Chapter 6
The Geomorphic Landscape: Criteria for Classifying Geoforms

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Abstract Combining the basic criteria to build a taxonomic system with the hierarchic arrangement of the geomorphic environment determines a structure of nested categorial levels. Five of these levels are essentially deduced from the epigeal physiographic expression of the geoforms. To substantiate the relationship between geoform and soil, it is necessary to introduce in the system information on the internal hypogeal component of the geoforms, namely the constituent material, which is in turn the parent material of the soils. As a result of the foregoing, an additional level is needed to document the lithology in the case of bedrock substratum or the facies in the case of unconsolidated cover materials. This leads finally to a system with six categorial levels, identified by their respective generic concepts, including from upper to lower level: geostructure, morphogenic environment, geomorphic landscape, relief/molding, lithology/facies, and the basic landform or terrain form. Such a system with six categories complies with *Miller's Law*, which postulates that the capacity of the human mind to process information covers a range of seven plus or minus two elements.

Keywords Geomorphic classifications · Classification system structure · Levels of landscape perception · Geoform taxonomy · Geomorphometry

6.1 Introduction

Unlike other scientific disciplines, geomorphology still lacks a formally structured taxonomic system to classify the forms of the terrestrial relief, hereafter designated as *geoforms*. There is some consensus for grouping the geoforms according to the

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families of processes that operate on given geologic substrata or in given bioclimatic zones. Examples of the former are the karstic forms generated by the dissolution of calcareous rocks, desert forms shaped by wind, glacial forms resulting from the activity of ice, or alluvial forms controlled by the activity of the rivers. However, these geoforms are not integrated in a structured hierarchic scheme. It is necessary to create a system that allows accommodating and organizing the geoforms according to their characteristics and origin and also considering their hierarchic relationships. This requires a multicategorial framework.

Geoform is the generic concept that designates all types of relief form regardless of their origin, dimension, and level of abstraction, similarly to how the concept of soil is used in pedology or the concept of plant in botany (Zinck 1988; Zinck and Valenzuela 1990). The term of geoform, with generic meaning, has been introduced recently in the Spanish version of the FAO Guidelines for soil description (FAO 2009). Geoforms have an internal (hypogeal) component and an external (epigeal) component in relation to the terrain surface. The internal component is the material of the geoform (the content), the characteristics of which convey genetic and stratigraphic (i.e., chronological) information. The external component of the geoform is its shape, its "form" (the container), which expresses a combination of morphographic and morphometric characteristics. The external component is directly accessible to visual perception, proximal or distal, either human or instrumental. Ideally, the classification of the geoforms should reflect features of both components, i.e., the constituent material and the physiographic expression. The external appearance of the geoforms is very relevant for their direct recognition and cartography. For this reason, a system of geoform classification must necessarily combine perception criteria of the geomorphic reality and taxonomic criteria based on diagnostic attributes.

Seemingly, geoform taxonomy has not fomented the same interest as plant taxonomy and soil taxonomy did. This might be due to the fact that more importance has been given to the analysis of the morphogenic processes than to geomorphic mapping which requires some kind of classification of the geomorphic units. There are few countries that have had, at some time, a systematic program of geomorphic mapping similar to those carried out in several Eastern European countries after the Second World War or in France in the second part of the last century (Tricart 1965; CNRS 1972).

Soil map legends often ignore the geomorphic context that, however, largely controls soil formation and distribution. Usually, the legend of the soil maps shows only the pedotaxa, without mentioning the landscapes where the soils are found, although the concept of "soilscape" is considered to provide the spatial framework for mapping polypedons (Buol et al. 1997). A mixed legend, showing the soil in its geomorphic landscape, facilitates the reading, interpretation, and use of the soil map by nonspecialists working in academic and practitioner environments (see the example in Fig. 4.2, Chap. 4). With the use of GIS, the geomorphic context is emerging as the structuring element of a variety of legends, including legends of taxonomic maps, interpretive maps, and land-use planning maps, among others.

6.2 Examples of Geomorphic Classification

Geomorphologists have always shown some interest in classifying geoforms, but the criteria used for this purpose have changed over the course of time and are still very diverse. After mentioning some geomorphic classification approaches, the structure of a taxonomic system for geoform classification is decribed. This has been developed from geopedologic surveys in Venezuela and later used in the ITC (Enschede, The Netherlands) to train staff from a variety of countries in Latin America, Africa, Middle East, and Southeast Asia (Zinck 1988; Farshad 2010).

6.2.1 *Classification by Order of Magnitude*

The dimensional criterion has been used by several authors to classify the geomorphic units (Tricart 1965; Goosen 1968; Verstappen and Van Zuidam 1975; among others). These classifications are hierarchic, with emphasis on structural geomorphology in the upper levels of the systems. The classification proposed by Cailleux-Tricart (Tricart 1965) in eight temporo-spatial orders of magnitude is a representative example of this approach (Table 6.1). The spatial dimension and the temporal dimension of the geomorphic units vary concomitantly from global to local and from early to recent. Tricart (1965) considers that the dimension of the geomorphic objects (facts and phenomena) intervenes not only in their classification, but also in the selection of the study methods and in the nature of the relationships between geomorphology and neighboring disciplines.

With a similar but less elaborate approach, Lueder (1959) distributes the geoforms in three orders of magnitude. The first order includes continents and ocean basins. Mountain ridges are an example of second order. The third order includes a variety of forms such as valley, depression, crest, and cliff.

Table 6.1 Taxonomic classification of the geomorphic units by Cailleux-Tricart

Order	Unit types	Unit examples	Extent (km^2)	Time (years)
I	Configuration of the earth's surface	Continent, ocean basin	10^7	10^9
II	Large structural assemblages	Shield, geosyncline	10^6	10^8
III	Large structural units	Mountain chain, sedimentary basin	10^4	10^7
IV	Elementary tectonic units	Serranía, horst	10^2	10^7
V	Tectonic accidents	Anticline, syncline	10	10^6–10^7
VI	Relief forms	Terrace, glacial cirque	10^{-2}	10^4
VII	Microforms	Lapies, solifluction	10^{-6}	10^2
VIII	Microscopic features	Corrosion, disaggregation	10^{-8}	–

Summarized from Tricart (1965)

6.2.2 Genetic and Genetic-Chorologic Classifications

There are variants of genetic classification of the geoforms based on the conventional division of geomorphology as a scientific discipline in specialist areas concerned with different types of geoforms (Table 6.2).

The genetic-chorologic classification of geoforms is based on the concept of morphogenic zone. The latitudinal and altitudinal distribution of the morphogenic zones parallels the division of the earth's surface in large bioclimatic zones, generating a series of morphoclimatic domains, each with a specific association of geoforms: glacial, periglacial, temperate (wet, dry), mediterranean, subtropical, and tropical (wet, dry). The classification combines origin and geographic distribution of the geoforms. It is often used to present and describe the geoforms by chapters in textbooks on geomorphology. This type of classification is based on some kind of hierarchic structure and leads to a typology of the geoforms but does not provide a clear definition of the criteria used in the ranking and typology. There is tendency to emphasize one type of attributes of the geoforms to the detriment of others: for instance, the dimension, or the genesis, or the geographic distribution.

