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The land unit – A fundamental concept in landscape ecology, and its applications

Isaak S. Zonneveld
ITC, P.O. ***Box 6,*** *7500* ***AA*** *Enschede, The Netherlands*

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Abstract

The land unit, as an expression of landscape as a system, is a fundamental concept in landscape ecology. It is an ecologically homogeneous tract of land at the scale at issue. It provides a basis for studying topologic as well as chorologic landscape ecology relationships. **A** land unit survey aims at mapping such land units. This is done by simultaneously using characteristics of the most obvious (mappable) land attributes: landform, soil and vegetation (including human alteration of these three). The land unit is the basis of the map legend but may be expressed via these three land attributes. The more dynamic land attributes, such as certain animal populations and water fluxes, are less suitable as diagnostic criteria, but often link units by characteristic information/energy fluxes.

The land unit survey is related to a further development of the widely accepted physiographic soil survey (see Edelman 1950). Important aspects include: by means of a systems approach, the various land data can be integrated more appropriately; geomorphology, vegetation and soil science support each other during all stages (photo-interpretation, field survey, data processing, final classification); the time and costs are considerably less compared with the execution of separate surveys; the result is directly suitable as a basis for land evaluation; the results can be expressed in separate soil, vegetation, land use and landform maps, or even single value maps.

A land unit survey is therefore: a method for efficient survey of land attributes, such as soils, vegetation, landform, expressed in either separate or combined maps; a means of stimulating integration among separate land attribute sciences; an efficient basis for land evaluation. For multidisciplinary projects with applied ecologic aims (*e.g.*, land management), it is therefore the most appropriate survey approach.

Within the land unit approach there is considerable freedom in the way in which the various land attribute data are 'integrated'. It is essential, however, that: during the photo-interpretation stage, the contributions of the various specialists are brought together to prepare a preliminary (land unit) photo-interpretation map; the fieldwork data are collected at exactly the same sample point, preferably by a team of specialists in which soil, vegetation and geomorphology are represented; the final map is prepared in close cooperation of all contributing disciplines, based on photo-interpretation and field data; the final map approach may vary from one fully-integrated land unit map to various monothematic maps.

Introduction

The concept of the 'land unit' is presented in this paper as a central concept in landscape ecology. It is a logical consequence of the main hypothesis that the landscape can be considered as a system, and follows the holistic assumption that it consists (as the whole of nature) of hierarchical wholes.

One of the main characteristics of landscape ecology is that it contributes to holistic theory by describing hierarchical wholes from organisms and society to the Earth as a total system. It does so by combining the systems approach developed in biology ('ecosystem relationships') with the methods developed by geography for describing tangible tracts of land. The land unit concept is treated in this paper as synonymous with that of the hierarchical whole.

Although it is a hypothetical construct, the land unit concept is used for very practical purposes:

- To reduce the costs of surveys of landscape attributes (resources): the land unit or physiographic survey (mapping) approach in soil, vegetation and landscape surveys;
- As a basis for the evaluation of the suitability of landscape for any kind of land use.

Thus the land unit is being used by landscape ecologists and related scientists for three purposes:

1. As a central concept in landscape ecology hypotheses.
2. As a mapping tool.
3. As a means of transferring landscape knowledge, via evaluation, to application. It is therefore important to describe the concept clearly to avoid misunderstanding. This paper is an attempt to fulfill this task.

What is a land unit

In the context of this paper, a land unit is a tract of land that is ecologically homogeneous at the scale level concerned. The terms land, ecological, homogeneous and scale level and also the concept of holism deserve some explanation.

*Land**

Land, as used here, is synonymous with landscape in its meaning as 'the total character of a part of the Earth's surface' (von Humboldt), or the tangible ecosystems including all biotic and abiotic aspects as they can be recognized visually at the Earth's surface. 'Landscape is a part of the space on the Earth's surface consisting of a complex of systems, formed by the activity of rock, water, air, plants, animals and man and that by its physiognomy forms a recognizable entity' (WLO 1975, translated in Zonneveld 1979); or 'Landscape is an entity formed by the mutual working of the living and the non-living nature on a recognizable part of the Earth's surface' (WLO 1975, translated in Zonneveld 1976); or 'Land comprises the physical environments including climate, relief, soils, hydrology and vegetation to the extent that these influence the potential for land use' (FAO 1976). The last definition includes the results of past and present human activity on soils and vegetation, but purely economic and social characteristics are not included in the concept of land (see also Fig. 1).

The point all these definitions have in common is that they emphasize the study of a complex body, one part of which is studied by soil scientists, another by vegetation scientists and others by geomorphologists, biologists, human geographers, climatologists and hydrologists.

Certain geographers and landscape ecologists claim that they study landscapes as a whole, not emphasizing one side or the other. Various monodisciplinary land attribute scientists (vegetation, soils, geomorphology) also often use the word landscape, for example soil landscape and vegetation landscape. Landscape is even used by some geomorphologists as a compilation of landforms.

