and later overturn the environmental determinism. Denevan is cautious, careful, and meticulous (one could even say conservative) in his descriptions of landscape features; interpretation of archaeological, colonial, and ethnographic documents; and the estimates of spatial scale and geographic distribution, carrying capacity, and dating of agricultural raised fields and terraces in South America. Through aerial photographs, maps, overflights, ground truth, interviews, and command of the literatures in the Science article and later work, Denevan showed that certain Amazonian peoples were capable of creating, transforming, increasing, and managing resources through active conversion of their environment into productive agricultural landscape.

In the Terrace chapter, Denevan takes on neo-environmental determinism that attempts to explain cultural change, collapse of civilizations, and agricultural abandonments in the Andes and Amazonia by evoking climate change. He shows that terrace farmers actively responded to their changing situation by concentrating and increasing production through selective abandonment and addition of irrigation.

Agricultural Collapse and Abandonment

The Terrace chapter is a short summary of a much larger edited work (Denevan 1986–1988) presenting the research and key conclusions of the Colca Valley Terrace Project directed by Denevan from 1984 to 1986. This publication was followed over the years by numerous dissertations and books and scores of articles and book chapters by Denevan and colleagues. Geographers, soil scientists, ethnographers, archaeologists, ethnohistorians, and others were assembled by Denevan to study the near-continuous 60 km of terracing in the Colca Valley, and as a result the valley became a testing ground of new techniques, interdisciplinary teamwork, and hypothesis testing that continues to the present. In a true multiscalar study, Denevan's investigators worked at the microscale of soil grains, potsherds, and individual fields; the medium scale of integrated field blocks, irrigation canal networks; and the macroscale of region: the middle Colca Valley.

Andean scholars have long wondered why large areas of once productive lands in the Andean coast, valleys, and highlands were abandoned (an estimated 60–80 percent of all terracing), some obviously before European conquest was abandoned sometime in the past. Denevan summarizes traditionally proposed factors or causes of terrace abandonment in the Colca Valley into "socioeconomic and demographic factors" (depopulation and resettlement through Inca and European reorganization, labor availability, land-use change, access to land and water, water management efficiency, and alternative livelihoods) and "natural factors" (climate change, tectonic uplift, water availability, vegetation, and soil change). Neo-environmental determinists assumed failure of the terrace technology and farmer's inability to adapt to the changing environmental situation as the cause.

Denevan first addresses the relation between cultivation intensity and productivity measured by productivity per unit area cultivated and total area cultivated during the later prehistory, the colonial period, and today. He notes that terraces on lower slopes and valley floor are irrigated, while terraces on upper slopes are not. Denevan shows that the process of abandonment and the causes involved were complex and that terrace agriculture is dynamic and nonlinear and involves constant decision-making by their users. After evaluating late prehistoric climate change and assuming that a period of drought and cooler temperatures occurred, he documents a contraction of terrace use during late prehistory and early colonial period rather than wholesale abandonment in the Colca Valley. Denevan argues that farmers intentionally abandoned of the upper slope terraces and began to intensify production on the lower slope and valley-floor terraces that can be irrigated and used year-round. Despite reduced total terraced land used, production remained the same or probably increased through the agricultural intensification of a smaller cultivated area. Rather than respond passively to climate change, farmers actively reorganized their landscape through social and technological innovations to meet the new challenges and expand capacity.

Second, Denevan attributes post-Inca abandonment of many of the irrigated terraces primarily to colonial depopulation mainly from introduced epidemic diseases. This depopulation for the Colca Valley is documented by Cook (1982).

Third, the failure to restore abandoned terraces today, despite population growth in Peru, seems to be the result of high labor costs, ownership issues, and rural to urban migration.

Denevan's Colca Valley Project inspired a wave of new research on terraces and indigenous farming systems more generally. More recent research demonstrates that terrace soils are anthropogenic creations for managing fertility and moisture and preserve remarkable fertility and productivity through time (Sandor 1987, 1992; Treacy 1994; Treacy and Denevan 1994; Goodman-Elgar 2008). Dating of settlements and actual terraces support Denevan's interpretation (Malpass 1987; Vera Cruz Chávez 1987; Brooks 1998). Ethnographic observations of contemporary terrace farmers demonstrate that terracing is sophisticated indigenous knowledge passed down over generations and part of an integrated system of land use, land tenure labor for construction, and maintenance, demonstrating long-term continuity and bottom-up organization of irrigation and terracing (Gelles 2000; Treacy 1994; Trawick 2003). Others show that much of the terrace structure and community organization recorded in the historical, ethnographic, and geographic literature for the Colca Valley is the product of Inca reorganization of this terraced landscape in late prehistory (Gelles 2000). Wernke (2013) demonstrates considerable continuity in terrace ownership, labor, and management between the structures and policies imposed by the Inca and the later Spanish colonial government through GIS, colonial documents, toponyms, and survey.

Applied Archaeology

Although the applied potential of pre-European agricultural research to the contemporary world rarely appeared in his early work, Denevan's publications on raised fields and terraces set experimental and applied archaeology into motion in Peru and Bolivia and were published at a time when scholars, governments, nongovernmental organizations, local communities, and the general public were interested in models of "appropriate" or sustainable technology, traditional Andean agriculture, and indigenous crops. In the late 1980s through the 1990s, nongovernmental organizations such as CARE, PIWA, and Catholic Church and government agencies such as CONCYTEC, the Ministries of Education and Housing, UNESCO, USAID, embassies, and political parties such as APRA supported "make work projects" involving terracing and raised fields in Peru and Bolivia (Torre and Burga 1986; Ramos Vera 1986a, b; Erickson 1985; Canahua Murillo and Larico Mamani 1992; Rivera Sundt 1989; Kolata 1996; Morris 2004).

Although relatively unsystematic and lacking continuity, the raised field and terrace experiments and small-scale development projects provided valuable insights about energetics, social organization of labor, crops cultivated, carrying capacity, functions, and sustainability. Despite the valuable contributions to understanding "abandoned" field systems through experiments in terrace and raised field agriculture, the various development and community projects spawned by this research had less success. The revolt led by the Shining Path, the violent military and police response, general civil unrest, and the poor economic situation throughout the 1980s and 1990s paralyzed scholarly, NGO, and government research on traditional agriculture and associated development projects. In addition, changes in production, markets, land tenure, and crops; lack of local labor; urban migration and rural abandonment; changing livelihoods; and other factors can be blamed for the lack of success as a development project (Erickson 2003; Morris 2004), while others blame farmers, scholars, and traditional agriculture for failure (Swartley 2002; Baveye 2013).

Conclusion

Although trained as a geographer, Denevan and colleagues successfully used archeological techniques such as systematic field survey, targeted excavation of specific landscape features, dating through pottery styles and radiocarbon analysis, pattern analysis, and analogy to understand the creation, structure, chronology, functions and use, maintenance, and abandonment of terraces and raised fields. The two publications helped lay the groundwork for Denevan's thinking about carrying capacity of intensive agriculture and implications for demography of indigenous peoples. At the same time, Denevan was mentoring a large number of motivated graduate students of diverse backgrounds from Wisconsin and other universities who are now professional colleagues exploring and expanding his pioneering work throughout the Americas.

Although framed in what would now be considered a landscape perspective, neither of these two publications use the word "landscape" in its modern sense (the *Science* article uses "landscape" twice to refer to natural environment and the Terrace chapter once). Denevan laid the groundwork for important research about the social organization of labor and taskscapes (Erickson 1993; Walker 2004, 2011), energetics (Denevan 1982; Gómez-Pompa et al. 1983; Erickson 1985), landesque capital (Blaikie and Brookfield 1987; Håkansson and Widgren 2014), agrodiversity (Brookfield 2001), historical ecology and indigenous knowledge systems (Erickson 2000, 2006; Balée and Erickson 2006), and appropriate technology (Renard et al. 2012; Erickson 2003; and detractors Baveye 2013; Lombardo et al. 2011; Swartley 2002). Denevan's contributions to knowledge about the origins, duration, and scale of human transformation of environment into landscape presage contemporary debates about the existence, origin, and timing of the Anthropocene.

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2.1 Drained-Field Cultivation in the Americas

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Abstract Pre-European reclamation of wet lands was widespread in the savannas and highlands of Latin America. Large numbers of drained ridges [raised] fields are found in Mexico, Central America, South America, and also in North America. Such intensive agriculture was apparently associated with relatively high population densities and probably complex social organization.

Keywords Chinampas · Drained fields · Garden beds · Indigenous agriculture · Raised fields · Latin America

Introduction

Where population growth begins to exceed the existing carrying capacity, self-sufficient aboriginal farmers may either migrate or increase production through higher yields, more frequent cropping, or the utilization of land which is marginal because of poor soil, steep slopes, lack of water, or excessive water. The denser populations and greater cultural achievements in the pre-European New World have been mainly associated with agricultural expansion by means of irrigation and terracing, and, accordingly, these reclamation methods have received considerable attention. In contrast, cultivation of land having excessive water has been almost ignored, mainly because such agriculture seldom survived into the European period, except in Mexico.

In recent years, extensive ridged-field remains have been found in seasonally flooded plains in widespread parts of lowland and highland South America. (Location and distribution maps can be found in Parsons and Denevan (1967).)

While much remains to be learned, a review of what is known about drained-field agriculture in the New World, and some of the implications, seems worthwhile at this time.

There are different types of poorly drained ground, each presenting different problems, as well as advantages, for reclamation and subsequent cultivation. Most obvious are the large river floodplains which are inundated during periods of high water. Because of the rich alluvial soils, population and cultivation are often concentrated in or adjacent to floodplains, with or without drainage control. However, some of the most extensive areas of inundation are large plains with broad, shallow depressions which fill with rainwater, and here soils may be quite poor, especially in the tropics.

Flooding is also characteristic of the immediate margins of lakes, rivers, and swamps, which fluctuate in coverage both seasonally and from year to year. In addition, there are sites covered by permanent, but shallow, bodies of water which can be cultivated following diking or draining, or through building soil islands. The least severe type of poor drainage is soil waterlogging, with little or no standing surface water, which can occur on sloping land as well as on flatland. Most crop root systems do poorly if waterlogging lasts more than a few weeks. But waterlogged soil can be readily reclaimed by ditching or by building up low crop ridges, if fertility warrants it, or cultivation can be concentrated during the dry periods, as long as there is adequate moisture.

An excess of water is obviously a great handicap to cultivation; however, this is frequently offset, in part, by high-quality soils, level surfaces, the availability of irrigation water, and the richness of aquatic wildlife resources. On the other hand, the labor requirements for constructing and maintaining drainage systems are high, and it is unlikely that drainage would be undertaken so long as other, more easily cultivable land was available.

The following types of wetland cultivation can be differentiated: (i) soil platforms built up in permanent water bodies; (ii) ridged, platformed, or mounded fields on seasonally flooded or waterlogged terrain; (iii) lazybeds or low, narrow ridges on slopes and flats subject to waterlogging; (iv) ditched fields, mainly for subsoil drainage; (v) fields on naturally drained land, including sandbars, riverbanks, and lake margins; (vi) fields diked or embanked to keep water out; and (vii) aquatic cultivation, in which complete drainage is not attempted and plants are grown in water. An agricultural system may employ more than one of these methods. Also, some techniques may serve functions other than drainage alone, such as irrigation, soil aeration, and improvement in the fertility of the soil. All these methods, with the exception of aquatic cultivation, were practiced by aboriginal people in the Americas. Brief descriptions of the major known examples follow. There was nothing comparable to Asian wet rice cultivation, although some wild aquatic plants, such as wild rice and the camus bulb, were harvested.

Chinampas

The one form of pre-European drainage that has long been known and well-studied is the *chinampa* system of the Valley of Mexico (Schilling 1939; West and Armillas 1950). *Chinampas* are rectangular garden plots built up above the water level of shallow lakes. These fields are characterized by the use of seed beds, fertilization with mulches of aquatic plants and bottom muds, and year-round irrigation by means of seepage and with water scooped from the bordering canals. The result is a continuous succession of crops – one of the most intensive systems of agriculture, past or present, in the Western Hemisphere, in terms of total annual production per unit of land. The *chinampas*, which played a major role in feeding the Aztec capital of Tenochitlán, were concentrated in lakes Zumpango, Xaltocán, Texcoco, Xochimilco, and Chalco. They are still being created and cultivated in the southern portions of Chalco and Xochimilco, and these modern survivals provide clues not only to ancient *chinampa* agriculture but also to the functions and technology of other types of drained fields no longer in use.

The first *chinampas* may date back as much as 2,000 years (Coe 1964). Pedro Armillas has attempted to measure the former distribution of *chinampas* on the basis of fossil remnants (*tlateles*) in drained portions of former lakes and suggests a preliminary total of 10,000 ha for just lakes Chalco and Xochimilco (Armillas 1968). While modern *chinampas* are quite broad (5 to 15 m), the fossil fields are often much narrower, suggesting that the present system is not necessarily "virtually unchanged" from the time of Cortes (Moriarty 1968). The narrow fossil fields are closer in form to the ridged fields of South America; also, many of them are found on former lake margins on relatively high land where flooding was not permanent but was seasonal, as is the case with the South American ridged fields.