The project of the Geomorphic Map of France (CNRS 1972) establishes a hierarchy of geomorphic information in five levels, called *terms*, as reference frames to gather the data, represent them cartographically, and enter them in the map legend. The five terms are in descending order: the location, the structural context (type of structural region, lithology, tectonics), the morphogenic context (age, morphogenic system), surface formations (origin of the material, particle-size distribution, consolidation, thickness, morphometry), and finally the forms. The last term contains the entire collection of recognized forms, with grouping into classes and subclasses according to the origin of the forms. Each form is given a definition and a symbol for its cartographic representation. Two main groups of forms are distinguished: (1) the endogenous forms (volcanic, tectonic, structural), and (2) the forms originated by external agents (eolian, fluvial, coastal, marine, lacustrine, karstic, glacial, periglacial and nival forms, and slope and interfluve forms).

For the purpose of soil mapping, Wielemaker et al. (2001) proposed a hierarchic terrain objects classification, qualified as morphogenic by the authors, which includes five nested levels, namely region, major landform, landform element, facet, and site. This system was derived from the analysis of a concrete case study located in Southern Spain, using a methodological framework to formalize expert knowledge on soil-landscape relationships and an interactive GIS procedure for sequential disaggregation of the landscape (de Bruin et al. 1999).

Table 6.2 Families of geoforms as per origin

Study fields of geomorphology	Types of geoforms
Structural geomorphology: types of relief	Cuesta, fold, shield reliefs, etc.
Climatic geomorphology: types of molding	Glacial, periglacial, eolian moldings, etc.
Azonal geomorphology: types of form	Alluvial, lacustrine, coastal forms, etc.

A variant of genetic-chorologic classification is the ordering of landscapes and geoforms in the context of a given country (Zinck 1974; Elizalde 2009). This type of classification combines physico-geographic units at the higher levels of the system with taxonomic units at the lower levels. The physico-geographic units belong to a specific regional context and, therefore, cannot be generalized or extrapolated to other regional situations. The division of a country into physiographic provinces and natural regions is an example of this type of nomenclature. Instead, the taxa of the lower categories (e.g., landscape types or relief types) convey sufficient abstraction to be recognizable on the basis of differentiating features in a variety of regional contexts.

6.2.3 Morphometric Classification

First attempts of morphometric relief characterization go back to mid-nineteenth century in the Germanic countries. However, it was only after the Second World War that systematic use of morphometric techniques was made to describe features of the topography, parameters of the hydrographic network, drainage density, and other measurable attributes of the relief (Tricart 1965). In recent decades, the technology of the digital elevation models (DEM) has given a new impulse to morphometry and automated extraction of morphometric information (Pike and Dikau 1995; Hengl and Reuter 2009). Geomorphometry focuses on the quantitative analysis of the terrain surface with two orientations: a specific morphometry that analyzes the discrete features of the terrain surface (e.g., landforms/terrain forms), and a general morphometry that deals with the continuous features. In its present state, geomorphometry pursues essentially the characterization and digital analysis of continuous topographic surfaces (Pike et al. 2009).

The use of DEM has allowed measuring and extracting attributes that describe topographic features of the landscape (Gallant and Wilson 2000; Hutchinson and Gallant 2000; Olaya 2009). The most frequently measured parameters include altitude, slope, exposure, curvature, and roughness of the relief, among others. The spatial distribution of these parameters allows inferring the variability of hydrologic, geomorphic, and biological processes in the landscape. The combination of data derived from DEM and satellite images contributes to improve predictive models (Dobos et al. 2000).

There are attempts to classify landforms and model landscapes using morphometric parameters (Evans et al. 2009; Hengl and MacMillan 2009; Nelson and Reuter 2012). Idealized geometric primitives (Sharif and Zinck 1996) and ideal elementary forms (Minár and Evans 2008) have been used to segment the landscape and approximate the representation of a variety of terrain forms. The implementation of automated algorithms to classify landforms has facilitated the mapping of landform elements and relief classes (Pennock et al. 1987; MacMillan and Pettapiece 1997; Ventura and Irvin 2000; Meybeck et al. 2001; Iwahashi and Pike 2007; MacMillan and Shary 2009). Ventura and Irvin (2000) analyzed different methods of automated landform classification for soil landscape studies, but the experiments were basically restricted to slope situations according to the classic models of Ruhe (1975) and Conacher and Dalrymple (1977).

The use of quantitative parameters allows describing continuous variations of topographic features with the support of fuzzy sets techniques (Irwin et al. 1997; Burrough et al. 2000; MacMillan et al. 2000). However, this approach may be less efficient in identifying differentiating characteristics of geoforms that have discrete boundaries, as is frequent in erosional (e.g., gullies, solifluction features) and depositional areas (e.g., alluvial or eolian systems). The DEM-based analysis leads to a classification of topographic features of the relief and contributes to the morphometric characterization of the terrain forms but does not generate a terrain form classification in the geomorphic sense of the concept. The classification of slope facets by shape and gradient is essentially a descriptive classification which does not convey information on the origin of the relief. However, this kind of classification results in an organization of the relief features that allows formulating hypotheses about their origin (Small 1970). Compared with the multiplication of tests carried out in rugged areas, the possibilities of digital mapping in flat areas, especially areas of depositional origin, have been so far less explored.

In the FAO Guidelines for soil description (2006), landforms are described by their morphology and not by their origin or forming processes. The proposed landform classification in a two-level hierarchy is based mainly on morphometric criteria. At the first level, three classes called, respectively, level land, sloping land, and steep land, are considered. These classes are subdivided according to three morphometric attributes including slope gradient, relief intensity, and potential drainage density. Applying this procedure to the level-land class, for instance, four subclasses are recognized, namely plain, plateau, depression, and valley floor. Sloping-land and steep-land include plain, valley, hill, escarpment zone, and mountain subclasses, differentiated by the above morphometric features.

6.2.4 Ethnogeomorphic Classification

Indigenous people in traditional communities use topographic criteria, before taking the soils into consideration, to identify ecological niches suitable for selected crops and management practices. Their approach to segment a hillside into relief units is similar to the slope facet models of Ruhe (1975) and Conacher and Dalrymple (1977). Likewise in depositional environments, where the topographic variations are often subtle and less perceptible, farmers clearly recognize a variety of landscape positions, as for instance the characteristic *banco-bajio-estero* trio (bank-depression-backswamp) for pasture management in the Orinoco river plains. Trials of participatory mapping, with the collaboration of local land users and technical staff, show that the mental maps of the farmers visualize the relief using a detailed nomenclature, which allows converting them into real maps that are very similar to the geomorphic maps prepared by specialists (Barrera-Bassols et al. 2006, 2009). The two maps in Fig. 6.1 show cartographic as well as taxonomic similarities: main unit delineations coincide, and taxa recognized by scientists and local farmers are comparable (e.g., gently sloping lava flow vs tzacapurhu meaning lava flow of stony land).