Ecological

Ecology in ecologically homogeneous is used here as 'the household of life', hence the land as the ba-

* **In** translation to Spanish, there is a problem because two terms are used: 'paisaje' and 'tierra'. The latter is used commonly in relation to land evaluation, the former in the context of basic landscape ecology and also of the visual aspects of landscape.

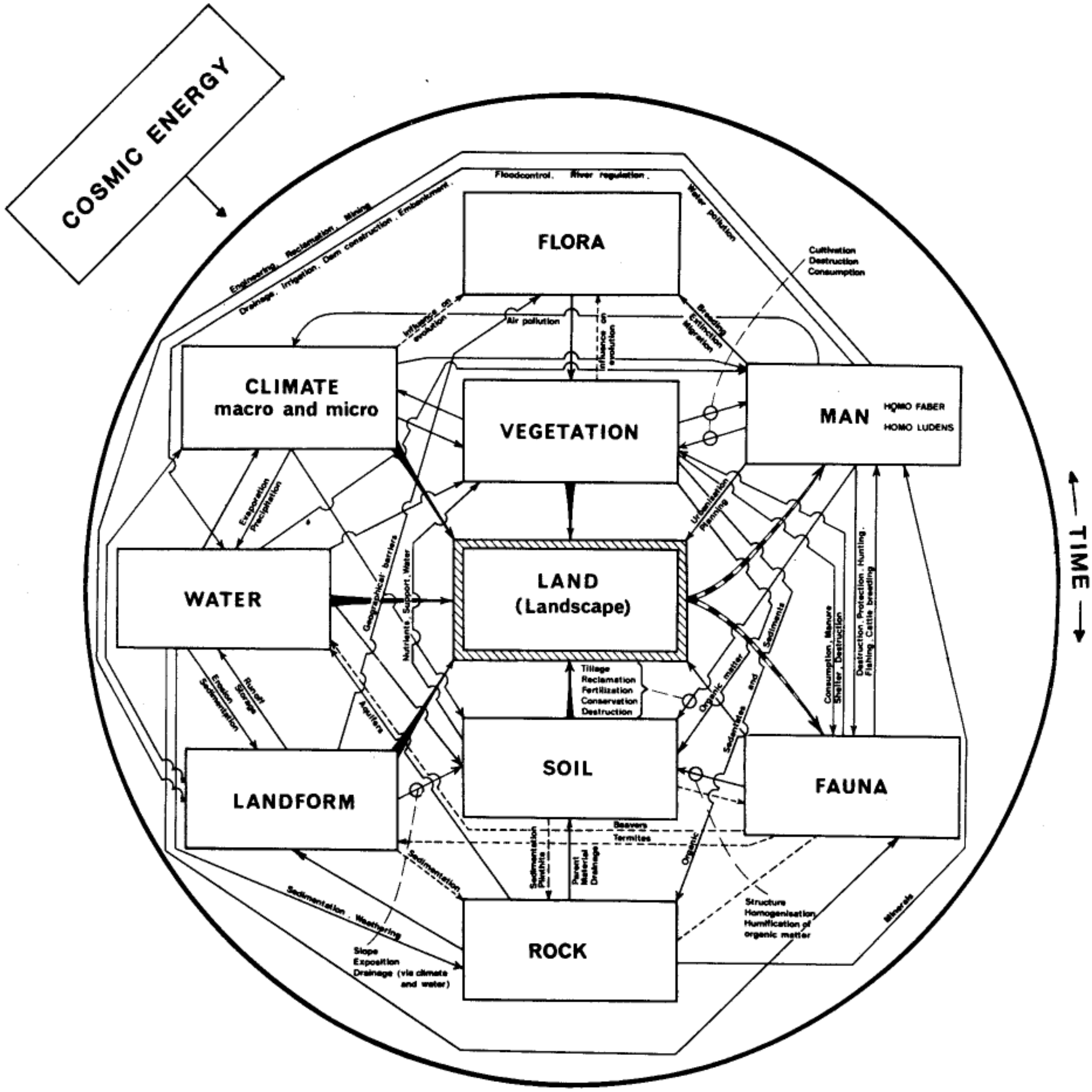

Fig. 1. Land factors and attributes.

sis of life (in the biological sense). Because life is a part of land, it means that a land unit is a tract of land in which life conditions are homogeneous. This means that, in principle, certain soil properties do not necessarily need to be homogeneous, provided they have no influence on life. The same holds for landform.

Scale and homogeneity

Homogeneous means that, within the tract of land as a whole, gradients cannot be distinguished, as from wet to dry, or poor to rich. In reality there are always differences; the smaller the scale of the map (the larger the area in nature), the more internal differences occur in the mapping unit. Still, we may call such a complex unit homogeneous if the composing elements occur in a regular pattern.

Large relief or climatic gradients are a special case. They can be subdivided into reasonable mapping units, each having an internal gradient. The environmental factors that determine the gradients differ within the units, but not enough to be considered significant (compare the price of a seat in a theater or cinema; price variation does not vary in absolute proportion to the distance to the platform or screen, but is broken into steps for practical reasons).