Ridged Fields of the Wet Savannas

There is no need to elaborate here on the *chinampas* and their important role in Mexican culture history. However, they are not as unique in the Americas as they were once believed to be. Since 1962, numerous remnants of large raised planting surfaces have been found in South America in both lowland tropical savannas and highland basins on terrain subject to seasonal inundation. These features have usually been referred to as "ridged fields," less often as "raised fields" or as *camellones.*

There are at least 170,000 ha (1700 square km) of ridged-field remnants in Surinam, Venezuela, Colombia, Ecuador, Peru, and Bolivia (Fig. 2.1). Some are isolated, but others are near modern settlements and roads. In view of their size and number, the fact that they have been ignored until recently is a puzzle. However, the ridges are not conspicuous on the ground, often being severely eroded or partly buried in sediment (Fig. 2.2). From the air, on the other hand, the ridges form distinctive and obviously human-made patterns (Fig. 2.3), especially at times of the

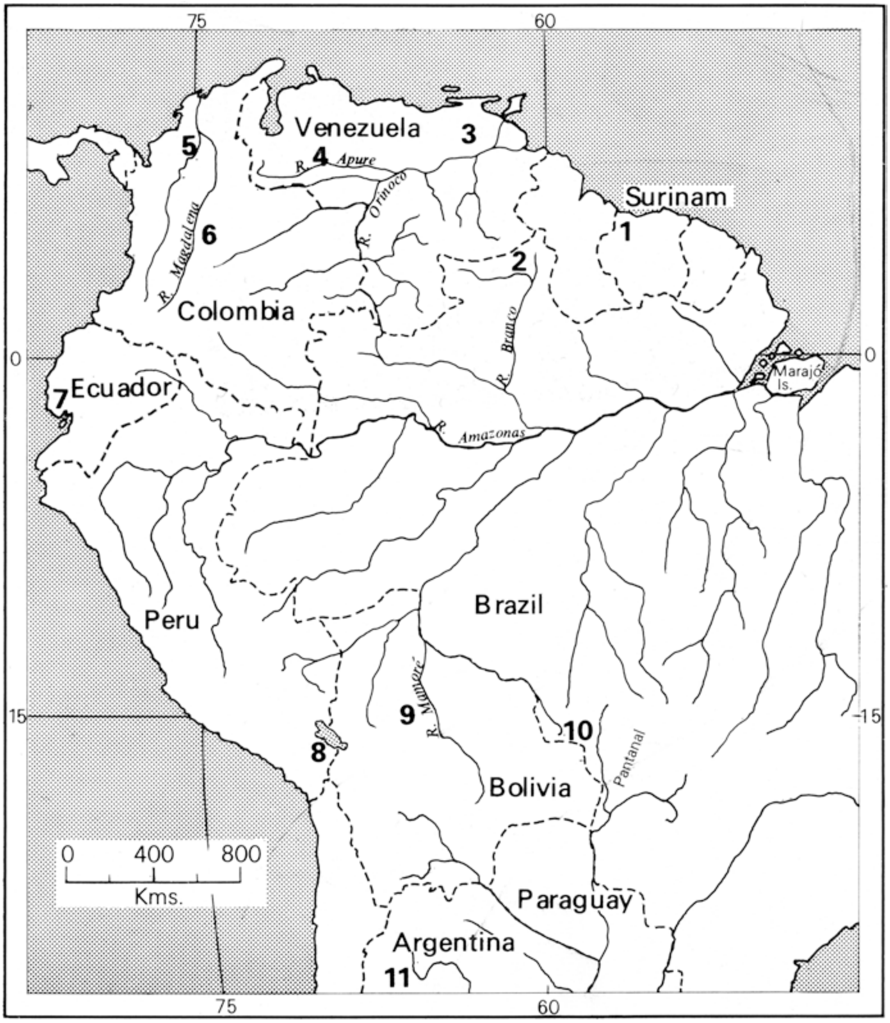

Fig. 2.1 Map of the drained-field areas in South America mentioned in the text. 1, Hertenrits; 2, Makuxí; 3, Karinya; 4, Caño Guanaparo; 5, San Jorge; 6, Sabana de Bogotá; 7, Guayas; 8, Lake Titicaca; 9, Llanos de Mojos; 10, Guato; 11, Lerma Valley

year when contrasting grass tones between ridges and ditches stand out, or when the ridges rise above floodwaters. Also, there has been a general lack of awareness, by both local people and scholars, of what long rows of linear soil features in swamp-lands might mean. In studying and mapping the ridged fields, aerial photographs have been essential, and these have only recently become available for much of South America.

Except for two very brief reports of obvious ridged fields in unidentified parts of the Orinoco Llanos in the sixteenth and eighteenth centuries (Castellanos 1955, 1:

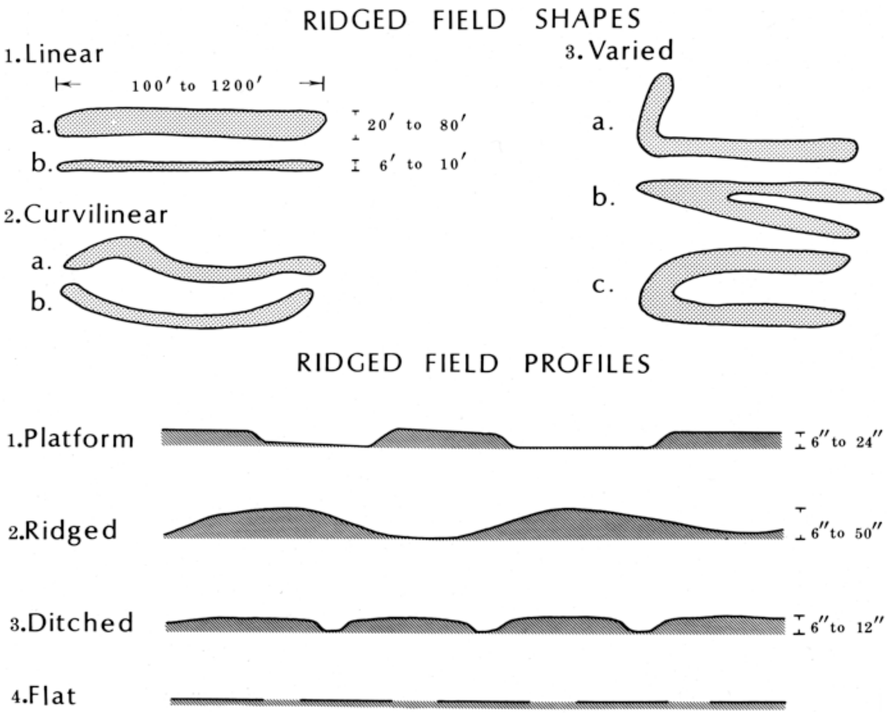

Fig. 2.2 Sketches of ridged-field shapes (above) and profiles (below) in South America. The "flat" profile is one where ridge and ditch relief has been leveled by plowing or sedimentation but with soil differences persisting

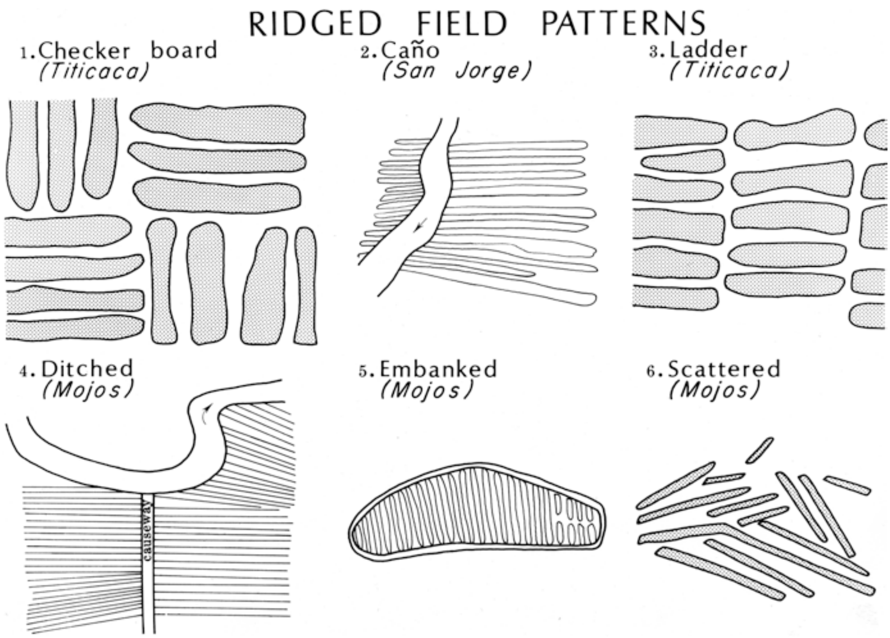

Fig. 2.3 Sketches of ridged-field patterns in South America

539; Gumilla 1945, 430–432), there apparently is no mention of such farming in the literature either of the conquest or of the colonial period. Presumably, the system was given up before the Spaniards arrived or very soon thereafter. In 1916, Nordenskiöld mentioned drainage works in the Llanos de Mojos of Bolivia, but he seems to have missed the largest concentrations and apparently was not impressed. The Reichel-Dolmatoffs mentioned drained fields in the San Jorge area of Colombia in 1953 but gave few details (Reichel-Dolmatoff and Reichel-Dolmatoff 1953, 14). Otherwise, the discoveries and descriptions of ridged fields have come only in the last few years.

A large portion of the vast tropical savannas of South America are subject to seasonal flooding for periods lasting up to several months. With their generally low soil fertility and their excessive water during the growing season, it is not surprising that these "wet" savannas are considered marginal for farming. The tribes of these savannas were agricultural, but they ordinarily confined this activity to the galley forests and forest islands within the savannas. Some of these tribes, such as the Yaruro in the Orinoco savannas and the Siriono in the eastern Mojos savannas, are now seminomadic hunters and gatherers for whom agriculture is of secondary importance (Holmberg 1960; Leeds 1961). Thus, it is some significance that evidence of drained-field cultivation has been found in several savannas.

In 1961, oil exploration geologists in the Mojos savannas of the Department of the Beni in eastern Bolivia came upon large numbers of low, parallel ridges which could only have been made by people (Denevan 1962; Plafker 1963). Independent field study and analysis of aerial photographs and aerial reconnaissance the following year provided a good idea of the nature, number, distribution, ecological situation, and probable function of the relic ridges, as well as revealing other, associated earthworks, including mounds, causeways, and canals (Denevan 1963, 1966, 84–96).

The Llanos de Mojos cover some 180,000 square km in the Beni Basin between the Andes and the western hills of the Brazilian Highlands. For a description of the drainage of the Beni Basin, see Plafker (1964). During high water, the Beni, Mamoré, and Guapore rivers and their tributaries overflow the *llanos*, and as much as 80 percent may be under a few centimeters to a meter or so of water for as long as 6 months. The climate is humid tropical, but the vegetation is open savanna with scattered forests on the higher, better drained ground. Soils are mostly high in clays and low in organic content, so it is not surprising that agriculture today is confined to the better and dryer soils of the forest, while the savannas are used for cattle raising. Nevertheless, there is mute evidence of former intensive savanna cultivation in the form of tens of thousands of raised field remnants which, together with intervening ditches, cover at least 20,000 ha.

West of the town of Trinidad, the old fields consist of narrow, closely spaced ridges (Fig. 2.3), but to the north, near Lago Rogoaguado, the fields are actually rectangular platforms as much as 25 m wide and 400 m long (Fig. 2.3). Elsewhere there are rows of small circular mounds, about 2 m across, similar to the *montones* reported in Hispaniola in the sixteenth century (Sturtevant 1961). Most of the fields are 15 to 50 cm high, wEuropeannough to place them above the level of average floods.

The Spanish explorers and the Jesuits found relatively sophisticated tribes in Mojos (the Arawakan Mojo and Baure) with large villages characterized by plazas, palisades, and moats, and containing as many as 3,000 people, but they made no mention of drained fields. However, the region was not settled and fully explored until the 1680s, by which time the savanna tribes already had been decimated by European diseases, and their cultures disrupted by the direct and indirect effects of initial Spanish contacts. Nevertheless, Jesuit accounts indicate that at least 100,000 Indians still remained in Mojos in the 1690s (Denevan 1966, 116). There has been little archaeology in the region, so the antiquity of the various earthworks is not known, but at the time of first contact in 1580, the Mojos tribes may still have been constructing them in order to provide artificial high ground for agriculture, transportation, and settlement.

The Mojos finds alerted scholars to the possibility of other relic drained fields in South America, and a number of such features have now been described. Particularly spectacular fields were found and photographed in 1965 by Parsons and Bowen in the San Jorge River floodplain, a part of the vast aquatic landscape of the lower Río Magdalena in northern Colombia (Parsons and Bowen 1966). The mapped fields, covering at least 64,000 ha of ditches and raised surface, consist of (i) ridges on, and perpendicular to, the back slopes of natural levees of stream channels (*caño* pattern, Fig. 2.3); (ii) short ridges arranged in checkerboard patterns (Fig. 2.4); and (iii)

Fig. 2.4 Partly inundated pre-European ridged fields in the Río San Jorge floodplain of northern Colombia. (Courtesy J.J. Parsons and W. Bowen)

parallel, but unoriented, ridges. The ridges are as much as 2 m high, 7 m wide on the average, and up to 1½ km long.

In Surinam, prehistoric ridged fields have been reported in the coastal savannas. The main concentration is associated with a large artificial mound called Hertenrits, built about AD 700, near Caroni in an uninhabited wet savanna now being reclaimed as part of a rice project (Laeyendecker-Roosenburg 1966; aerial photographs in Parsons and Denevan 1967). Here the ridges are short and narrow, with no regular arrangement.

In the Guayas River floodplain in Ecuador, there are at least 4,000 ha of old ridges and platforms (Parsons 1969). It is especially surprising that they have been ignored, since they are very close to the city of Guayaquil and since there has been archaeological research in the region (Meggers 1966). The field remnants are associated with *tolas*, artificial burial and house mounds built by the gold-working Milagro culture, which occupied the floodplain from about AD 500 to the arrival of the Spaniards. While ridges are no longer being constructed, some of the old ones are again being cultivated, with rice in the ditches and maize and other crops on the raised surfaces.

The fifth area of relic ridged fields in lowland South America is the Orinoco Llanos of Venezuela. This is one savanna for which there are historical accounts of ridged-field construction (with *macanas*), fertilization (grass mulch), and use (maize, manioc, and peppers) (Castellanos 1955, 539). No locations were given, but the Llanos seemed a likely place to search for ridged-field remnants because of the region's possible role as a major cultural hearth in prehistoric times (Rouse and Cruxent 1963, 88), the environmental conditions being similar to those of the other ridged-field areas, and the known presence of other earthworks (mounds and causeways) probably built for adaptation to floods (Cruxent 1966). Reports of ridges in the Tame-El Yopal area of the Colombian portion of the Llanos have not been verified and may result from confusion with wind-oriented fire scars. However, aerial photographs show an apparent cluster of ridged-field remnants along the Caño Guanaparo in southern Barinas, about 15 km north of the Río Apure and from 125 to 150 km west of San Fernando de Apure. These were first reported by J.H. Terry from the Inter-American Geodetic Survey (pers. comm.). The ground stripes are at right angles to old stream meander scars, similar to some of the San Jorge patterns, and are fairly narrow and as much as 700 m long (Fig. 2.5). The Orinoco Llanos seems to be undergoing very rapid sedimentation, so it is possible that many old fields have been buried.

Undoubtedly more ridged-field remnants will be found in tropical America. The seasonally flooded Brazilian savannas, especially on Marajó Island and in the Pantanal of Mato Grosso, are likely areas. The finding, by A. Siemens (pers. comm.), of a group of apparently pre-European ridged fields in 1969 in the Candelaria area of the western Yucatán peninsula may be one indication of intensive cultivation by the lowland Maya.