Indigenous soil classifications usually include the relief at the top level of the classification system, forming the basis of ethnogeopedology. In their perception of the environment, indigenous farmers use the relief, along with other features of the

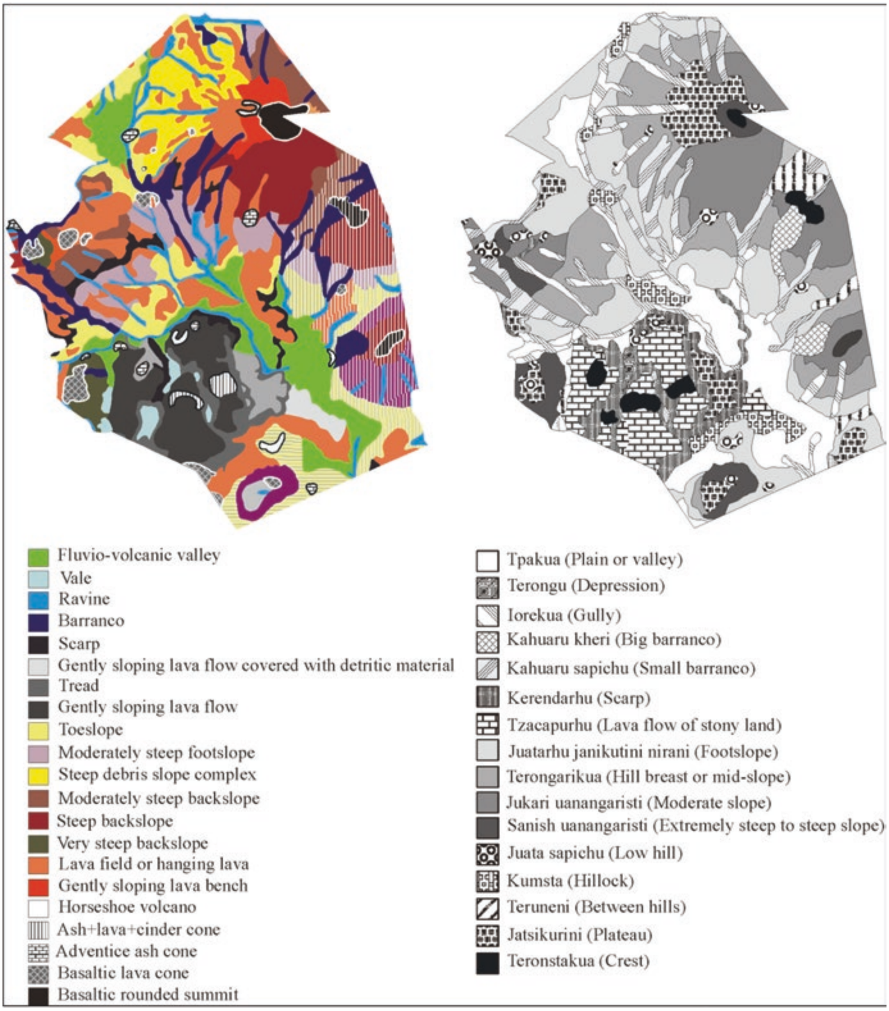

Fig. 6.1 Comparison of a geomorphic map made using technical criteria (left) and a relief map drawn up according to the indigenous Purhépecha nomenclature (right) of the territory of San Francisco Pichátaro, Michoacán, in the volcanic belt of Central Mexico. (Adapted from Barrera-Bassols et al. 2006)

landscape, as a main factor for identifying, locating, and classifying soils. Because of the importance that both disciplines give to the relief factor, ethnopedology and geopedology are strongly related.

6.3 Bases for a Taxonomic Classification System of the Geoforms

6.3.1 Premises and Basic Statements

A set of assumptions is formulated hereafter as a basis for structuring a taxonomic system of the geoforms and improving the traditional approaches to geomorphic classification.

- The object to be classified is a unit of the geolandscape or subdivision thereof that can be recognized by its configuration and composition. The most commonly used term to designate this entity in English-written geomorphic literature is *landform.* The same term is indistinctly used by geomorphologists, geologists, pedologists, agronomists, ecologists, architects, planners, contemplative and active users of the landscape, among others, but there is no standard definition accepted by everybody. In the FAO Guidelines for soil description (2006), the concept of *major landform* is considered to refer to the morphology of the whole landscape. Way (1973) provides a satisfactory definition in the following terms: "*Landforms* are terrain features formed by natural processes, which have a defined composition and a range of physical and visual characteristics that occur wherever the form is found and whatever is the geographic region". This statement poses two basic principles: (1) a landform is identified using internal constituents as well as external attributes, and (2) a landform is recognized by its intrinsic characteristics and not according to the context in which it occurs. In Spanish language, landform literally means *forma de tierra(s*), a term that has an agricultural or agronomic connotation. *Land* in landscape ecology includes not only the physical features of the landscape, but also the biota and the human activities (Zonneveld 1979, 1989). The term *terrain form* is more appropriate to designate the elementary relief form, while the term *geoform* is the generic concept that encompasses the geomorphic units at all categorial levels. *Terrain form* is etymologically equal to terms with similar geomorphic meaning used in other languages, such as *forma de terreno* in Spanish and *forme de terrain* in French.
- The objects that are classified are the geoforms, or geomorphic units, which are identified on the basis of their own characteristics, rather than by reference to the factors of formation. Local or regional combinations of criteria such as climate, vegetation, soil, and lithology, which are associated with the geoforms and contribute to their formation, can be referred to in the legend of the geomorphic map, but are not intrinsically part of the classification of the geoforms. The climate factor is implicitly present in the geoforms originated by exogenous morphogenic agents (snow, ice, water, wind).

- Classes of geoforms are arranged hierarchically to reflect their level of membership to the geomorphic landscape. For instance, a river levee is a member of a terrace, which in turn is a member of a valley landscape. Therefore, levee, terrace, and valley shall be placed in different categories in a hierarchic system, because they correspond to different levels of abstraction. Similarly, the slope facets (i.e., summit, shoulder, backslope, and footslope) are members of a hill, which is a member of a hilland type of landscape.
- The genesis of the geoforms is taken into consideration preferably at the lower levels of the taxonomic system, since the origin of the geomorphic units can be a matter of debate and the genetic attributes may be not clear or controversial, or their determination may require a number of additional data. At higher levels, the use of more objective, rather descriptive attributes are privileged, in parallel with the criteria of pattern recognition implemented in photo and image interpretation.
- The dimensional characteristics (e.g., length, width, elevation, slope, etc.) are subordinate attributes and are not diagnostic for the identification of the geoforms. A geoform belongs to a particular class regardless of its size, provided it complies with the required attributes of that class. For instance, the extent of a dune or a landslide can vary from a few m^2 to several km^2.
- The names of the geoforms are often derived from the common language and some of them may be exposed to controversial interpretation. Priority is given here to those terms that have greater acceptation by their etymology or usage.
- The concepts of physiographic province and natural region, as well as other kinds of chorologic units related to specific geographic contexts, are not taken into account in this taxonomic system, because they depend on the particular conditions of a given country or continental portion, a fact that limits their level of abstraction and geographic repeatability.
- The geographic distribution of the geoforms is not a taxonomic criterion. The chorology of the geoforms is reflected in their cartography and in the structure of the geomorphic map legend.
- Toponymic designations can be used as phases of the taxonomic units (e.g., Cordillera de Mérida, Pantanal Basin).