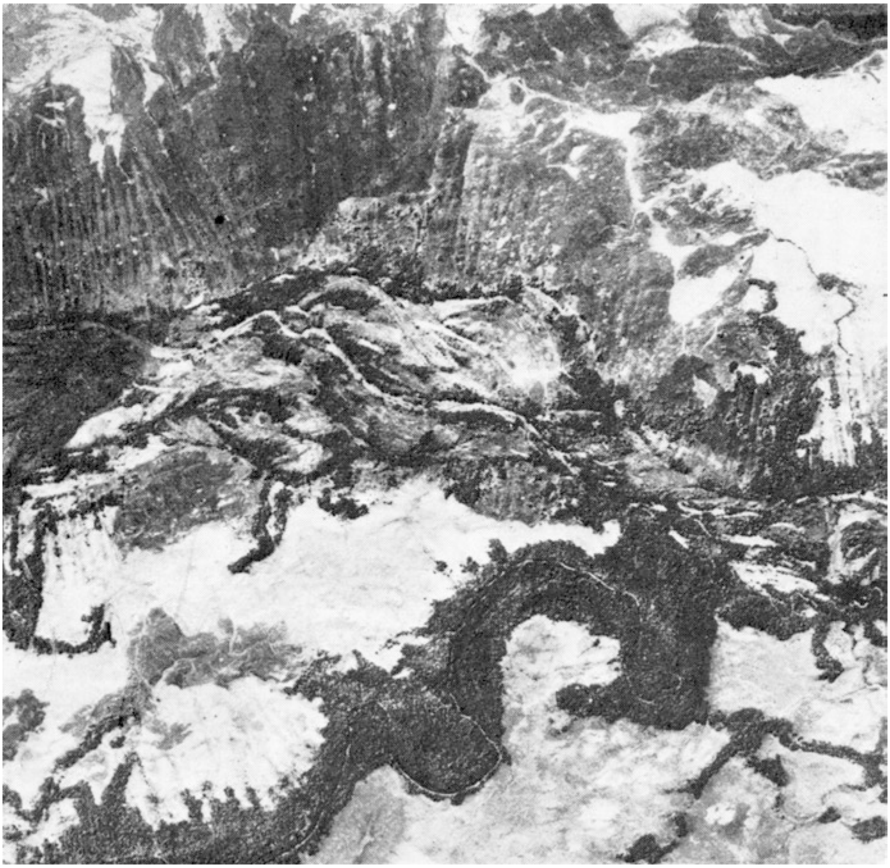

Fig. 2.5 Ridged-field remnants at right angles to streams near the Caño Guanaparo (at bottom) about 130 km west of San Fernando de Apure in the Orinoco Llanos of Venezuela. (Scale: about 1:37,000). (Courtesy J.H. Terry)

Highland Drained Fields

Drained-field systems, relic and contemporary, occur in the highlands of the Andes and Mexico. They are less of a surprise there than in the lowlands, since the highlands contained sophisticated civilizations with other forms of agricultural earthworks. Nevertheless, newly found highland fields add support to the arguments for very dense populations in the Lake Titicaca (Smith et al. 1970) and Bogotá basins, in the same way the *chinampa* system supports similar arguments for the Valley of Mexico.

The prehistoric Titicaca and Bogotá ridged fields resemble those in the lowlands more than they do *chinampas*, since they were built for reclaiming seasonally flooded terrain. The Titicaca fields are the most extensive of all, covering a measured 82,056 ha (Smith et al. 1968). The Titicaca fields were first called to our attention by F. Monheim and J. Dickenson. Nevertheless, they were overlooked until 1966 – even by me when I drove through them between Puno and Juliaca in 1965. They are arranged in a variety of patterns and sizes, but some are as much as 2 m high and 25 m wide and appear as islands along the lake edge during high water (Figs. 2.6 and 2.7). Most are located on the western lake plain in both Peru and Bolivia at elevations of 3,800 and 3,850 m. Crops of potatoes, quinoa, cañihua, and barley are grown here today but mainly on hill slopes. Because of high alkalinity, poor drainage, and night frosts, but also for historical reasons, most of the lake plain has been used for ranching since the conquest, rather than for farming. Ancient fields have thus been preserved, although encroaching plow cultivation in some sectors is destroying what remains.

The Sabana de Bogotá in Colombia is a broad mountain basin, at an elevation of 2,600 m containing seasonally flooded and waterlogged land. With good soil and a temperate climate, the Sabana has been a grain-producing area since at least the sixteenth century, with the aid of subsoil drainage by way of elaborate ditch and drain-off canal systems. Narrow garden beds (*camellones*) are made today by farmers without plows to improve drainage and to handle the heavy clay soils, and such beds are possibly aboriginal in origin (Donkin 1968; Eidt 1959). They do not compare in size with the ridged fields of Titicaca and the lowlands. However, Broadbent has recently discovered the remains of large, ancient drained fields, mostly in the area of Suba, some 20 km north of Bogotá (Broadbent 1968). Many of these are in zones covered until recently by forest and probably owe their preservation to the fact that they, in contrast to most of the Sabana, have not been plowed over for four centuries. In aerial photographs, dated 1940, of Hacienda La Conejera, the former field patterns show up clearly within modern fields recently cleared from forest. On photographs taken of the same site in 1968, after only 28 more years of plowing, the old fields are much less distinct. As seen from the ground, the old fields showed no greater relief than the surrounding land. They are discernible only because of differences in the soil which have persisted, despite the leveling of the ridges and filling of the ditches, so that there is now a differential growth of maize and wheat crops which is expressed in rectangular block form. It seems reasonable to speculate that much of the Sabana de Bogotá was covered by ridged and also ditched fields prior to the arrival of the Spaniards and that these fields were related to the population density and to the cultural achievements of the great Chibcha chiefdom of the Sabana.

Large ridged fields have not been found in the smaller, poorly drained basins in the Andes. However, in Peru I have seen deeply ditched fields in use today (as they have probably been for a long time past) in the Pampa de Anta near Cuzco, the Taraco and Pomata areas of Lake Titicaca, and elsewhere. They are similar to the present Bogotá ditch systems, although smaller and less systematic. Rather than creating raised surfaces, they serve to reclaim waterlogged soils by providing subsoil drainage and by channeling excess water away from crops. The present Sibundoy Indians near Pasto in the Colombian Andes also drain their fields by this means (Bristol 1968).

There is another form of drained field which is very common in the Andes today and is clearlEuropeaniginal origin. This is the lazybed system, locally referred to as

Fig. 2.6 Ground view (July 1966) of one of the large ridged fields at the edge of Lake Titicaca near Requeña, Peru. The pockmarks were made by rooting pigs. Note the eroded edges of the ridge and the alkaline deposits on both sides of the ridge

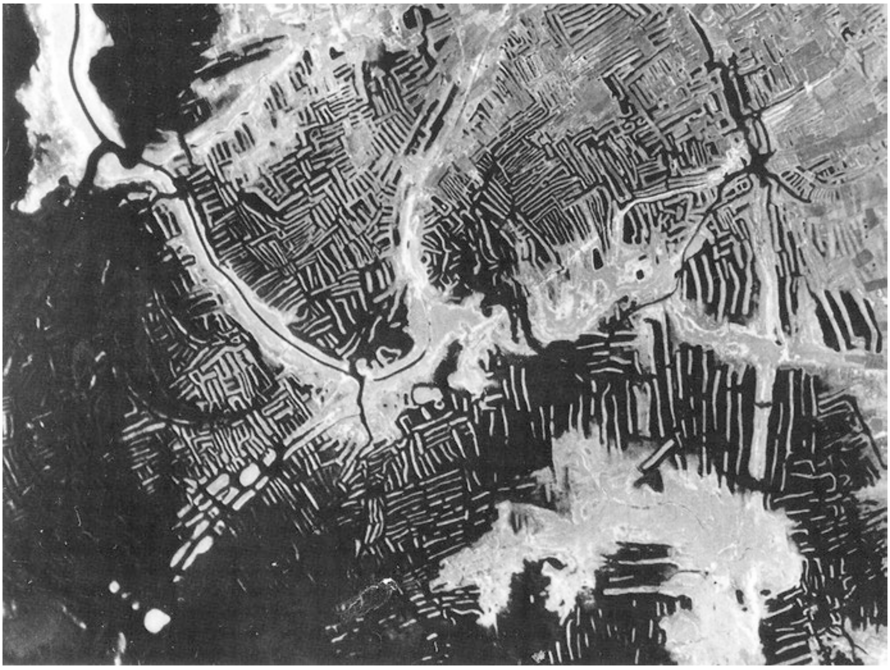

Fig. 2.7 Pre-European raised fields extending into Lake Titicaca northeast of Juliaca in Peru. [This was the cover photo in the original]. (Photo from the William Denevan collection)

huachos or *eras*, which is found from Colombia to Bolivia (West 1959). Potatoes are the main crop, along with cañihua, barley, and arracacha. These fields are commonly made with the Andean foot plow (*chaqui taclla* – similar to the Scottish *cashcrom*), which is used to break and turn heavy grass sods where larger plows are not available or usable, especially on steep slopes. However, lazybeds are also made on poorly drained flat terrain and waterlogged lower slopes in order to improve drainage. Usually they are about 1 meter wide and 30 to 60 cm high. Some of the Titicaca ridged fields have been or are being destroyed by lazybeds built on top of them.

In the Mexican highlands, there are other types of drained fields besides the *chinampas*. The only detailed published descriptions are by Wilken for Tlaxcala (Wilken 1969), but similar fields exist elsewhere – for example, in Puebla, Oaxaca, and the State of Mexico – in poorly drained valley and basin bottoms. In southwestern Tlaxcala contemporary drained fields occur on sites ranging from swampland to land watered only by seasonal rain. In all cases waterlogged soil must be two words swamp land drained before cultivation is possible. The main technique is to dig drainage canals several meters wide and deep, but raised garden plots some 10 m wide may also be built up between the ditches. The ditches are periodically cleaned, and muck and vegetation are spread on the fields to increase fertility.

North American Garden Beds

In North America, remnants of aboriginal raised fields were quite common until most were destroyed by plowing in the nineteenth century (Schoolcraft 1860, 1:58–64; Fox 1959; Peske 1966; Fowler 1969). These fields, usually referred to as "garden beds," are linear or curved and fairly narrow (1 to 4 m), and they occur in clusters of several hundreds. At least 180 such clusters have been reported in Wisconsin and Michigan, and undoubtedly there were once many more. The primary function of the garden beds may have been to break up grassland sod. However, many if not most of the fields occur in the bottomlands of the Mississippi drainage system; hence they probably also had a drainage purpose. There seem to be no historical descriptions of the garden beds in use. Probably they were a product of the "Mississippian" cultures (about AD 700 to 1500), which were characterized by a dependence upon agriculture and by a village orientation to "the major streams with large alluvial floodplains which provided fertile and easily worked soils" (Griffin 1967).

The occurrence of ridged fields in the mid-latitudes and subtropics is partly confused by what is called *gilgai* topography. This is a landscape crumpled into a complex microrelief of mounds and ridges and depressions. It is known, in North America, India, Australia, and Africa – regions where there are marked wet and dry seasons – usually in lowland savannas and grasslands. *Gilgai* seems to be the result of the "self-plowing" of black, montmorillonite clay soils experiencing severe seasonal swelling and contraction. In some instances, the topography may take the form of parallel linear or curved stripes and depressions somewhat similar to garden beds, lazybeds, and ridged fields (Hallsworth et al. 1955 – see especially plate IV, of "wavy gilgai"). Some features considered to be made by humans such as ridged fields may actually be *gilgai* soils, and some features labeled *gilgai* may really be ridged fields. Certainly, soil scientists and culture historians should be aware of the alternative possibilities.

Other Types of Drained Fields

One of the few contemporary examples of Indian cultivation of wet savannas is in the Rio Branco campos of northern Brazil, where the Makuxí (Macusí) Indians near Serra do Flechal build large manioc mounds some 50 cm high and 1 to 2 m across (H, Sternberg, pers. comm.). These are larger than the small hillocks of tropical forest cultivators and may be comparable to the *montones* of Hispaniola and Mojos. Over 1,000 small mounds in an orchard pattern were found in the Lerma Valley in Salta, Argentina; they seem to have been used for cropping of poorly drained ground (Von Rosen 1924).

Large burial and settlement mounds of aboriginal origin are common throughout tropical America, and many are located on land subject to seasonal flooding, as in Mojos and on Marajó Island. Many of these mounds have had farms on them in the past and still do. One striking example is the Guato Indian mounds reported by Schmidt in 1914 in the savannas between the upper Río Paraguay and the upper Rio Guaporé in western Mato Grosso, one of which, 2 m high, European40 by 76 m (Schmidt 1914). Groves of *Acuri* palms (*Attalea*) were planted on top.

There are a few instances of embanked or diked fields, in which walls were built to keep water out, in Mojos (Fig. 2.3) and the Titicaca plain, but ridges, mounds, and ditches are the more common means of coping with poor drainage.

The cultivation of river land (banks, sandbars, low islands) during low water has been a common aboriginal practice in the floodplains of the Amazon, Orinoco, and other large rivers. While little is known about such agriculture, it was apparently common in the past and is still practiced by both Indians and settlers today. The large Omagua tribe, for example, concentrated cultivation on Amazon *playas* and on islands subject to flooding (Sweet 1969). Crops are planted which have a short growing season and do well in sandy soils – such as peanuts, sweet potatoes, squashes, and some beans.

Seasonally flooded savannas have also been cultivated during the dry season. Padre Gumilla in the eighteenth century reported that the Otomaco Indians between the Orinoco and Río Apure in Venezuela planted crops on the grassy margins of savanna lagoons as the lagoons dried up (Castellanos 1955, 1:539). Today the Karinya in the Orinoco Llanos cultivate *moriche* (*Mauritia*) palm swamps during the dry season with the aid of surface mulches and ash and, in some places, with drainage ditches dug by communal labor (Denevan and Schwerin 1978). Mounding or ridging is minimal, but this system may be a survival of more elaborate earlier practices.

Discussion

There is now evidence, mostly of a reconnaissance nature, of a wide variety of drained-field agricultural systems occurring in a variety of ecological situations in the Americas. However, except for the fields in highland Mexico, we now very little about these systems and the societies responsible for them. The South American field remnants have not been dated or correlated with archaeological materials, and there are few descriptions of the fields in use. That the relic ridged fields were agricultural is implicit, there being no other rational explanation for them (Parsons and Denevan 1967). The fields are sufficiently extensive and impressive to warrant detailed archaeological and ecological studies. Also, additional areas of field remnants may be discovered through careful examination of conventional aerial photographs or with the aid of infrared and other remote sensing techniques. See, for example, Schaber and Gumerman (1969) and Deuel (1969, 40–58) for discussions of photo techniques used in Europe to detect prehistoric "crop marks." Meanwhile, only preliminary conclusions can be drawn concerning causation, techniques, crops, and demographic and cultural implications.

Drained-field agriculture is, of course, common today in the mid-latitudes as increasing efforts are being made to cultivate marginal lands by modern techniques. In Europe, there are classic preindustrial examples, such as the fens of England and the polders of the Netherlands (Darby 1956; Smith 1967, 444–464 and plate 41). But it is to the tropics of the Eastern Hemisphere that we may look for aboriginal drainage techniques that might provide the best clues to pre-European practices in tropical South America. Ridge and mound agriculture is common in the African savannas, but the primary function seems more often to be for aeration, root removal, and concentration of topsoil rather than for drainage (Netting 1968, 58–60; Faulkner 1944). In Melanesia, however, there are excellent contemporary examples of ridged-field agriculture in poorly drained situations. Fields photographed in the Baliem Valley of New Guinea are remarkably similar in pattern and dimensions to some of those in South America. (See Brass [1941] and also Gardner and Heider [1968], especially photograph 24 and also photographs 92–102.) Prehistoric drained fields in the Wahgi Valley of New Guinea have been dated as older than 350 BC plus or minus 120 years by Lampert (1967). Sweet potato fields are constructed by teams of men using simple digging sticks and wooden spades to raise long ridges by throwing earth up from drainage ditches. Fertility is maintained by mixing in a mulch of grass and aquatic plants that make it possible to grow crops continuously for several years before fallowing. The *chinampas* of Mexico are managed somewhat similarly, and the same methods must have been used in South America. It is unlikely that aboriginal people would have developed elaborate drainaEuropean unless each field could have been cultivated numerous times.

But why attempt to farm poorly drained land in the first place, especially when there is more fertile and more cultivable land locally available? For one thing, seasonally flooded areas generally have rich protein resources in the form of fish and other aquatic life such as various turtles, rodents, and birds. Such resources are especially important in the South American tropical lowlands, where the stable crop is manioc, which has a very low protein content. The same reasoning might apply to the Lake Titicaca plain, where the potato is the staple. Proximity to rivers and riverbanks is, of course, also important for transportation and for fertile, easily worked soils.

A second possible reason for the great efforts that were, and are, expended on building and maintaining drained fields is demographic. Boserup (1965) and others have argued that agricultural intensification is a result of, rather than a cause of, increased population, and this does seem to be true for many preindustrial societies. In New Guinea, for example, for groups of essentially the same culture, the ratios of extensive to intensive cultivation vary with local population densities. The argument has been applied to aboriginal agriculture in New Guinea by Brookfield (1962) and Clarke (1966). An increase in productivity per unit of land is resisted as long as there is adequate land available for more extensive systems, mainly because intensification requires greater inputs of labor, at least initially, in terms of productivity per man-hour. In the South American savannas, population must have been initially concentrated on the more fertile soils of the gallery and island forests. Such forest soils now cover only about 10 to 15 percent of the Llanos de Mojos. Once the forest soils were fully in use, surplus populations might have been motivated to cultivate the savannas despite the greater labor required. Probably, as population increased, more and more savanna was brought into cultivation.

That the ridged-field areas in the lowland savannas were relatively densely settled is suggested by historical documents of Mojos (Denevan 1966, 116) and by archaeological evidence for San Jorge (Parsons and Bowen 1966) and Guayas (Parsons 1969; Meggers 1966). The presence of the drained fields provides additional support if the preceding argument is valid. Estimating population densities from the extent of the drained fields is difficult, however, since it is not known how many fields were cultivated at any given time. For San Jorge, if a conservative 0.8 hectare of land and water surface is allowed per person and if only 20 percent of the fields were farmed at once, the population density comes to a substantial 25 persons per square kilometer. Locally, all the ridges may have been in cultivation at once, in which case the densities could have been more than 100 persons per square kilometer. Such densities are not unreasonable in view of present populations of up to 400 per square kilometer in the Baliem Valley of New Guinea, where swamp drainage is practiced (Brookfield 1962).

In the highlands, drained fields were clearly associated with dense populations. These were nuclear areas in terms of population growth and cultural evolution and were apparently characterized by the progressive utilization of ecological niches as population increased and new technology was developed; the most difficult habitats were brought into cultivation last, usually with elaborate reclamation. For discussions of agricultural expansion with population growth in pre-European Mexico, see Flannery et al. (1967) and Spores (1969). Presumably when population and production demands were reduced, as they were drastically in the sixteenth century, the least easily cultivated habitats were abandoned first. Around Lake Titicaca this meant the higher terraced slopes and the drained fields of the lake plain, both of which are still largely uncultivated today. Thus, preconquest populations of the Titicaca area may have been even greater than the present dense populations. Much of the lake plain is hacienda pasture and not available to the

Indians. However, where Indians do control such land, as around the town of Huata north of Puno, there is increasing lake plain agriculture, but with the lazybed system rather than construction of large ridges. Most of the areas of drained-field remnants in Latin America probably supported substantially larger populations than they do toay.

Summary and Conclusion

The three main types of land reclamation in aboriginal America were irrigation, terracing, and drainage. Of these, drainage techniques have received the least attention, probably because they are no longer important and because the remnants are not conspicuous. Nevertheless, drained-field cultivation was widespread and was practiced in varied environments, including highland basins, tropical savannas, and temperate floodplains. Sites ranged from seasonally waterlogged or flooded areas to permanent lakes. Ridging, mounding, and ditching were emphasized, rather than diking. Tools were simple, crops varied, and fertilization was accomplished mainly by mulching.

The presence of drainage agriculture probably indicates that populations exceeded the carrying capacity of the more easily cultivated land. When populations declined, following the conquest by Europeans, the drained fields were probably given up because of the large amount of labor required to cultivate them. Most of these lands are now used only for cattle but could undoubtedly be reclaimed again for agriculture. Advisory programs have yet to reintroduce agriculture to the Mojos and San Jorge savannas, and much of the Lake Titicaca plain having drained-field remnants has been labeled by modern resource surveys as unsuitable for cultivation. However, the cost of such reclamation might be prohibitive where populations are sparse, transportation is poor, and distances to markets are long. The *chinampas* of Mexico are an exception, since there is a major urban market close at hand.

The aboriginal cultures responsible for drainage ranged from the seminomadic Guato to farm villages and chiefdoms and to the high civilizations. The ridged-field farmers of the savannas were capable people but less comparable to the farmers of the efficient and sophisticated states of the Andes and Mexico. Most of the drained-field systems could have been constructed and managed through small-scale family and community cooperation, as in New Guinea, rather than through central political control. On the other hand, there does seem to be a frequent relationship between degree of agricultural intensification, population size, and complexity of social organization (Carneiro 1967). Unfortunately, not much is known yet about the intensification process for drained-field cultivation or for other reclamation systems.

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2.2 Terrace and Irrigation Origins and Abandonment in the Colca Valley, Peru

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Abstract For the Colca Valley of southern Andean Peru, extensive agricultural terracing of pre-European origin is now over 60 percent abandoned. A University of Wisconsin, Madison interdisciplinary project sought to determine the cause of abandonment. This involved mapping the terraces from air photos, archaeological excavation of terraces and associated canals, historical research on colonial censuses, ecological study, and examination of current terracing and canals. We concluded that depopulation resulting from the Spanish occupation of the valley in the sixteenth century was the primary cause of abandonment. We also asked why the abandoned terraces had not now been restored to use, given population recovery in Peru. We concluded that socio-economic factors, primarily the perception of better opportunities in the highland and coastal cities, have resulted in population stagnation or decline in the valley and thus little motivation to restore terraces.

Keywords Andes · Colca Valley · Irrigation · Terrace agriculture · Terrace abandonment

Introduction

> [T]he higher terraces that extend well up the slopes above the main valley floor are abandoned ... [and] show only faintly in contrast to the fresh appearance of those on the valley floor and along the sides of the inner valley. (Lt. George R. Johnson, USN, 1930, 9).

In the Department of Geography at the University of Wisconsin, Madison, in the 1960s and 1970s, the Latin Americanists were interested in the cultural ecology of shifting cultivation, agroforestry, traditional crops, and raised fields. We assumed that terraces and canals, so often photographed, were well-studied; however, Donkin's (1979) terrace survey showed otherwise. Furthermore, the magnitude of terrace abandonment in the Andes was astonishing given current demographic pressures on farmland. We were thus motivated to propose an interdisciplinary project which would examine abandoned terraces and associated irrigation and attempt to determine the cause or causes of abandonment. John Treacy, who had worked with me on raised fields at Samborondón in Ecuador and on Bora agroforestry on the Río Ampiyacu in Peru, had lived for 8 years in the southern Andes of Peru, and he wanted to return to carry out research for his doctoral dissertation. Chatting in my office in Science Hall (or was it over a beer on the lake terrace?), we agreed that a study of Peruvian terraces could be rewarding. Any one of many terraced valleys and basins could have served, but we were particularly impressed by the spectacular aerial photography of the Colca Valley appearing in the reports of the Shippee-Johnson aerial expedition of 1931 (Shippee 1932, 1934; also Johnson 1930). Here was a long stretch of dense and varied terraces, in large part abandoned. The environment, archaeology, and history of the Colca Valley villages had been little studied, but there were detailed colonial *visitas* (censuses) available, recent air photography in 1974, and a demographic history had just been published (Cook 1982). The dirt road from Arequipa to the Colca had recently been improved by the Majes Project which built a cement canal to transfer water from the Río Colca to an irrigation site on the coast.

In the summer of 1983, Treacy and I visited the Colca Valley, where we were assisted by anthropologist David Guillet, who already had initiated a study of water management in the village of Lari. We then assembled our own project (Denevan 1987) with a team consisting of geographers Treacy, Hildegardo Cordova, and mysEuropeaneologists Maximo Neira, Dan Shea, Michael Malpass, and Pablo de la Vera Cruz; ethnohistorian Maria Benavides; and soil scientist Jon Sandor, in addition to North American and Peruvian students. Primary field research was conducted during the summer and fall of 1984, with individual sub-projects continuing over the next decade. Our efforts were initially concentrated in the village of Coporaque, with additional archaeological excavations in Achoma and Cabanaconde and later in Chivay by Brooks (Fig. 2.8).

The main reports of the original Colca Terrace Project are found in Denevan (1986–1988) and in Denevan et al. (1987). Several theses and doctoral dissertations at the University of Wisconsin, Madison, and in Peru resulted directly or indirectly (Treacy 1989; Vera Cruz Chávez 1988, 1989; Webber 1993; González 1995; Femenias 1997; Brooks 1998). During this period there were numerous ecological studies by other US scholars attracted to the Colca, including Guillet (1992), Gelles (1990), McCamant (1986), and Eash (1989). Many studies and reports were also soon produced by Peruvians and Peruvian institutions on history, agronomy, sociology, archaeology, and anthropology. The result has been that in only a few years, the Colca Valley changed from a little-known backwater to one of the best-studied regions in Peru, accompanied by an upsurge in tourism and media attention, with resulting social change for the Colca villagers.

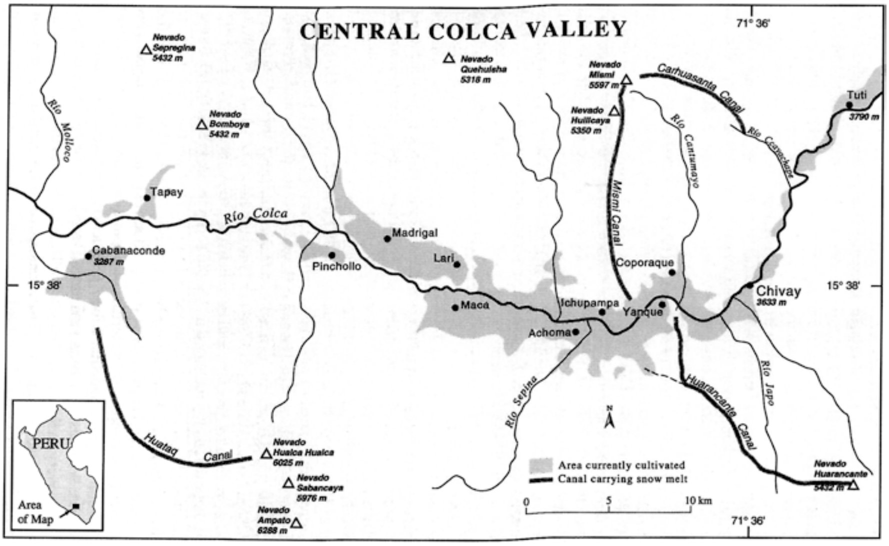

Fig. 2.8 Map of the central Colca Valley, Peruvian Andes, showing Coporaque, other villages, and the Río Japo Basin. Pampa Finaya is located between Coporaque and Chivay. Cultivated land, mostly terraced, is shaded. (From Brooks 1998, 6)

The Colca Valley

The valley of the Río Colca is located in the northern Department of Arequipa in southern Peru on the western slope of the Andean cordillera. It is but one of a series of deep valleys on the southwestern Andean flanks, most of which were terraced in pre-European times. The Colca is incised into a large, flat river terrace (*pampa*). The main cultivable portion of the valley is approximately 40 km long between the villages of Chivay and Cabanaconde at elevations between 3200 and 3600 m. Maize and quinoa were the primary prehistoric crops. Today, maize is planted mainly on terraces, while quinoa, broad beans, alfalfa, and barley appear both on terraces and *pampa* fields. Potatoes are not as common as might be expected. Alfalfa has become a major crop as cattle feed. In addition to cattle, most farmers also have sheep, llamas, and alpacas which are grazed on the *puna* (plateau) above the valley, as well as on fallow fields.

The valley's arid climate has influenced the nature of terrace construction. The agricultural core has a semiarid montane steppe climate, receiving an annual average of 385 mm of precipitation at the principal village of Chivay.

Rains are highly seasonal, peaking in December and declining sharply during late May to early August. For this reason, almost all cultivable land is irrigated by canals bringing water either from natural springs or from streams flowing from mountains topped by glaciers and permanent snow. The roles of irrigation are thus (1) to extend te growing season by 1 to 2 montas,bacowingarmers to plant in August and harvest in May, and (2) to provide supplementary water in case rains slacken during the growing season. Soils are mainly of volcanic origin and are of good structure and fertility. Cultivated and abandoned terraces are located on the *pampas*, on the slopes of the canyon below, and on the steep mountain slopes above to an elevation of nearly 4,000 m.

The Colca Valley has been occupied by terrace farmers since possibly 2,400 BC (Brooks 1998, 270). The immediate pre-Inca culture was the Collaguas which dominated the valley. Little is known about pre-Collaguas people, although Brooks (1998, 313) has identified an earlier ceramic style she calls Japo. Lithic tools in caves indicate that preceramic hunters were long present. The Inca interacted with the valley after 1471; however, there is little evidence of a strong Inca presence in that no Inca administrative center has been located and Inca ceramics, while present, are not common. Also, there is little evidence (a few sherds) of the Wari (Huari) culture, which dominated much of southern Peru, c. AD 650–1000.

The Spaniards arrived in the 1540s and found numerous small villages and dispersed farmsteads which were then converted into *encomiendas* (land and labor grants). Later, as part of the survey of Peru under Viceroy Francisco de Toledo, 1571–1574, the Colca Indians (Collaguas region) were consolidated into 24 Spanish-style villages (*reducciones*) numbering an estimated 62,500 to 71,000 people projected back to 1530. European crops and livestock were introduced, transforming the economy; however, population declined rapidly due to introduced diseases and removal of people to the mining centers. By 1721, the population had been reduced to about 8,600 (87 percent decline). Population increased slowly to 27,534 in 1940 (Province of Caylloma), reflecting out migration to Arequipa and elsewhere (Cook 1982, 83–87). By 1993, the population had only increased to 37,600 (corrected from INEI 1993, 38–39).

In the main terrace sector of the valley from Tuti to Cabanaconde, there are now 12 villages, each numbering between about 1,000 and 5,000 people, the largest being Chivay. Large units of once productive terraces are unused. This is in the Peruvian context of an increase of population from 6.2 million in 1940 to 23 million in 1993, inadequate food production, and apparent scarcity of arable land. Why has there been agricultural stagnation, or an earlier collapse without recovery, in the Colca Valley, as well as elsewhere in the Andes? Are the reasons environmental, such as climatic change or soil depletion and erosion, or are the reasons social? To consider this question, we examined not only terrace abandonment but the history and pre-European history of terracing in the Colca Valley, including the origins of terracing and irrigation.

The Colca Terraces

The ecology of current Colca irrigated terraces has been best studied in the communities of Coporaque (Fig. 2.9) (especially Treacy 1989, 1994a, b; Treacy and Denevan 1994) and Lari (especially Guillet 1987a, b, c, 1992) on the north side of the valley. Most of the Colca terraces were originally constructed in pre-European

Fig. 2.9 Air photo of the Coporaque region in the Colca Valley, Peruvian Andes, showing cultivated and abandoned terraces. See Fig. 2.11. (Photograph by Robert Shippee and George Johnson, 1931. Servicio Aerofotográfico Nacional, Lima, Peru)

times; however, with repairs subsequently, any given wall represents different construction dates and techniques.