6.3.2 Prior Information Sources

The development of the geoform classification system uses prior knowledge in terms of concepts, methods, information, and experience.

- Existing geoform typologies, with definitions and descriptive attributes, have been partially taken from the literature. The proposed classification builds on and organizes prior knowledge in a hierarchic taxonomic system. Some of the key documents that were consulted for this purpose are as follows:

  - Various classic texbooks of geomorphology: Tricart and Cailleux (1962, 1965, 1967, 1969), Tricart (1965, 1968, 1977), Derruau (1965, 1966), Thornbury (1966), Viers (1967), CNRS (1972), Garner (1974), Ruhe (1975), Huggett (2011), among others.
  - Dictionaries and encyclopedias: Visser (1980), Lugo-Hubp (1989), Fairbridge (1997), Goudie (2004), among others.
  - Manuals of geomorphic photo-interpretation: Goosen (1968), Way (1973), Verstappen and Van Zuidam (1975), Verstappen (1983), Van Zuidam (1985), among others.

- For the structure of the system, inspiration was taken from the conceptual framework of the USDA Soil Taxonomy (Soil Survey Staff 1975, 1999) with regard to the concepts of category, class, and attribute.
- Development and validation of the system have taken place essentially in Venezuela and Colombia, within the framework of soil survey projects at different scales from detailed to generalized, with the implementation of geomorphology as a tool for soil mapping (applied geomorphology). The system was modified and improved progressively as ongoing field surveys provided new knowledge. Subsequently, the already established system became teaching and training matter in postgraduate courses in soil survey at the ITC (Zinck 1988) for students from different parts of the world, especially Latin America, Africa, Middle East, and Southeast Asia.

6.3.3 Searching for Structure: An Inductive Example

Let's consider the collection of objects included in Fig. 6.2 (Arnold 1968). Squares, triangles, and circles can be recognized. The objects are large or small, green (G) or red (R). Thus, the objects are different by shape, size, and color. Based on these three criteria, the objects may be classified in various ways. One option is to sort the objects first by size, then by color, and finally by shape (Fig. 6.3). They can also be sorted successively by shape, color, and size. Six hierarchization alternatives are possible. This simple experiment shows that artificial or natural objects may be classified in various ways. Any alternative is valid if it meets the objective pursued.

From example in Fig. 6.2, three basic elements of a hierarchic classification system can be induced by effect of generalization: category, class, and attribute.

- The categories are hierarchic levels that give structure to the classification system. Three categories are present, identified by generic criteria (size, color, shape). Several (6) hierarchic arrangements are possible.
- Classes are groups of objects that have one or more differentiating characteristics in common. There are seven differentiating characteristics: large, small, red, green, square, triangular, and circular. The aggregation of characteristics generates an increase of classes from the top to the bottom of the system.
- Attributes are characteristics or properties of the objects, such as red, green, large, small, square, triangular, and circular.

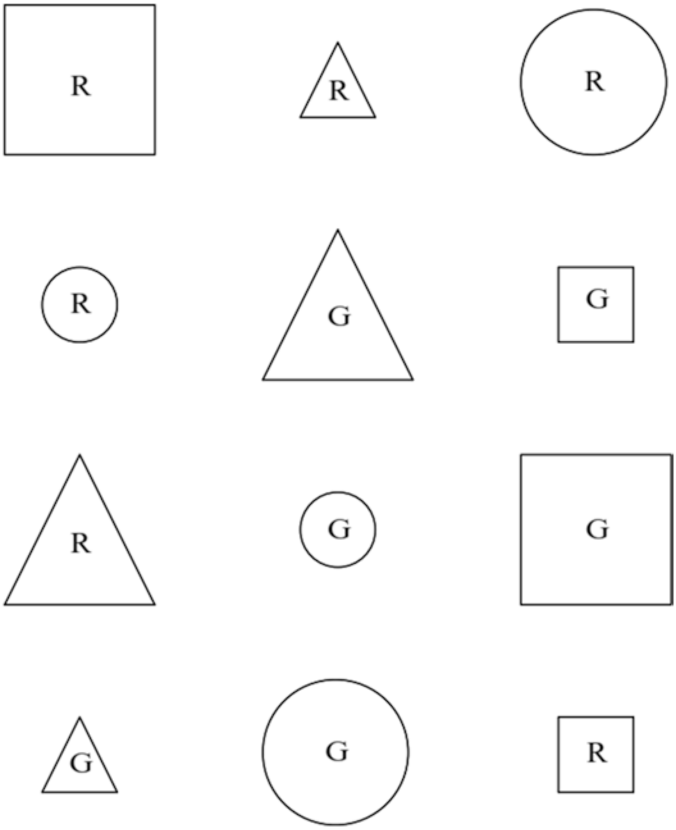

Fig. 6.2 Collection of objects different by shape, size, and color. (Adapted from Arnold 1968)

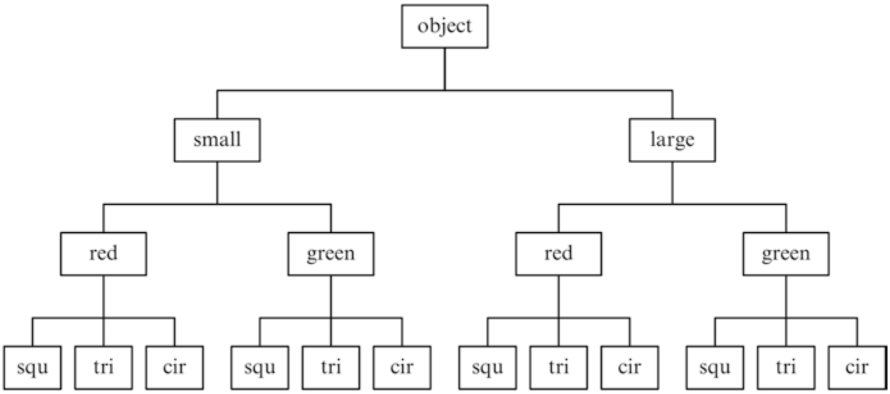

Fig. 6.3 Hierarchic arrangement of the objects displayed in Fig. 6.2 by size (2 classes), color (4 classes), and shape (12 classes) (*squ* square, *tri* triangular, *cir* circular)

6.4 Structure and Elements for Building a Taxonomic System of the Geoforms

A taxonomic system is characterized by its structure (or configuration) and its elements (or components).

6.4.1 Structure

Various configuration models are possible: hierarchic, relational, network, and linear, among others (Burrough 1986). In general, the hierarchic multicategorial model is considered appropriate for taxonomic purposes. Haigh (1987) states that the hierarchic structure is a fundamental property of all natural systems, while Urban et al. (1987) consider that breaking a landscape into elements within a hierarchic framework allows to partially solve the problem of its apparent complexity. Although a hierarchic structure is less efficient than, for instance, a relational system or a network system in terms of automated data handling by computer, it is however particularly suitable for archiving, processing, and retrieving information by the human mind (Miller 1956, 2003).