The Colca Valley features a variety of terrace types (Fig. 2.10) that may be keyed into the terrace typology described by Treacy and Denevan (1994), Brooks (1998, 126–136), and Denevan (2001, 175–181). The common and most visually impressive type is the contour or bench terrace on valley-side slopes. Bench terraces

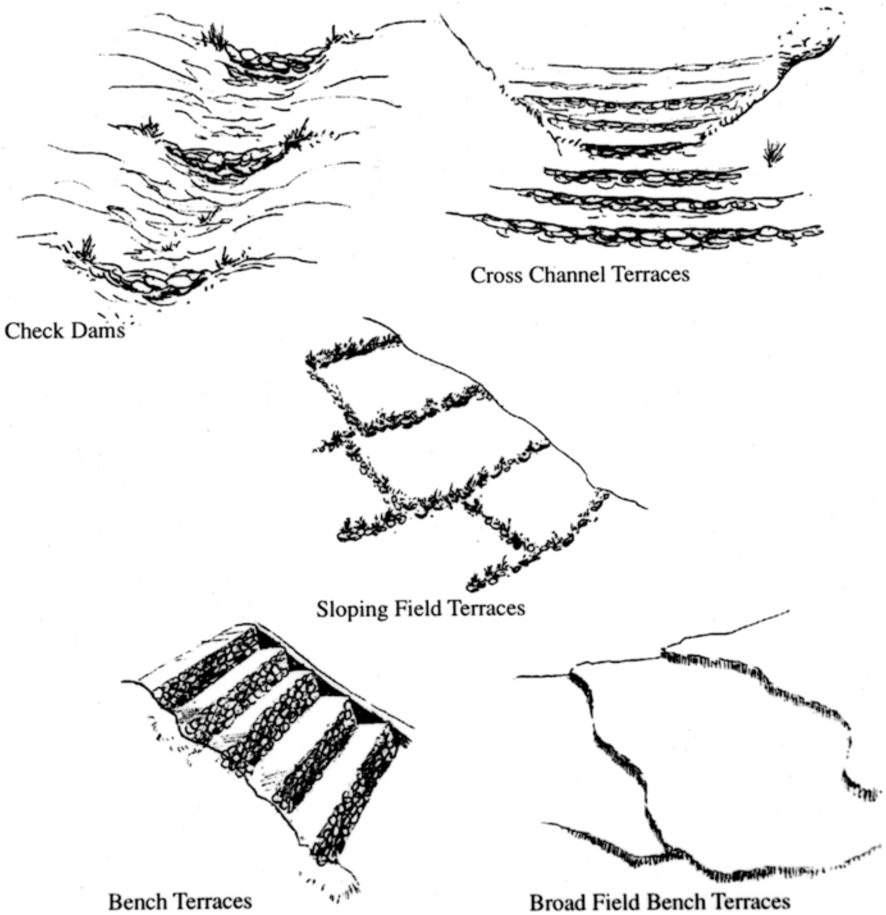

Fig. 2.10 Examples of terrace types. (From Brooks 1998, 2. [Added here from Denevan 2001, 175])

measure between l and 3 m in wall height, between 3 and 7 m in width depending upon degree of hillside slope, and from 40 to 60 m in length. Most Colca Valley bench terraces are irrigated by gravity-fed canals, and terraces often have water drops and channels built into walls and on the terrace platform. Most bench terraces are essentially irrigation platforms on steep slopes; their microclimatic virtues (frost reduction, moisture conservation) allow intensive maize cultivation. Brooks (1998, 192–5) reports finding numerous abandoned, unirrigated bench terraces in the Río Japo Basin between Chivay and Yanque, as well as elsewhere in the Colca Valley. Nearly half of all the terraces in the Japo Basin are of this type. Although not irrigated, the flat cultivation surface of such a bench terrace captures more rainwater than most of a sloping-field terrace, where rainfall runs off the upper surface to the lower surface, and hence, with inadequate rainfall, bench terraces are more productive per unit of slope.

Builders used cut-and-bench methods to construct bench terraces. They excavated through A horizon topsoil into an indurated B horizon to emplace wall base stones ranging in size from 30 to 60 cm in diameter. Stability and interlocking fit were more important than the size of the wall stones; base stones may be smaller than stones placed on top of them. Next, soil was removed from the exposed vertical soil face in order to make the cobble and earthen drainage horizon which most Colca Valley bench terraces have. Builders then moved soil down the slope behind the wall,[1] while stonemasons built the wall higher to retain the soil. Mineralogical examination shows that terrace fill soil is composed of in situ slope soil; no exogenous soils were used (Sandor 1987a, 185). In extensively terraced regions such as the Colca Valley, with steep slopes, the costs in labor would preclude transport of soil fill from elsewhere, at least not in quantity.

Often, a bench terrace is damaged when waterlogged soil bursts the retaining wall and spills forth. Careless wall repair hastens further wall failure. Builders blame poor masonry techniques or dry-soil construction for broken walls. Builders prefer to terrace with wet soil since dry soil is porous and will quickly become saturated following heavy rains, thus provoking sudden, early bursting. Common mistakes cited include not fitting wall stones together tightly or failure to press stones against the earthen fill behind. In the latter case, a gap forms between the wall and fill causing the wall to collapse when the gap fills with water.

Bench-terrace reconstruction duplicates the labor techniques of construction, except that soil spilled from ruptured walls has to be thrown back upslope and re-walled. Workers trench down to the original base to remove the fallen and buried stones from the original wall. The wall is rebuilt and the fill stones and soil are carefully repacked in behind the wall and tamped down. When reconstructing fields, masons replace up to 80 percent of the ancient walls and must laboriously throw spilled soils upslope, which demands more effort than moving soils downslope for new terraces.

An interesting aspect of Colca Valley terracing is the numerous *maquetas* (carved boulders) which depict patterns of irrigated terraces. Brooks (1998, 287–293) identified 14 and describes several. They show primary canals, feeder canals, reservoirs, and end walls between terraces. Different functions have been suggested, but Brooks believes that the Colca *maquetas* served as general plans for terrace irrigation systems and also had a ceremonial role. The famous Sahuite *maqueta* in Cuzco depicts terraces and canalsEuropeaner features. There is a full-scale model in the Museo de la Nación in Lima (Denevan 2001, Fig. 1.1).

For Coporaque, Treacy (1994b, 81–84) described three types of sloping-field terraces: (l) linear, valley side, segmented, some with side walls (124 ha); (2) roughly rectangular, fully walled, near ridge tops (122 ha); and (3) stone-bordered, roughly rectangular, in nearly flat areas (460 ha). All were probably designed to trap

[1] Treacy (1987a, 53; Treacy 1994b, 147) believed that the Coporaque bench-terrace fills were done by hand, whereas sloping-field terraces were self-filling via downslope movement of soil. Sandor (1987a, 185), however, believes that the Coporaque bench terraces were filled by natural slope processes.

runoff. Slope runoff was also directed by diversion walls into reservoirs and into canals which fed irrigated bench terraces. Treacy (1994b, 108) mapped five such sectors in the Coporaque area. Sloping-field terraces tend to measure between 1.3 and 2 m in wall height, 13 to 16 m in width, and between 30 and 50 m in wall length. The broad, sloping catchments of these terraces suggest that they were in part accretional or self-filling fields; they do feature artificial cobble drainage horizons. Most fields of this type are now abandoned in the Colca Valley.

Broad-field, irrigated bench terraces occur in places where steep upper slopes become more gentle, and they are often enclosed by stone walls. Valley-floor broad-field terraces occur on the nearly flat, alluvial terraces (*pampas*) of the Río Colca. Walls are of stone or earth and are only 20–100 cm high, with very wide cultivation sectors between walls, compared to narrow bench terraces on slopes.

Simple cross-channel terraces and check dams, some no more than a rough line of stacked stones, are scattered thinly through parts of the valley. They generally cross gullies or intermittent stream channels on moderate slopes. Examination of aerial photographs shows that barrage-like terraces – stone walls flanked by long, perpendicular water diversion walls – may have been constructed in some areas of the Colca Valley, but field ground checks are needed to confirm them. Cross-channel terraces, like most sloping-field terraces, are today unfarmed.

Non-terraced fields in the valley include large numbers of abandoned, stone-lined plots. There are 460 ha of these east of Coporaque in dissected lava-flow terrain between the Pampa Finaya plateau and the Río Colca. Smaller sectors occur in Tuti, Yanque, and Maca. The walls are of stacked stones 0.5 to 2 m high. They enclose mostly gently sloping fields rectangular or irregular in shape, ranging from 400 to 5000 m^2 in size (Treacy 1994b, 86). The function of the stone walls is not known, possibly a means of moisture conservation.

There are now numerous unterraced, irrigated valley-floor fields of roughly rectangular shape on the *pampas*. They are surrounded by adobe or stone walls which serve to keep cattle out. These walls are rare on the Shippee-Johnson air photos of 1931, when sectorial, open-field grazing was still being practiced. Enclosure took place after 1940 as cattle greatly increased and seriously damaged crops (González 1995, 44–58). Other fields are house and garden plots and recent (since the 1970s), unterraced but irrigated, valley-side sloping fields. The latter fields were made following new canal construction; such unterraced fields probably would have been unthinkable in pre-European times.

The Soil Factor

We have considerable information about the soils of the Colca terraces and associated non-terraced terrain, thanks in particular to the research by Jon Sandor and Neal Eash (Sandor 1987a, 1987b; Eash 1989; Sandor and Eash 1995; Eash and Sandor 1995; also Dick et al. 1994). Most of the Colca terraces still utilized have been in near-continuous cultivation since the early colonial period, given the descriptions of specific fields in the *visitas* (censuses) – fields we can still identify from their names. Cultivation of these same fields undoubtedly extended well into pre-1492, given the dates we have from excavated terraces. Hence, a major question is what was the impact of many centuries of cultivation on the terrace soils? How was soil fertility maintained? Is soil decline related to terrace abandonment?

The region is underlain by volcanic andesitic and rhyolitic rocks, which generally weather into fertile soils. The soils consist of alluvium and colluvium derived from these materials. There are also lava flows and some volcanic ash present. The natural soils on slopes are mainly mollisols, which are grassland soils with abundant humus found in semiarid regions. The degree of soil development in the Colca varies with geomorphic surface and age.

The terrace soils show significant differences from non-terraced soils as a result of long-term cultivation. The thickness of the A horizon is greater, and phosphorus, nitrogen, and organic carbon levels are higher, as are earthworm activity, friability, and water capacity. These differences reflect centuries, possibly 1,000 years or more, of application of fertilizers (manure, hearth ash, garbage, crop residues); terracing which reduces erosion; and tillage, irrigation, crop rotation, fallowing, and use of legumes. These soil characteristics generally pertain to both still-cultivated terraces and long-abandoned terraces, as compared to terrain not terraced, thus indicating persistence of earlier, even ancient, soil management impacts. Phosphorus levels are less, however, in abandoned terraces, indicating partial depletion during the historical period with cessation of fertilization except from livestock manure. High levels of phosphorus appear in the B horizons of terrace soils, suggesting a very long period of downward movement of phosphorus from fertilizer (Sandor and Eash 1995, 177). Thus the "data suggest that soil changes have taken the forms of increased fertility and tilth and that traditional agriculture management practices have conserved soils" (Sandor and Eash 1995, 178). This has made possible near-continuous cultivation of some sectors for as long as 1,500 years (Sandor and Eash 1995, 170).

Terrace Origins

The origins and evolution of the Colca terraces, particularly the irrigated bench terraces, may be related to circumstances that could help explain later abandonment of both irrigated and unirrigated (rainfed and runoff) terraces. Our archaeological excavations at Chijra (Chishra) and Chilacota (Ch'ilaqota)[2] near Coporaque, at Cabanaconde and Achoma, and later in the Río Japo Basin near Chivay (Fig. 2.8) are not conclusive but provide instructive insights. I will focus on Chijra and to some extent the Japo Basin, areas for which we have the best descriptions, ceramics, and carbon-14 (C-14) dates.

[2] These local names are not villages but rather locales, specific habitats with clusters of fields, whose present toponyms can usually be found in the early colonial *visitas*.

The Chijra Area Terraces

The Chijra terraces are located on a ridge just west of Coporaque along a slope extending from 3,752 m down to 3,272 m at the edge of the Río Colca (Figs. 2.9, 2.11, and 2.12). The site of Chijra is an uplifted alluvial fan of moderate slope. There are over 100 abandoned terraces, of which we measured and described 30 (Treacy and Denevan 1986–1988). Of these all are valley-side bench terraces except for six broad-field bench terraces on the gentler lower slope. A large stone aqueduct crosses the terraces at a right angle, splitting into two arms before ending at the sharp break in slope at the lower edge of the broad-field terraces. The aqueduct is 5 m wide at the base and 1 m or more in height in places. On top are the remnants of a stone-lined canal, with a rock gate which could be closed by large stones to force water out of the canal laterally onto the terraces. Water was then dropped, terrace by terrace via stone water-drop grooves, down the faces of the back walls onto spreading stones at the base of the grooves (Denevan 2001) (Fig. 2.13). Small channels of stones across the bench surfaces led the water to the edge of the next wall

Fig. 2.11 Air photo of Chijra, Coporaque ina the Colca Valley, Peruvian Andes, showing abandoned terraces, aqueduct (inverted Y), and prehistoric house walls. The terraces on a steep slope at the lower center and left are in the sector of Alto Cayra. [The terraces in the upper left corner are in cultivation.] (Photograph by Robert Shippee and George Johnson, 1931. American Museum of Natural History)