A system can be compared to a box containing all the individuals belonging to the object that is sought to be classified: for example, all soils, all geoforms. The collection of individuals constitutes the universe that is going to be divided into classes and arranged into categories. The classification results in (1) a segmentation of the universe under consideration (e.g., the soil cover continuum) into populations, groups, and individuals by descending disaggregation, and (2) a clustering of individuals into groups, populations, and universe by ascending aggregation.

6.4.2 Elements

6.4.2.1 Category

A category is a level of abstraction. The higher the level of the category, the higher is the level of abstraction. Each category comprises a set of classes showing a similar level of abstraction. A category is identified by a generic concept that characterizes all classes present in this level (color, size, shape, in Fig. 6.3). For instance, a valley landscape, a fluvial terrace, and a river levee are objects belonging to different levels of abstraction. The levee is a member of the terrace, which in turn is a member of the valley. In a hierarchic system of geoforms, these geomorphic entities shall be placed in three successive categories.

6.4.2.2 Class

A class is a formal subdivision of a population at a given categorial level. A class can be determined using different modalities among which the two following are commonly implemented: (1) the range of variation of a diagnostic attribute or a combination thereof, and (2) a central class concept in relation to which other classes deviate by one or more characteristics.

An example of the first modality is provided by the way the percentage of base saturation is used in soil taxonomy as a threshold parameter to separate Alfisols (≥35%) and Ultisols (<35%). Using a similar procedure, the strata dip in sedimentary rocks allows separating several classes of monoclinal relief, including mesa, cuesta, creston, hogback, and bar (Fig. 6.4). A similar approach can be applied to the classification of the geoforms caused by mass movements through segmentation of the continuum between solid and liquid states using the consistence limits (Fig. 6.5). There are very few references in the geomorphic literature where the segmentation of a continuum is used to differentiate related geoforms.

The central typifying concept is used to position a typical class in relation to intergrades and extragrades, which depart from the central class by deviation of some attributes. This is the case, for instance, of the "Typic" as used at subgroup level in the USDA Soil Taxonomy (Soil Survey Staff 1975, 1999). No examples were found in the geomorphic literature implementing formally the central concept to distinguish modal situations from transitional ones.

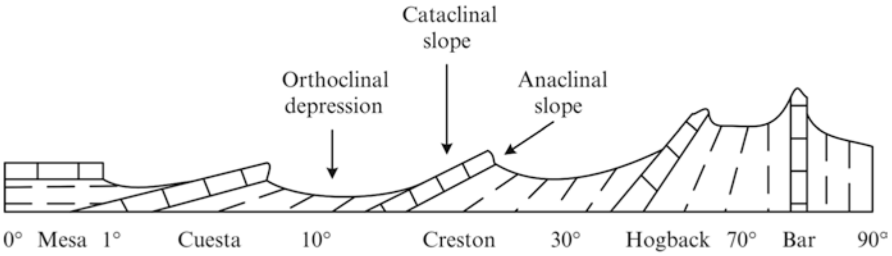

Fig. 6.4 Monoclinal relief classes determined based on strata dip ranges in sedimentary bedrocks (e.g. limestone, sandstone). (Adapted from Viers 1967)

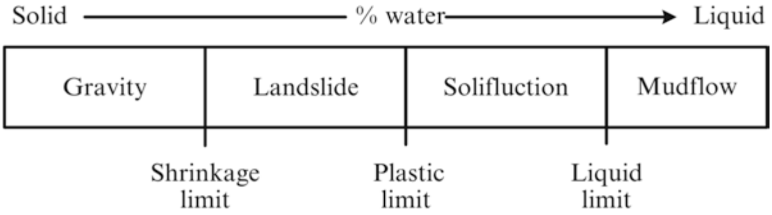

Fig. 6.5 Classes of geoforms originated by different kinds of mass movement

6.4.2.3 Taxon

A taxon (or taxum) is a concrete taxonomic unit as a member of a class established at a given categorial level. Usually, a particular taxon covers only part of the range of variation allowed in the selected attributes that define the class. For instance, the texture of a river bank, above the basal gravel strata, can vary from gravelly to sandy clay loam. A particular bank can be sandy to sandy loam without covering the entire diagnostic textural range.

6.4.2.4 Attribute

An attribute is a characteristic (or variable) used to establish the limits of the classes that make up the system and to implement these limits in the description and classification of individuals. There are several kinds of attribute, as for instance:

- Dichotomous: e.g., presence or absence of iron reduction mottles, concentration of carbonates or other salts.
- Multi-state without ranges: e.g., types of soil structure, types of depositional structure.
- Multi-state with ranges: e.g., size of structural aggregates, plasticity and adhesion classes.
- Continuous variation: e.g., base saturation, bedrock dip.

Implementing these basic taxonomic criteria in geomorphology requires (1) the inventory of the known geoforms and their arrangement in a hierarchic system, and (2) the selection, categorization (diagnostic or not), hierarchization, and measurement of the attributes used to identify and describe the geoforms.

6.5 Levels of Perception: Exploring the Structure of a Geomorphic Space

Geomorphology is primarily a science of observation, aiming at the identification and separation of landscapes from topographic maps, digital elevation or terrain models, and remote-sensed documents allowing stereoscopic vision, but mainly by reading the physiographic features in the field. Geoforms can be perceived by human vision or artificial sensors because they have a physiognomic appearance on the earth's surface (i.e., geolandscape). Physiography describes this external appearance corresponding to the epigeal component of the geoforms. Thanks to their scenic expression, geoforms are the most directly structuring elements of the terrain, more than any other object or natural feature. Even a non-scientific observer can notice that any portion of the earth's crust shows a structure determined by the relief, which allows subdividing it into components. The times that a terrain area can be subdivided into elements depend on the level of perception used for the segmentation. Although the concept of perception level is subjective when the human eye is used, it helps hierarchize the structural components of a terrain surface.

Hereafter, an example is developed that illustrates the effect of the perception scale on the sequential identification of different terrain portions. The example refers to the contact area between the Caribbean Sea and the northern edge of the South American continent in Venezuela (Zinck 1980). The use of successive perception levels, increasingly detailed, materialized by observation platforms of decreasing elevation in relation to the earth's surface, allows dividing the selected portion of continent into classes of geoforms that are distributed over various hierarchic categories (Fig. 6.6 and Table 6.3). An observer mounted on a spaceship at about 800–1000 km elevation would distinguish two physiographic provinces, namely the east-west oriented coastal mountain chain of the Cordillera de la Costa to the north and the basin of the Llanos Plains to the south. These two macro-units of contrasting relief correspond to two types of geostructure: a folded cordillera-type mountain chain and a geosincline-type sedimentary basin, respectively. From an airplane flying at about 10 km elevation, one can distinguish the two parallel branches of the Cordillera de la Costa, namely the Serranía del Litoral range to the north and the