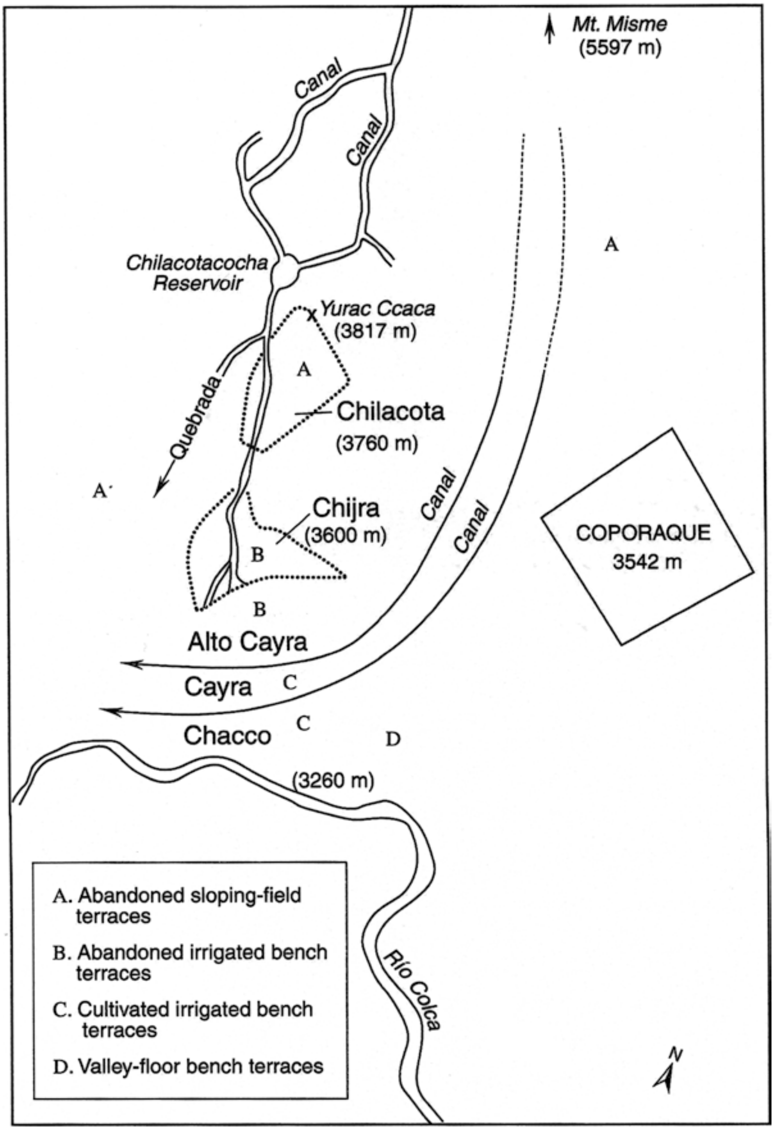

Fig. 2.12 Map of Chijra and environs, District of Coporaque, Colca Valley, Peruvian Andes. See Fig. 2.9. (By W.M. Denevan)

below, or water was allowed to fall all along the edge to the next level, as is done today in the area. Farmers now use hoes to spread water evenly over a cultivation surface ("teaching water" Treacy 1994a, 100) and then move it quickly to the next level to avoid oversaturation. Stepping stones and benches in the walls are common, as are vertical interior drains. The aqueduct was fed by a canal leading from a reservoir above at Chilacotacocha (Fig. 2.12). The bench terraces average 1.7 m in

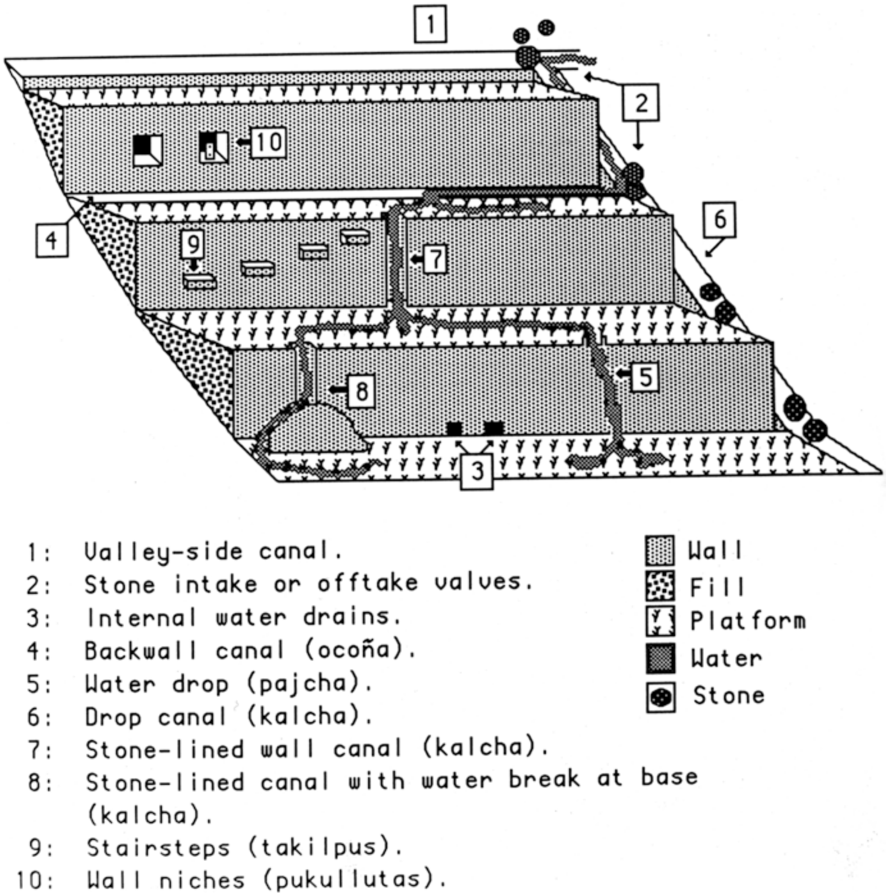

Fig. 2.13 Schematic view of bench terrace and associated features, Coporaque, Colca Valley, Peruvian Andes. (From Treacy 1994b, 111. [Added here from Denevan 2001, 179])

height and 7 m in width, and some were over 100 m in length. Terrace walls are single walls of uncut stone without mortar; they are underlain by cobble-fill to facilitate drainage. Vertical end walls may have served as divisions between household fields. (For details, see Treacy 1994.) Also, there are ruins (walls) of ten Collaguas houses at Chijra, most located on the broad-field terraces (Fig. 2.11).

Above Chijra at about 3,600–3,750 m on a gently sloping plateau is the site of Chilacota (Martin 1986–1988). There is no evidence of any irrigation. There are three massive earthen walls across the plateau that may have served to trap runoff for crop growth. Between the walls there are 15 roughly rectangular smaller walls (double stone walls vertically and single walls horizontally) – a form of sloping – field terracing. The abandoned Chilacotacocha reservoir (3,400 m^2) is just north of the plateau, separated by a *quebrada* (gully). The south wall of the reservoir is 5 m high and has a water gate in it. From the gate a canal leads past Chilacota both to

Chijra and to a *quebrada* which fed canals and terraces west of Chijra (Fig. 2.12). The reservoir was fed by canals receiving meltwater from the snow line well above on the slopes of Cerro Mismi. Also, there is a long wall from a *quebrada* to the northwest which apparently diverted water to the reservoir.

Below Chijra, the slope becomes very steep and is covered with abandoned, highly deteriorated, very narrow bench terraces (Alto Cayra). Some of these were irrigated by the aqueduct, while others were apparently unirrigated. Below this there are two active horizontal canals coming from the east side of the ridge. They irrigate active bench terraces between them at Cayra (Qayra) and bench and broad-field terraces between the lower canal and the Río Colca at Chacco (Chaqo) (Figs. 2.11, 2.12, and 2.14).

At Chijra, three terraces were trenched through sections of bench and wall, and two more terraces were excavated at Cayra and Chacco (Malpass 1987). Neira Avendaño (1990, 155–166) excavated one of the house ruins. We obtained 20 C-14 dates from the terraces, the house floor, and an irrigation canal (Malpass 1987, 61). Ceramics, lithics, animal bones, and pollen were collected (Malpass and Vera Cruz 1986-1988). At Chilacota, seven test pits and trenches were made in and near the sloping-field terraces. The accumulation over well-developed soil was only about 20 cm. No house walls were found, but a possible hearth was trenched near the terraces. Ceramic fragments were found, mostly undiagnostic, along with lithics, including very small (2–4 cm long) obsidian points used in hunting, and substantial

Fig. 2.14 Abandoned terraces (upper) at Alto Cayra and cultivated terraces (lower) at Cayra, oporaque, in the Colca Valley, Peruvian Andes. They are separated by an active, horizontal irrigation canal, which does not show clearly. (From Treacy 1994b)

quantities of deer and camelid bone. The only C-14 dates for the house, AD 300 ± 70 and 1570 ± 80 BC, were from soil below walls and are not good indicators of time of wall construction, but they do suggest a considerable antiquity.

The Japo Basin Terraces

In the Río Japo Basin between Chivay and Yanque, geographer/archaeologist Sarah Brooks (1998) carried out a detailed study of terrace history in the vicinity of the Collaguas ruins of Juscallacta (above Chivay). Here there are a variety of abandoned and still-cultivated terraces. These include crosschannel, sloping-field, and bench terraces, all abandoned and never irrigated, between 3,775 and 4,000 m (Fig. 2.15). About 1,500 irrigated, mostly still-cultivated bench terraces, occur between 3,450 and 3,750 m. Just above the irrigated terraces, there is a lateral canal which feeds the terraces below. There is a total of about 394 ha of terraces, of which 200 ha are currently abandoned (Brooks 1998, 150); thus about 51 percent of the terraces are abandoned, almost all of which are above the canal level. There are only ten or so sloping-field terraces surviving (compared to hundreds in the Coporaque area), and a few dozen cross-channel terraces, so most of the abandoned terraces are unirrigated bench terraces. Most of the lower, irrigated bench terraces are broken up into segments by vertical stone walls, whereas the upper, unirrigated abandoned

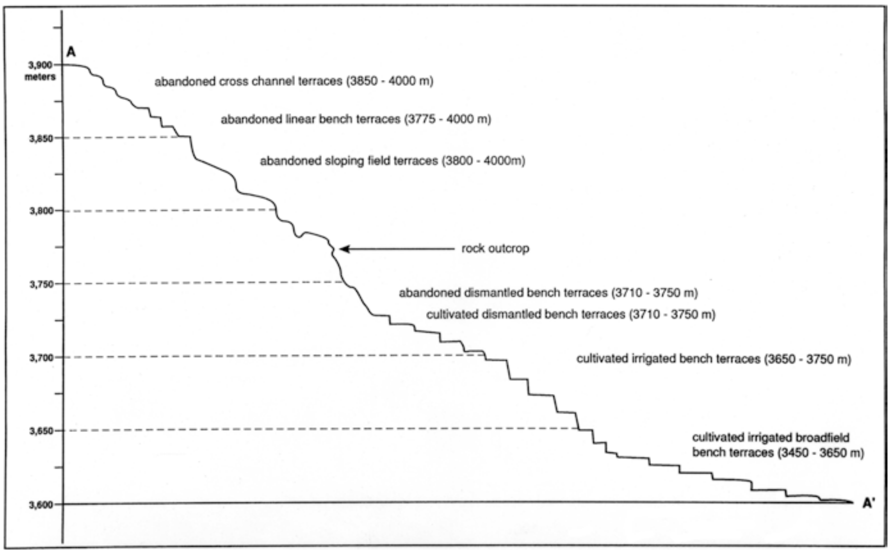

Fig. 2.15 Generalized slope profile showing approximate elevations of terrace types in the Japo Basin, Colca Valley, Peruvian Andes. The linear bench terraces were unirrigated. (From Brooks 1998, 149)

terraces are not. There is much less abandonment of irrigated terraces at Japo than at Coporaque.

Between 3,710 and 3,750 m, there is a band of dismantled (front walls removed) irrigated bench terraces, some cultivated and some abandoned. This destruction is of narrow terraces on steep slopes where the removal of terrace walls facilitates plowing with oxen. It may have begun in the colonial period and is continuing. The result is a probable increase in soil erosion and a reduced control of irrigation water (Brooks 1998, 170–176). Water can still be released from the horizontal feeder canal above onto the now unterraced sloping fields. Elsewhere, terraces are removed to plant forage for livestock (Benavides 1997).

Other terraces or locales in the Colca Valley were excavated at Achoma (Shea 1987, 1997) and Cabanaconde (Vera Cruz Chávez 1987, 1988), and ceramics have been collected elsewhere (Vera Cruz Chávez 1989); however, no terraces or anything else were dated from these areas.

Terrace Chronology

We obtained several C-14 dates for terraces and canals from our excavations at Chijra near Coporaque (Malpass 1987, 61), as did Brooks (1998, 286) for the Japo Basin. These dates are from buried soil and charcoal from within terrace fills and beneath terrace walls. A word of caution is necessary before looking at these dates. Terrace walls are continually being rebuilt or repaired, and the soil fill behind the walls is disturbed by cultivation and also by both erosion and soil movement from above. Hence, anything dated in a terrace wall or fill, or an original soil surface beneath a fill or wall, may not be a reliable date for cultivation of that horizon or surface.

Brooks dated a sloping-field terrace at 3,790 m in the Japo Basin to 2350 BC. A date of 1570 BC for a sloping-field terrace at 3,760 m at Chilacota (Fig. 2.12) suggests that this type of terrace was also in use very early in the Colca Valley. There are no dates available for cross-channel terraces, but they are also undoubtedly very early. Probably both sloping-field and cross-channel terraces are older than unirrigated bench terraces, as the former are less complex and less labor-intensive but have a lower portion of cultivated space than do bench terraces. Probably all three types of unirrigated terraces continued in use until the development of irrigated bench terraces, and some continue in use today in the Colca Valley. Brooks dated an unirrigated bench terrace at 3,790 m the Japo Basin to AD 1510 and one at Pampa Finaya [between Coporaque and Chivay] at 3,880 m at AD 655.

For irrigated bench terraces at Chijra (Fig. 2.12), the most reliable early dates are for the lowest levels of three excavated terraces: AD 510 and 660 (Trench I), 550, and 570. For Trench I there are upper horizon level dates of AD 940, 1020, and 1370, and at Cayra there is a terrace date of AD 1340. In the Japo Basin, Brooks has dates for irrigated bench terraces of AD 780, 1690, and 1847. There seems to have been terrace cultivation throughout the colonial period.

Thus, the pattern of terrace types, elevations, and dates in the Japo Basin and in the Coporaque area indicates early unirrigated terraces (2350 BC or older) above 3,790 m (Japo) and 3,760 m (Chilacota) and a shift downslope to irrigated bench terracing by at least AD 500–600. Most of the irrigated bench terraces in the Japo Basin continued in use to the present. In the Coporaque area, the terraces at Chijra and Alto Cayra were abandoned at some time, whereas the lower terraces at Cayra and Chacco have continued in use (Fig. 2.12). Settlement also moved downslope, from Juscallacta to the area of present Yanque and Chivay and from Chilacota and Chijra to the area of Coporaque.

Changing Terrace Forms

The shift of terrace cultivation downslope, with irrigation added, can be related both to changing climatic conditions and to increasing population pressure which necessitated dependable production in a region of undependable precipitation. Rainfall for Yanque at 3,417 m currently averages 419 mm Brooks 1998: 65), which is inadequate for rainfed (unirrigated, non-runoff, watered) maize (c. 600 mm minimum) and potatoes (c. 500 mm minimum); however, quinoa and cañihua, when well-spaced, need as little as 300 mm and were probably important crops on nonirrigated terraces (Treacy 1994b: 107). Rainfall in the Colca is somewhat higher at higher elevations, an estimated 518 mm at 4,000 m (Brooks 1998, 390).[3] Certainly there is sufficient moisture today for runoff fields (cross-channel terraces and sloping-field terraces), and even unirrigated bench terraces planted in quinoa. However, very few of these terraces are cultivated now, only 9 percent in the Colca Valley, mostly in the community of Achoma and none in Coporaque or in Chivay which includes the Japo Basin (Denevan 1988: 22).

There were relatively dry periods in the central Andes of Peru during AD 540–560, 570–610, 650–730, and 1040–1490 with precipitation reduced c. 5–20 percent, based on ice core measurements at Cerro Quelccaya east of the Colca Valley (Thompson et al. 1994; Brooks 1998, 74). Such a decline in rainfall could have contributed to the development of irrigated bench terraces at lower elevations where slopes are gentler and more easily irrigated. In addition, there is a frost factor. While there is greater precipitation above 3,750 m, there is also a greater frequency of frost and hence crop failure. The upper limit of agriculture, based on frost risk, was depressed as much as 150 m during the periods AD 650–850 and especially 1240 or 1255 to 1850 or 1880 AD (Little Ice Age) (Brooks 1998, 71, 384). The shift to irrigated terraces at lower elevations may relate to dry or cold periods or both. However, with sloping fields as high as 4,200 m above Chilacota and irrigated bench terraces being below 3,760 m at Japo and Cayra, a decline in the frost line would be of limited significance.