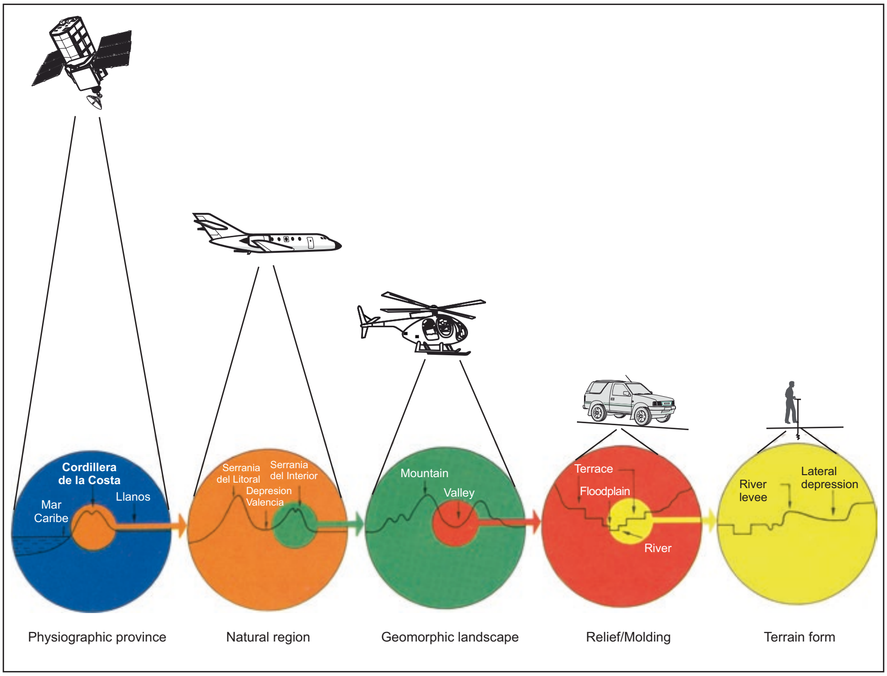

Fig. 6.6 Successive levels of perception of geoforms from different observation elevations. From left to right: physiographic province (geostructure), natural region (morphogenic environment), geomorphic landscape, relief/molding, terrain form (Zinck 1980). The features referred to are explained in Table 6.3

Table 6.3 Sequential identification of geoforms according to increasing levels of perception

Observation platform	Observation area	Observed features	Criteria used Inferred factors	Resulting geoforms	Derived generic categorial concepts
Satellite	Large continental portion	*Cordillera de la Costa* narrow, longitudinal, high relief mass; abrupt limits	Topography Internal geodynamics (orogenic area)	Cordillera (folded mountain chain)	Geostructure
		Llanos del Orinoco Extensive, flat, low relief mass	Topography Internal geodynamics (sinking area)	Geosyncline (sedimentary basin)	
Airplane	Cordillera	*Serranía del Litoral Serranía del Interior* parallel, dissected mountain ranges	Topography Internal/external geodynamics (erosion)	Structural/ erosional environment	Morphogenic environment
		Depresión de Valencia Low-lying, flat terrain areas; concave margins	Topography Internal/external geodynamics (sedimentation)	Depositional environment	
Helicopter	Structural/ erosional environment	Parallel mountain ridges	Topography Tectonics Hydrography	Mountain	Geomorphic landscape
		Narrow longitudinal depressions, parallel or perpendicular to the ridges	Topography Tectonics Hydrography	Valley	
Earth surface	Valley	Topographic step treads separated by risers	Topography	Terrace	Relief/ molding
		Valley bottom, river system, riparian forest	Topography Drainage Vegetation	Floodplain	

(continued)

Table 6.3 (continued)

Observation platform	Observation area	Observed features	Criteria used Inferred factors	Resulting geoforms	Derived generic categorial concepts
Terrain surface and subsurface	Terrace	Longitudinal, narrow, convex bank; well drained, coarse-textured	Topography Drainage Morphogenesis	Levee	Terrain form
		Large, concave depression, poorly drained, fine-textured	Topography Drainage Morphogenesis	Basin	

Based on the features observed in Fig. 6.6. Zinck (1988)

Serranía del Interior range to the south, separated by an alignment of tectonic depressions such as that of Lake Valencia. These units are natural regions that correspond to types of morphogenic environment: the mountain ranges are structural environments undergoing erosion, whereas depressions are depositional environments. When increasing the level of perception as from a helicopter flying at two km elevation, a mountain range can be divided into mountain and valley landscapes. A field transect through a valley allows to cross a series of topographic steps with risers and treads that correspond to fluvial terraces. Detailed field observation of the topography and sediments in a given terrace will reveal a sequence of depositional units from the highest, the river levee (bank), to the lowest, the decantation basin (swamp). The results of this exploratory inductive procedure, leading to a sequential segmentation of a portion of the South American continent, are summarized in Table 6.3. This empirical approach generates a hierarchic scheme of geoforms in five nested categorial levels, each identified by a generic concept from general to detailed (Fig. 6.7).

6.6 Structure of a Taxonomic System of the Geoforms

Combining the basic criteria to build a taxonomic system (Sects. 6.3 and 6.4) with the results of the exploration aimed at detecting guidelines of hierarchic arrangement in the geomorphic environment (Sect. 6.5), a structure of nested categorial levels is obtained. Five of these levels are essentially deduced from the epigeal physiographic expression of the geoforms. The units recognized at the two upper levels are identified by local names, because they belong to a particular national or regional context. These are chorologic units which are formalized as taxonomic units under the generic concept of geostructure and morphogenic environment,

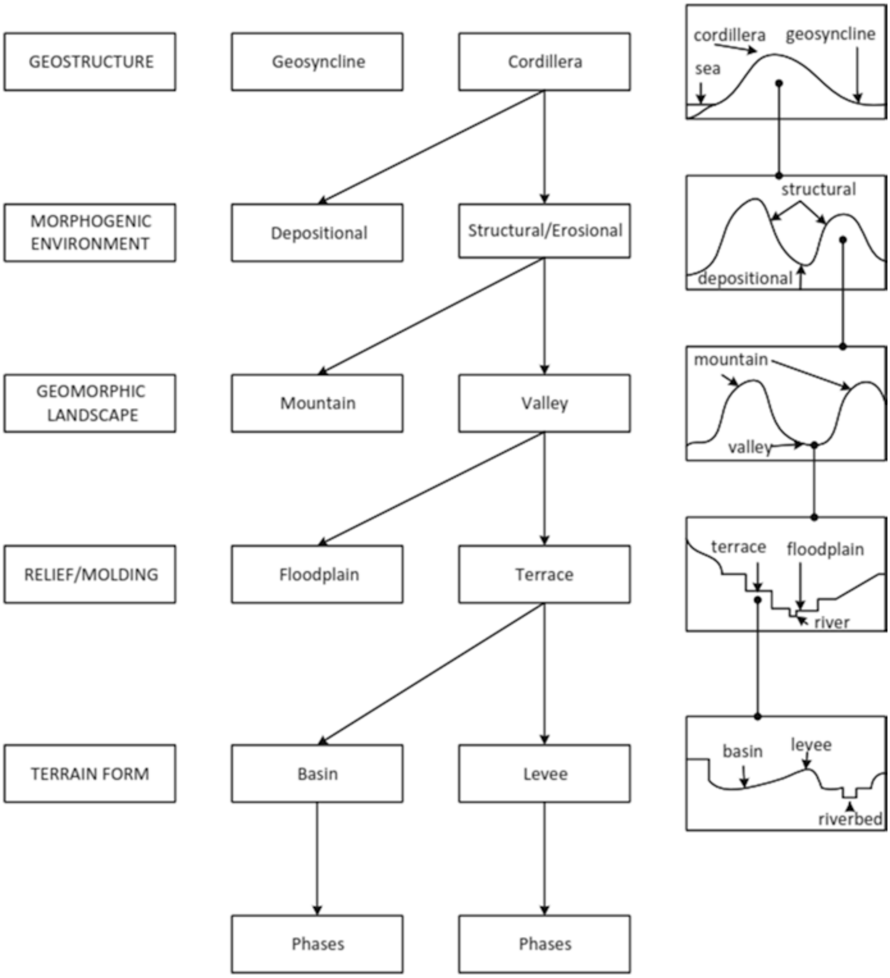

Fig. 6.7 Generalization of the information displayed in Table 6.3. (Zinck 1988)

respectively. To substantiate the relationship between geoform and soil, it is necessary to introduce in the system information on the internal hypogeal component of the geoforms, namely the constituent material, which is in turn the parent material of the soils. As a result of the foregoing, an additional level is needed to document the lithology, in the case of bedrock substratum, or the facies in the case of unconsolidated cover materials. After several iterations, this category was inserted between the level of relief/molding (level 3) and the level of terrain form (level 1). Its inclusion in the lower part of the system is justified by the fact that field data are often needed to supplement or clarify the general information provided by the

Table 6.4 Synopsis of the geoform classification system (Zinck 1988)

Level	Category	Generic concept	Short definition
6	Order	Geostructure	Large continental portion characterized by a type of geologic macro-structure (e.g., cordillera, geosyncline, shield)
5	Suborder	Morphogenic environment	Broad type of biophysical environment originated and controlled by a style of internal and/or external geodynamics (e.g., structural, depositional, erosional, etc.)
4	Group	Geomorphic landscape	Large portion of land/terrain characterized by given physiographic features: it corresponds to a repetition of similar relief/molding types or an association of dissimilar relief/molding types (e.g., valley, plateau, mountain, etc.)
3	Subgroup	Relief/molding	Relief type originated by a given combination of topography and geologic structure (e.g., cuesta, horst, etc.) Molding type determined by specific morphoclimatic conditions and/or morphogenic processes (e.g., glacis, terrace, delta, etc.)
2	Family	Lithology/ facies	Petrographic nature of the bedrocks (e.g., gneiss, limestone, etc.) or origin/nature of the unconsolidated cover formations (e.g., periglacial, lacustrine, alluvial, etc.)
1	Subfamily	Landform/ terrain form	Basic geoform type characterized by a unique combination of geometry, dynamics, and history

geologic maps (see Fig. 7.3 and Table 7.2 in Chap. 7). This leads finally to a system with six categorial levels (Table 6.4), identified by their respective generic concepts that are explained in Chap. 7. It can be noted that obtaining a system with six categories complies with the rule called *Miller's Law*, which postulates that the capacity of the human mind to process information covers a range of seven plus or minus two elements (Miller 1956, 2003).

6.7 Conclusion

Geoforms are the emerging parts of the earth's crust. Their distinct physiognomic features make them directly observable through visual and artificial perception from remote to proximal sensing. Changing the scale of perception changes not only the degree of detail but most significantly the nature of the object observed. For instance, a levee is a member of a terrace which is a member of a valley, thus three geomorphic objects bearing different levels of abstraction. The geolandscape is a hierarchically structured and organized domain. Therefore, a multicategorial system, based on nested levels of perception to capture the information and taxonomic criteria to organize that information, is an appropriate frame to classify geoforms.

References

Arnold R (1968) Apuntes de agrología (documento inédito). Barquisimeto, Ministerio de Obras Públicas (MOP)

Barrera-Bassols N, Zinck JA, Van Ranst E (2006) Local soil classification and comparison of indigenous and technical soil maps in a Mesoamerican community using spatial analysis. Geoderma 135:140–162

Barrera-Bassols N, Zinck JA, Van Ranst E (2009) Participatory soil survey: experience in working with a Mesoamerican indigenous community. Soil Use Manage 25:43–56

Buol SW, Hole FD, McCracken RJ, Southard RJ (1997) Soil genesis and classification, 4th edn. Iowa State University Press, Ames

Burrough PA (1986) Principles of geographical information systems for land resources assessment. Clarendon Press, Oxford

Burrough PA, van Gaans PFM, MacMillan RA (2000) High-resolution landform classification using fuzzy k-means. Fuzzy Sets Syst 113:37–52

CNRS (1972) Cartographie géomorphologique. Travaux de la RCP77, Mémoires et Documents vol 12. Editions du Centre National de la Recherche Scientifique, Paris

Conacher AJ, Dalrymple JB (1977) The nine-unit landscape model: an approach to pedogeomorphic research. Geoderma 18:1–154

de Bruin S, Wielemaker WG, Molenaar M (1999) Formalisation of soil-landscape knowledge through interactive hierarchical disaggregation. Geoderma 91:151–172

Derruau M (1965) Précis de géomorphologie. Masson, Paris

Derruau M (1966) Geomorfología. Ediciones Ariel, Barcelona

Dobos E, Micheli E, Baumgardner MF, Biehl L, Helt T (2000) Use of combined digital elevation model and satellite radiometric data for regional soil mapping. Geoderma 97(3–4):367–391

Elizalde G (2009) Ensayo de clasificación sistemática de categorías de paisajes. Primera aproximación, edn revisada. Maracay

Evans IS, Hengl T, Gorsevski P (2009) Applications in geomorphology. In: Hengl T, Reuter HI (eds) Geomorphometry: concepts, sofware, applications, Developments in Soil Science, vol 33. Elsevier, Amsterdam, pp 497–525

Fairbridge RW (ed) (1997) Encyclopedia of geomorphology. Springer, New York

FAO (2006) Guidelines for soil description, 4th edn. Food and Agricultural Organization of the United Nations, Rome

FAO (2009) Guía para la descripción de suelos, cuarta edn. Organización de las Naciones Unidas para la Agricultura y la Alimentación, Roma

Farshad A (2010) Geopedology. An introduction to soil survey, with emphasis on profile description (CD-ROM). University of Twente, Faculty of Geo-Information Science and Earth Observation (ITC), Enschede

Gallant JC, Wilson JP (2000) Primary topographic attributes. In: Wilson JP, Gallant JC (eds) Terrain analysis: principles and applications. Wiley, New York, pp 51–85

Garner HF (1974) The origin of landscapes. A synthesis of geomorphology. Oxford University Press, New York

Goosen D (1968) Interpretación de fotos aéreas y su importancia en levantamiento de suelos. In: Boletín de Suelos 6. FAO, Roma

Goudie AS (ed) (2004) Encyclopedia of geomorphology, vol 2. Routledge, London

Haigh MJ (1987) The holon: hierarchy theory and landscape research. Catena Supplement 10. CATENA Verlag, Cremlingen, pp 181–192