[3] Based on Winterhalder (1994, 47, 60). Winterhalder demonstrates why irrigation is required in the Colca Valley on the western side of the southern Peruvian Andes, whereas in the Sandia Valley on the eastern side, rainfed cultivation of terraces is possible due to greater total rainfall and other factors.

Thus, there were two climatic stress periods during the past 1,000 years: first, AD 540–730 (dry) and 650–850 (cold), and second, AD 1040–1490 (dry) and 1240–1880 (cold). The dates for irrigated bench terraces suggest that they were first being constructed during the earlier period. They may have been elaborated and expanded during the latter period. Malpass (1988) believes that the presently utilized irrigated terraces at Cayra and Chacco were not developed until the Inca period, but this seems much too late given such terracing in many parts of Peru well before then. The abandoned irrigated terraces at Chijra and Alto Cayra, fed by vertical feeder canals, probably date to the earlier dry period, whereas the still-cultivated terraces lower down at Cayra (a single date of AD 1340) and Chacco, fed by horizontal canals, may date to the later dry period (Fig. 2.12). Also, fewer animal bones and lithics (obsidian arrow points) were found in the lower terraces compared to Chijra and Chilacota, indicating a greater emphasis on agriculture and less on hunting and grazing at the lower terraces.

In parts of the areas of irrigated bench terraces, there already may have been sloping-field and unirrigated bench terraces that were either destroyed by the new irrigated terraces or were converted into the new terraces. This is suggested by the sharp divisions between abandoned unirrigated terraces and irrigated terraces, the division marked by a lateral canal constructed to irrigate the lower terraces. Such a sharp lower boundary for the unirrigated terraces would not have existed prior to the canal, so unirrigated terraces may have extended below the level of the present canal. Our excavation of Trench 1 at Chijra did expose a buried stone rubble wall, dated AD 940, suggesting the construction of the present terrace over a previous one (Malpass 1987, 54–56). Both Treacy (1994b, 102–105) for Chijra and Brooks (1998, 392) for the Japo Basin argue for the conversion of unirrigated terraces into irrigated terraces below 3750–3760 m. The two terrace types could have coexisted for a time until the superiority of the irrigated bench terraces was clearly recognized. Some seemingly abandoned sloping-field terraces in Coporaque are cultivated today when adequate rainfall occurs or is anticipated.

This scenario, drawing on Brooks and Treacy, is an argument that the development of complex labor-intensive irrigated terraces resulted, in part at least, from climatic stress.[4] This is contrary to some popular and academic thinking that climatic deterioration (dryer, colder) was the cause of agricultural and social collapse at various places in the world. In the Colca Valley, climatic stress instead seems to have motivated the development of a more efficient, more productive, and less risky method of food production. There is another dimension to this story, however. Even without long-term climatic change, there was regular climatic variation, especially in precipitation, and thus a great risk to crops during very dry years. For example, at Yanque with an average of 419 mm rainfall over 31 years, the wettest year had 708 mm, and the driest year had only 213 mm. Intermittent crop failure during dry

[4] Cardich (1985) argues that shifts of cultivation to lower slopes in the Andes were due to climatic changes toward colder temperatures. He believes it was warmer from 300 BC to AD 500; colder from AD 500–1000, warmer from AD 1000–1350; and colder from AD 1320 through the Inca period. This might explain an abandonment of the Chilacota fields after 1320; however, temperature would not explain the often sharp division between irrigated and unirrigated terraces elsewhere.

years became progressively more of a problem to people as population grew. Irrigation is not fully dependent on immediate precipitation, but rather can also draw on reservoirs, springs, and meltwater from snowcaps. Irrigation can provide a more secure supply of water in terms of quantity and predictability, and it can extend the growing season. Thus, it is a great advantage even when there are not decades or centuries-long periods of reduced rainfall. Irrigation continues during wet periods, as we see in the twentieth century.

Finally, an expansion of terracing and a shift of cultivation downslope during late pre-European contact may have been associated with a greater interest in maize, which requires reliable moisture, a long growing season, and minimal frost. An important role of irrigation for Andean valleys, such as the Colca, is to lengthen the growing season for maize (Mitchell and Guillet 1994, 6–7).

Thus, shifts in terrace form and elevational level could have involved more than shifts in precipitation patterns and frost lines. This question is of more than local concern. The pattern of abandoned, unirrigated terraces at higher elevations and cultivated, irrigated terraces below them is widespread in the Andes (Malpass 1988). Firmer dating of climatic, agricultural, demographic, and other events in the Colca and elsewhere is essential if we are to better understand the history of Andean agricultural fields.

Terrace Abandonment

We have considered the abandonment of unirrigated terraces; however numerous irrigated terraces have also been abandoned. Explanation is important given plans for restoring abandoned terraces.[5] There are actually two issues involved. One is the cause or causes of abandonment. The second is the reason or reasons why terraces are not restored to cultivation, given apparent land shortages in the Andes. Terrace restoration projects in Peru have paid Indian farmers to rebuild terraces and associated canal systems without knowing why the farmers themselves do not rebuild and use old terraces. It is quite possible that once terraces are rebuilt, they will not be cultivated because of lack of sufficient irrigation water, conflicts over land rights, excessive labor costs, excessive distances from villages, or for other reasons. The situation is complex, involving environmental change, technology, social and economic organization, demography, and markets. Conditions change over time and from village to village, both for the Colca and for other terraced regions of the Andes (Treacy and Denevan 1994).

[5] Proponents of the restoration and expansion of traditional terracing in Peru include Peruvian ecologist Marc Dourojani (1983, 66, 70) and several contributors to the volume on *Andenes y camellones* (Torre and Burga 1986). The United States Agency for International Development had a major project to improve traditional terrace agriculture and to construct new terraces in Venezuela, Guatemala, and Peru (Williams 1986).

Mapping Abandonment

In order to determine the degree of terrace abandonment, cartographer Laura Hartwig and I mapped and measured both cultivated and abandoned fields for the Colca Valley (Denevan 1988). We used the 1974 overlapping vertical air photos which were taken for the Majes irrigation project.[6] At a scale of 1:17,000, they are quite suitable for differentiating cultivated from abandoned terraces.

Our study included 10 of the 12 Colca communities, Tuti and Tapay lacking complete photo coverage. Seven categories were mapped: upland (sloping-field terraces) cultivated and abandoned, terrace (irrigated bench terraces) cultivated and abandoned, bottomland (valley-floor bench terraces and enclosed non-terraced fields) cultivated and abandoned, and not cultivated land.

For the mapped sectors of the valley (some of the upper zones are not on the air photos), we determined that the total area of fields was 14,356 ha, of which 6,071 ha, or 42 percent, were abandoned. The total area of bench terraces was 8,962 ha, of which 5,426 ha, or 61 percent, were abandoned. Of the sloping-field terraces, 91 percent were abandoned, and of the valley-floor non-terraced fields, only 7 percent were abandoned, possibly in fallow.

For the community of Coporaque, using the 1974 air photos at 1:17,000 scale, we measured 1,399 ha of fields, of which 726 ha were abandoned, or 52 percent. Initially, Treacy (1987a, 153, 155), using the 1955 air photos at 1:55,000 scale, obtained a total of 1,445 ha, of which 970 ha, or 67 percent, were abandoned in 1983–1984 when 475 ha were reported in cultivation or in fallow. Using our 1974 air photo mapping units plus ground checking to revise our categories of field types and cultivated versus abandoned fields, we measured a new total of 1,456 ha, of which 784, or 54 percent, were abandoned (Denevan 1988, 22). This was then adjusted by Treacy to give a total field area of 1,367 ha, of which 847 ha, or 62 percent, were abandoned or semi-abandoned (Treacy 1989, 75–76; 1994, 66). His 62 percent abandonment for Coporaque, compared to our 52 or 54 percent, suggests that for the entire valley our 42 percent based on air photo analysis alone, without ground checking, may be too low.

In Coporaque, of the valley-side bench terraces (270 ha), 43 percent are abandoned or semi-abandoned; 10 percent of the valley-floor bench terraces (267 ha) are abandoned or semi-abandoned; 100 percent of the sloping-field terraces (246 ha) and stone-bordered fields (460 ha) are abandoned; and none of the valley-floor walled, non-terraced fields are abandoned (Treacy 1994b, 66). Most of the bench terraces are or were irrigated; however at least 20–30 ha of the valley-side terraces are semi-abandoned and may never have been irrigated. The distribution of the various types of terraces and other fields in Coporaque is mapped by Treacy (1994b, 87). Figure 2.16 shows cultivated and abandoned terrace areas for most of Coporaque and Chivay and part of Yanque.

[6]The 1931 vertical photos at a scale of 1:13,000, taken by the Shippee-Johnson Expedition (Denevan 1993), are of excellent quality, and we used them to determine the change in extent of terracing for the community of Coporaque between 1931 and 1974. The difference was very small – an increase of overall cultivated area of 30 ha or c. 4 percent. This increase was on sectors of *pampa* (river terrace) land which had been uncultivated in 1931.

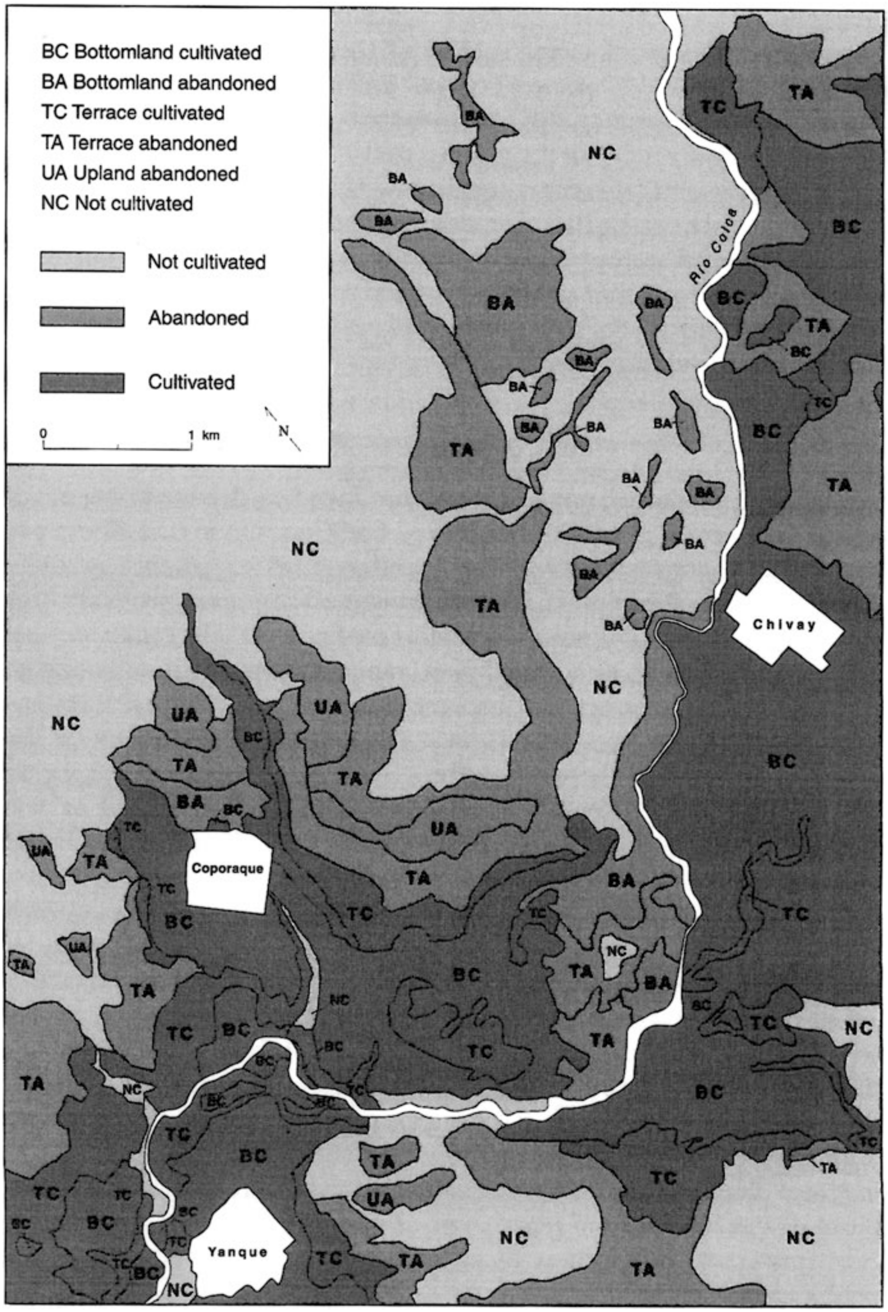

Fig. 2.16 Map of abandoned and cultivated terraces, Chivay, Yanque, and Coporaque, Colca Valley, Peruvian Andes. Based on 1974 air photos. By Laura Hartwig: corrected by John Treacy from ground observation. (From Denevan 1988, 27)

Our mapping and measurements from air photos demonstrate the following: (1) The degree of abandonment is considerable. This supports undocumented speculation that over half the visible terraces in the Andes are abandoned. (2) The abandoned terraces tend to be on the high slopes and more distant from current villages than the now cultivated bench terraces and bottomland fields. Accessibility is clearly a factor. (3) Most of the unirrigated, sloping-field terraces are abandoned – 91 percent overall and 100 percent in some communities. Sloping-field terraces still cultivated may be irrigated from springs. (4) The least abandonment is on the *pampas* near the Río Colca – only 7 percent overall and 0 percent for some communities. Here, many of the fields are now enclosed by adobe walls; they are irrigated, but many are not terraces.[7] (5) Within the mapped sectors of the valley, which total 18,128 ha, 46 percent is now cultivated, 33 percent consists of abandoned terracing, and only 21 percent is neither. Thus, a very high portion (79 percent) of the landscape is cultivated or was cultivated in the past.

Time of Abandonment

To understand why bench terraces were abandoned, we need to know not only where abandonment occurred but when. For Coporaque, the sloping-field terraces at Chilacota must have been abandoned before the Inca period (AD 1470–1530), given the absence of Inca-influenced ceramics, probably during one of the preceding prolonged dry and/or cold periods. The bench terraces at Chijra and Alto Cayra, now abandoned, were undoubtedly in use during the Inca period, given the presence of Inca ceramics. The *visitas* for 1591, 1604, and 1616 give the place names for terrace irrigation sectors, with data on crops grown in each. Many of these names (toponyms) persist today. From the three *visitas*, Treacy (1994b, 259–62) located 74 sectors for Coporaque of which 23 are not listed for 1616, suggesting their abandonment was between 1591 (or 1604) and 1616.