Hengl T, MacMillan RA (2009) Geomorphometry: a key to landscape mapping and modelling. In: Hengl T, Reuter HI (eds) Geomorphometry: concepts, software, applications, Developments in soil science, vol 33. Elsevier, Amsterdam, pp 433–460

Hengl T, Reuter HI (eds) (2009) Geomorphometry: concepts, software, applications, Developments in soil science, vol 33. Elsevier, Amsterdam

Huggett RJ (2011) Fundamentals of geomorphology. Routledge, London

Hutchinson MF, Gallant JC (2000) Digital elevation models and representation of terrain shape. In: Wilson JP, Gallant JC (eds) Terrain analysis: principles and applications. John Wiley & Sons, New York, pp 29–50

Irwin BJ, Ventura SJ, Slater BK (1997) Fuzzy and isodata classification of landform elements from digital terrain data in Pleasant Valley, Wisconsin. Geoderma 77:137–154

Iwahashi J, Pike RJ (2007) Automated classifications of topography from DEMs by an unsupervised nested-means algorithm and a three-part geometric signature. Geomorphology 86(3–4):409–440

Lueder DR (1959) Aerial photographic interpretation: principles and applications. McGraw-Hill, New York

Lugo-Hubp J (ed) (1989) Diccionario geomorfológico. Universidad Nacional Autónoma de México, Cd México

MacMillan RA, Pettapiece WW (1997) Soil landscape models: automated landscape characterization and generation of soil-landscape models. Research Report 1E:1997

MacMillan RA, Shary PA (2009) Landforms and landform elements in geomorphometry. In: Hengl T, Reuter HI (eds) Geomorphometry: concepts, software, applications, Developments in Soil Science, vol 33. Elsevier, Amsterdam, pp 227–254

MacMillan RA, Pettapiece WW, Nolan SC, Goddard TW (2000) A generic procedure for automatically segmenting landforms into landform elements using DEMs, heuristic rules and fuzzy logic. Fuzzy Sets Syst 113:81–109

Meybeck M, Green P, Vorosmarty CJ (2001) A new typology for mountains and other relief classes: an application to global continental water resources and population distribution. Mount Res Dev 21:34–45

Miller GA (1956) The magical number seven, plus or minus two: some limits on our capacity for processing information. Psychol Rev 63(2):81–97

Miller GA (2003) The cognitive revolution: a historical perspective. Trends Cogn Sci 7(3):141–144

Minár J, Evans IS (2008) Elementary forms for land surface segmentation: The theoretical basis of terrain analysis and geomorphological mapping. Geomorphology 95:236–259

Nelson A, Reuter H (2012) Soil projects. Landform classification from EU Joint Research Center, Institute for Environment and Sustainability. http://eusoils.jrc.ec.europa.eu/projects/landform

Olaya V (2009) Basic land-surface parameters. In: Hengl T, Reuter HI (eds) Geomorphometry: concepts, software, applications, Developments in soil science, vol 33. Elsevier, Amsterdam, pp 141–169

Pennock DJ, Zebarth BJ, De Jong E (1987) Landform classification and soil distribution in hummocky terrain, Saskatchewan, Canada. Geoderma 40:297–315

Pike RJ, Dikau R (eds) (1995) Advances in geomorphometry. Proceedings of the Walter F. Wood memorial symposium. Zeitschrift für Geomorphologie Supplementband 101

Pike RJ, Evans IS, Hengl T (2009) Geomorphometry: a brief guide. In: Hengl T, Reuter HI (eds) Geomorphometry: concepts, sofware, applications, Developments in soil science, vol 33. Elsevier, Amsterdam, pp 3–30

Ruhe RV (1975) Geomorphology. Geomorphic processes and surficial geology. Houghton Mifflin, Boston

Sharif M, Zinck JA (1996) Terrain morphology modelling. International Archives of Photogrammetry and Remote Sensing XXXI Part B3:792–797

Small RJ (1970) The study of landforms. A textbook of geomorphology. Cambridge University Press, London

Soil Survey Staff (1975) Soil taxonomy. A basic system of soil classification for making and interpreting soil surveys. USDA Agric Handbook 436. US Government Print Office, Washington, DC

Soil Survey Staff (1999) Soil taxonomy. USDA Agric Handbook 436. US Government Print Office, Washington,DC

Thornbury WD (1966) Principios de geomorfología. Editorial Kapelusz, Buenos Aires

Tricart J (1965) Principes et méthodes de la géomorphologie. Masson, Paris

Tricart J (1968) Précis de géomorphologie. T1 Géomorphologie structurale. SEDES, Paris

Tricart J (1977) Précis de géomorphologie. T2 Géomorphologie dynamique générale. SEDES-CDU, Paris

Tricart J, Cailleux A (1962) Le modelé glaciaire et nival. SEDES, Paris

Tricart J, Cailleux A (1965) Le modelé des régions chaudes. Forêts et savanes. SEDES, Paris

Tricart J, Cailleux A (1967) Le modelé des régions périglaciaires. SEDES, Paris

Tricart J, Cailleux A (1969) Le modelé des régions sèches. SEDES, Paris

Urban DL, O'Neill RV, Shugart HH Jr (1987) Landscape ecology. A hierarchical perspective can help scientists understand spatial patterns. Bioscience 37(2):119–127

Van Zuidam RA (1985) Aerial photo-interpretation in terrain analysis and geomorphological mapping. ITC, Enschede

Ventura SJ, Irvin BJ (2000) Automated landform classification methods for soil-landscape stydies. In: Wilson JP, Gallant JC (eds) Terrain analysis: principles and applications. John Wiley & Sons, New York, pp 267–294

Verstappen HT (1983) Applied geomorphology; geomorphological survey for environmental development. Elsevier, Amsterdam

Verstappen HT, Van Zuidam RA (1975) ITC system of geomorphological survey. ITC, Enschede

Viers G (1967) Eléments de géomorphologie. Nathan, Paris

Visser WA (ed) (1980) Geological nomenclature. Royal geological and mining society of the Netherlands. Bohn, Scheltema & Holkema, Utrecht

Way DS (1973) Terrain analysis. A guide to site selection using aerial photographic interpretation. Dowden, Hutchinson & Ross, Stroudsburg, Pennsylvania

Wielemaker WG, de Bruin S, Epema GF, Veldkamp A (2001) Significance and application of the multi-hierarchical landsystem in soil mapping. Catena 43:15–34

Zinck JA (1974) Definición del ambiente geomorfológico con fines de descripción de suelos. Ministerio de Obras Públicas (MOP), Cagua

Zinck JA (1980) Valles de Venezuela. Lagoven, Petróleos de Venezuela, Caracas

Zinck JA (1988) Physiography and soils. ITC soil survey lecture notes. International Institute for Aerospace Survey and Earth Sciences, Enschede

Zinck JA, Valenzuela CR (1990) Soil geographic database: structure and application examples. ITC J 1990(3):270–294

Zonneveld JIS (1979) Land evaluation and land(scape) science. ITC, Enschede

Zonneveld JIS (1989) The land unit – A fundamental concept in landscape ecology, and its applications. Landsc Ecol 3(2):67–86