The presently cultivated sectors of Cayra and Chacco were in cultivation in 1591, 1604, and 1616 (also in 1931). Chijra does not appear in the *visita* lists and apparently was abandoned by 1591. Other Coporaque terrace sites listed in the *visitas* were not identified and located by Treacy and probably represent now abandoned fields. While we cannot be more precise about the dating of terrace abandonment, much of it certainly occurred during the early colonial period. Unirrigated bench terraces were abandoned earlier, at least in the Japo Basin; Brooks did not find Collaguas sherds on most of the unirrigated bench terraces above 3,800 m. Undoubtedly, terraces went in and out of cultivation from place to place and from time to time depending on circumstances, in addition to short-term periods of fallow and long-term abandonment.

[7] Most of the enclosure process occurred between 1930 and 1980 in order to prevent animal infringement into fields, thus eliminating open-field, communal grazing (González 1995).

Theories of Abandonment

The causes of irrigated terrace abandonment in the Andes have been the subject of considerable discussion and debate. Field (1966, 484–489) emphasized population decline and land-use change rather than climate. Wright (1963, 73–74) mentioned a “drying landscape” and also out migration. Donkin (1979, 35–38) gave priority to colonial depopulation, but he also discusses climatic and other theories.

A major discussion of abandonment appears in the journal *Current Anthropology* (Guillet 1987c). Guillet’s article, focusing on Lari in the Colca Valley, is followed by 11 commentaries, including by Andean cultural ecologists William Mitchell, Jeffrey Parsons, Jeanette Sherbondy, Gregory Knapp, and John Treacy; Guillet provides a final response. Guillet (1987b, 409) believes that terrace expansion and contraction are closely related to water availability, with abandonment in the short term due to “constraints in the system of water distribution” and in the long term due to periodic droughts. “During periods of relative water abundance, constraints are relaxed, allowing new terraces to be constructed and abandoned ones rebuilt.” The commentators elaborate on this thesis, raise objections, and suggest other significant factors. Treacy (425) pointed out that “one need not invoke climatic shifts alone to account for water scarcity.” J.R. Parsons (423) says there needs to be “a systematic consideration of the cultural forces that may be casual factors in terrace expansion and contraction.” Mitchell (422) emphasizes that terrace farmers today are involved in a market economy, so that there is not a direct relation between population and amount of land in cultivation. Knapp (421) reminds us that “deintensification” is a more accurate term than “abandonment,” since no-longer irrigated terraces may still be grazed or dry farmed from time to time.

Factors of Abandonment

Prehistoric Abandonment We have mentioned that the unirrigated, sloping-field terraces and bench terraces were abandoned, either because of reduced rainfall or because of the greater reliability of irrigated terraces. There was a second period of prehistoric abandonment of some of the higher irrigated bench terraces such as at Chijra and Alto Cayra, for reasons unknown. There was a concomitant shift of settlement downslope, during one or both periods, and probably a shift from a staple of frost-tolerant and low moisture-tolerant quinoa to less tolerant maize. Thus, there was considerable abandonment of terraces prior to the third period of abandonment during the early colonial period.

Colonial Depopulation We know from the ethnohistorical study by Cook (1982) that the Colca Valley suffered a major population decline in the sixteenth century due primarily to introduced epidemic diseases. For the Colca villages, the estimated decrease from 1530 to 1721 was 87 percent. For the community of Coporaque, the population changed from an estimated 5,957 in 1520 to 1,956 in 1604 (Treacy 1994b, 167), a 67 percent decrease in less than a century. Commonly, under conditions of depopulation, the most intensive forms of cultivation and the least accessible agricultural lands are abandoned. In the Colca Valley, with Spanish-controlled Indian settlements being located on the *pampas* near the river and the population reduced, the higher terraces were indeed abandoned. Population has partly recovered, but the 1981 total for the Collaguas villages was still only 68 percent of the 1530 estimate. This compares with at least a 42 percent reduction in land cultivated; however, much of the land now cultivated is in alfalfa for livestock for market; in addition, some food staples are brought in from outside the valley.

Climatic Change The relationship between terrace construction, use, and abandonment and climate is complex and inconsistent. Less precipitation (both rain and snow) would presumably mean a reduction of water available for irrigation and hence a reduction of terrace cultivation. On the other hand, decreased rainfall could have made rainfed agriculture impossible and labor-intensive irrigated terracing feasible. Farmers today say they would restore old, unused terraces to production if they had more water. However, abandoned canals reaching *quebradas* fed by snowmelt on the high slopes, such as Cerro Mismi, could be restored and irrigation water thus increased, but this has not happened. At Coporaque, there are three sectors of abandoned terraces, including Chijra, totaling 112 ha, that could be restored, each linked to unused canal systems (Treacy 1994b, 227).

I have already suggested that the shift to irrigated bench terracing first occurred during the dry period between AD 540 and 730, with later expansion during the later dry period AD 1040–1490. Large portions of both periods experienced colder temperatures which would have forced cultivation downslope where precipitation is even less, but only down c. 150 m or less. The subsequent period, AD 1500–1720, was wetter than average, but this was the time of probably the greatest abandonment of irrigated terraces.[8] The twentieth century has also been a wetter than average period, but without significant terrace restoration. (There has been some expansion of valley-floor *pampa* fields.) Thus, climate change would not seem to be a primary factor in post-conquest terrace abandonment or in the lack of much restoration of old terraces today.

Springs Many terraces on slopes are watered from springs rather than from irrigation canals leading from *quebradas* fed by rainfall and snowmelt. These springs stop flowing or dry up due to unclear events, including depleted aquifers and tectonic activity; periodically they may revive and new springs may appear. Terraces are abandoned or restored accordingly.

Tectonic Activity Stanish (n.d.) has suggested that in the Moquegua Valley, tectonic uplift may have disrupted terrace/canal connections resulting in terrace abandon-

[8] This is true for most of the Colca Valley, but not for the Japo Basin where very few irrigated terraces have been abandoned.

ment due to the cutoff of irrigation canal intakes from stream channel sources which have downcut. David Keefer (pers. comm. 1997) reports that in the Moquegua area, landslides caused by earthquakes buried a section of a prehistoric canal resulting in terrace abandonment. Some terraces have been destroyed at Lari by landslides due to undercutting by the Río Colca.

Canal Water Loss Stanish (1987, 360) believes that in the Moquegua region of southern Peru, prehistoric settlement may have been relocated up river in association with shortening of irrigation canals in order to reduce water loss from seepage and evaporation. This could have resulted in terrace abandonment in the original sectors irrigated downriver. This does not seem to be a factor in the Colca Valley where most canals have always been of relatively short length.

Canal Abandonment When canals are abandoned, the associated irrigated terraces will, of course, also be abandoned. Canal abandonment may be due to a reduction of the amount of water available but also for social and political reasons. Water may be diverted from one community or farming sector to another. In the Colca Valley, such conflicts are of long-standing and have led to bloodshed. Also, the labor required to maintain and repair a canal may become excessive in relation to productivity, especially on high, steep, and distant slopes. Figure 2.12 shows abandoned canals and a reservoir and aqueduct that once provided water to the terraces at Chijra and Alto Cayra. The abandoned 10 km long Carhuasanta Canal north and east of Cerro Mismi (Fig. 2.8) [apparently] brought water from the Río Apurimac drainage (Amazon) to the Río Colca drainage (Pacific Ocean) on the western slopes of Pampa Finaya, east of Coporaque, via another 30 km of *quebrada* and canal (Treacy 1994b, 116–120).

Water Availability and Management Efficiency How much water is actually available at the present time in canal systems in relation to crop needs? The study of the hydrology of the irrigation system in Coporaque by Waugh and Treacy (1986–1988) suggests that there is nearly three times as much water available for crop production as is used by the present crops. This would seem to indicate that in terms of water availability, the area cropped could be considerably expanded. We must keep in mind, however, that during some periods of the growing season, there is more irrigation water available than can be used and the surplus is vented into the main *quebradas* and the Río Colca and thus lost to the crop system. Furthermore, no system of water management for crop production is 100 percent efficient in capturing all the water brought into an irrigation system. Nevertheless, the loss of two-thirds of the water available seems excessive and raises the question of possible change in water management efficiency since prehistoric times.

Variation over time in water management efficiency would mean increased or decreased water supplies for irrigation. For example, if water is dropped too rapidly through a terrace system, more water runs off rather than being absorbed by the soil and being available for greater crop production. Indications are that water management technology in pre-European times differed from current technology. For one thing, the Spaniards destroyed a social organization that probably contributed to efficient management of complex terrace/irrigation systems.

Maria Benavides (1997) points out that in the Colca Valley, there is insufficient irrigation water available to irrigate both the existing abandoned terraces and the currently cultivated terraces. Thus, she believes, when terraces were developed at lower elevations, where irrigation is more feasible, the terraces at higher elevations had to be abandoned. However, the higher terraces were not irrigated but were fed by rainfall and runoff. The moisture captured by the high terraces, which otherwise could have ended up in the canal system for the irrigated terraces below, would have only been a portion of the total water available for irrigation.

Vegetation and Soil Change Agriculture and overgrazing have drastically modified and reduced the natural vegetation cover, making slopes more susceptible to rapid runoff rather than water retention in the soil. Hence, the moisture available to crops from rainfall and runoff is reduced. Soil analyses by Sandor (1987a, b) indicate that soil fertility was improved with terracing and thus was not likely a factor in terrace abandonment. Soils are mostly derived from volcanic and alluvial material and are relatively fertile. Furthermore, they are now maintained by the application of manure and compost and by periodic fallowing, and both were likely true in the past. Sandor surprisingly found fertility of the surface soils to be comparable in both cultivated and abandoned terraces. The latter are not actively fertilized, but do receive manure from grazing livestock.

Loss of Terrace Knowledge An anonymous reviewer has queried whether terrace abandonment could be the result of post-Columbian loss of knowledge of how to construct and maintain terraces effectively. Ancient terraces are still maintained and repaired and some new bench terraces are being constructed. The quality of terraces has indeed deteriorated in some places, resulting in premature wall collapses and washouts (Treacy 1987b, 53–54). A higher frequency of breakdowns occurs where previous breeches were not adequately repaired. However, terrace farmers are well aware of good versus poor practices, so deficiencies are not necessarily a matter of loss of knowledge. And regardless of their knowledge about maintenance and rehabilitation, farmers today know little about how their terraces were initially developed, most present terraces having been first constructed hundreds of years ago (Williams 1990, 91). Involved is not only information about construction but also decision-making as to location, dimensions, soil and water management, etc. Knowledge which may have been lost could have been replaced by adequate similar or different techniques. So, we do not know if loss of traditional knowledge has contributed to terrace abandonment, but this seems unlikely.

Labor Inputs Today these are clearly larger for terraces on higher slopes compared to those for lower slopes. This is due to (1) greater distances from settlements to fields and hence travel time; (2) the difficulty of working on high, steep slopes; and (3) the higher level of maintenance necessary for terraces on steep slopes. Also, soils may be poorer on higher, steeper slopes, resulting in lower crop yields per investment of labor. Nevertheless, farmers in Coporaque say that high labor input is not the reason why they do not restore and farm abandoned terraces.

Changes in Land Use The introduction of European crops and cattle caused the breakdown of a fragile agroecology. Cattle rapidly damage terraces, increasing maintenance and at times leading to terrace abandonment. The walls of bnch terraces, both abandoned and used, have been ripped out in some areas in order to facilitate both plowing and grazing. The Spaniards brought about a greater emphasis on pastoralism, which has low labor requirements, at the expense of agriculture. The recent shift toward planting alfalfa for cattle feed has reduced the land in subsistence crops. Thus, the relation between land terraced, food production level, and number of people supported is less direct than in the past. Finally, segments of terraces, abandoned and cultivated, have been destroyed by the road and canal-building activities of the Majes water diversion project.

Social Access to Land and Irrigation Water Communities as well as individual households do not have equal access to irrigation water. (This can result in violent conflict or in efforts to renegotiate access to water.) One community or some farmers, as a result, can have sufficient water to cultivate all the land available, whereas adjacent communities or neighbors do not have enough water to irrigate all their terraces. Furthermore, if more water were available, it would be very difficult for people in a community to agree on who would have access to it as well as to the new land which would be irrigated. Additional land for additional irrigation would not likely come from private holdings but rather from unused land that is almost all communal land used for pasture. J. Treacy (pers. comm. 1988) indicated that in Coporaque in the 1980s, there were prospects of obtaining additional water and opening up an abandoned canal (the "Inca" Canal east of the village), but agreement could not be reached on who would get the abandoned terrace land for restoration and the new water to irrigate it, and hence the plan was dropped.

As Treacy (1989, 342) pointed out, farmers are most concerned with the timing of water availability, "making sure that supplies are distributed in an orderly fashion among many users during the time scarce supplies are available to seed crops. The total amount of water [available] is an abstraction of little interest to many Coporaqueños." Timing has to do with crop needs in relation to climate, water storage capacity, the irrigation system, and the social allotment of water. "Few would be willing to give up their water rights and privileges to risk watering new lands under unfavorable conditions." Water security is more important than maximizing water supply in order to increase land area cultivated. For a discussion of the problems with attempts to restore abandoned terraces at Coporaque, see Treacy (1987b).

Alternative Livelihoods Under conditions of population growth and even with population stability, there may be attractive alternatives to farming terraces under difficult conditions as well as to subsistence farming in general. These alternatives include seeking wage labor locally and migration in search of jobs in Arequipa or on the coast. The attractions may be food, or cash, or urban excitement and opportunities, or hopes of a better life for the next generation. Low market prices for farm staples is another factor. Rural to urban migration is occurring throughout the South American Andes for these reasons.[9] For the 12 central Colca villages, the population increased from 15,201 in 1940 to only 21,517 in 1981[10] (Denevan 1987, 17), a period during which the population of Peru nearly tripled. The young people of the Colca Valley have chosen to go elsewhere rather than restore and farm abandoned terraces.

Conclusion

By the completion of our Colca terrace project, the focus of research had shifted from explaining bench-terrace abandonment, which was primarily related to sixteenth-century population decline, to explaining why abandoned terraces had not been restored and brought back into production. We realized that in our emphasis on ecological research, we had neglected socioeconomic matters which are critical to understanding why abandoned terraces stay abandoned – resource management policy (especially water rights), land tenure, and alternative livelihoods. These conditions, of course, are themselves affected by the expansion and contraction of land under cultivation. Subsequent studies of the Colca Valley gave greater attention to water management as the key to land use, particularly terrace use: Treacy (1989, 1994b) on Coporaque, Guillet (1987b, 1992) on Lari, and Gelles (1990, 1994) on Cabanaconde, as well as elsewhere in the Andes (Mitchell and Guillet 1994).

The short- and long-term variability in the environment, especially climate, creates conditions which the Colca people have more or less adapted to by changing the form and location of terracing. However, demographic growth, or lack of growth, or decline seems to be the most important reason for [either] terrace expansion or contraction. Today, there is demographic stagnation without terrace restoration. There is demographic stagnation because people perceive better opportunities elsewhere. As the population continues to grow and external opportunities decline, there may be an indigenous movement back to the semiarid Andean mountain valleys such as the Colca. In the Colca, at least, environmental conditions do not seem to preclude the restoration of now abandoned irrigated terraces. What was done in pre-European times should be able to be done today and without resorting to energy- and capital-expensive modern technology.

[9] Depopulation or stagnation has occurred in many Andean villages in recent decades, despite higher fertility and survival rates (Preston 1996).

[10] The 1993 Census gives a lower total of 18,344 (Brooks 1998, 104).

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