Small-scale land units (that are mapped as large-scale mapping units) will usually be delineated from each other by relatively discontinuous transitions caused by relief and/or human influences that justify the separation. The content, at least patterns of elements, then also differs sufficiently.

Scale is important not only in relation to homogeneity; scale leads also to an important concept that is too often misunderstood: 'holism'. This philosophical concept, introduced by Smuts in **1926,** is essentially concentrated on scale in the universe and will be treated below.

Holism

Holism is based on the hypothesis that nature consists of a hierarchy of 'wholes' (holons): quarks – protons – atoms – molecules – minerals – living cells – tissues – organisms – population – society). **A** large-scale body (*e.g.*, the total cosmos) cannot be understood by directly studying only the smallest elements, but should be examined at the various hierarchical levels as an entity.

Modern systems theory and landscape ecology add ecosystems as wholes composed of abiotic and biotic (and even noospheric, or human mental) factors. *Hence land units have aplace in this hierarchy* and, moreover, certain hierarchic levels can be distinguished in land units.

This is the reason that we pose the hypothesis that land units are *holistic* entities with all the properties of holistic bodies. It should be clear that:

a. This is a hypothesis and as such must be tested and proved; at the same time, it is already very useful for practical purposes.
b. *Holism does not mean that we should study everything* before drawing conclusions; in a way, *the opposite is true.*

Holism means that the object with all its properties can be considered as a natural whole, that, as such, can be recognized as a type by only a few well-chosen diagnostic characteristics. *Holism is hence also the basis of any typology or classification.*

Soil, vegetation (land cover), landform, are also considered by most scientists as wholes and hence can be classified using a set of diagnostic characteristics ('kenmerken' in Dutch). Land units as wholes can also be classified, as will be described below.

The land unit as a system

A crucial concept of a whole ('holon') is that it either remains the same over a certain period of time or shows a slow gradual change, without large, sudden changes. Nevertheless, we know that a great many energy fluxes are occurring inside a land unit and between a land unit and its environment. This means *it is a system in a kind of equilibrium.*

The land unit hypothesis postulates that it is an (open) system with a certain self-regulation (homeostasis and homeorhesis). Indeed management of land usually aims at a 'steady', a persistent or at least relatively constant, state*, which means either pure conservation (prevention of damage) or at least *sustained* yield (no deterioration through use).

Thus, a land unit is a tangible set of internal as well as external relationships (see Figs 1, **2** and **3).** From an applications point of view, we are very much interested in certain of these relationships, for example vegetation versus mineral supply and water regime of the soil. Soil conservationists are much interested in the relationships between erosion processes and the factors involved, in the atmosphere, vegetation, and the soil itself.

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* Steadiness or persistency does not necessarily mean 'stability' in a thermodynamic sense. Landscapes as well as 'life' represent at most 'dissipative' systems that may be far out of thermodynamic equilibrium, but are – because of energy fluxes – nevertheless more or less persistent (Prigogin and Strengers 1985; Navez and Liebermann 1984).

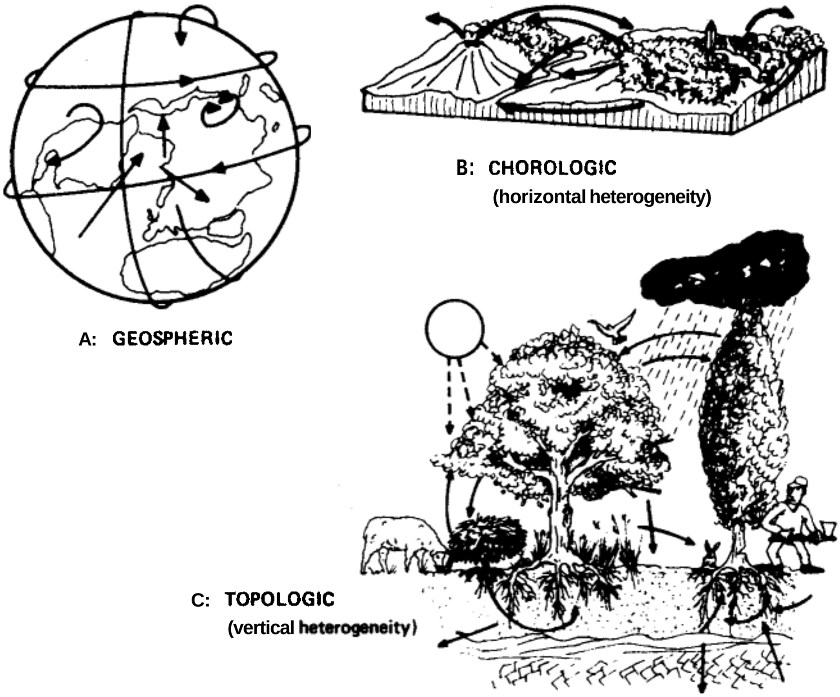

Fig. 2. Landscape ecologic dimensions.

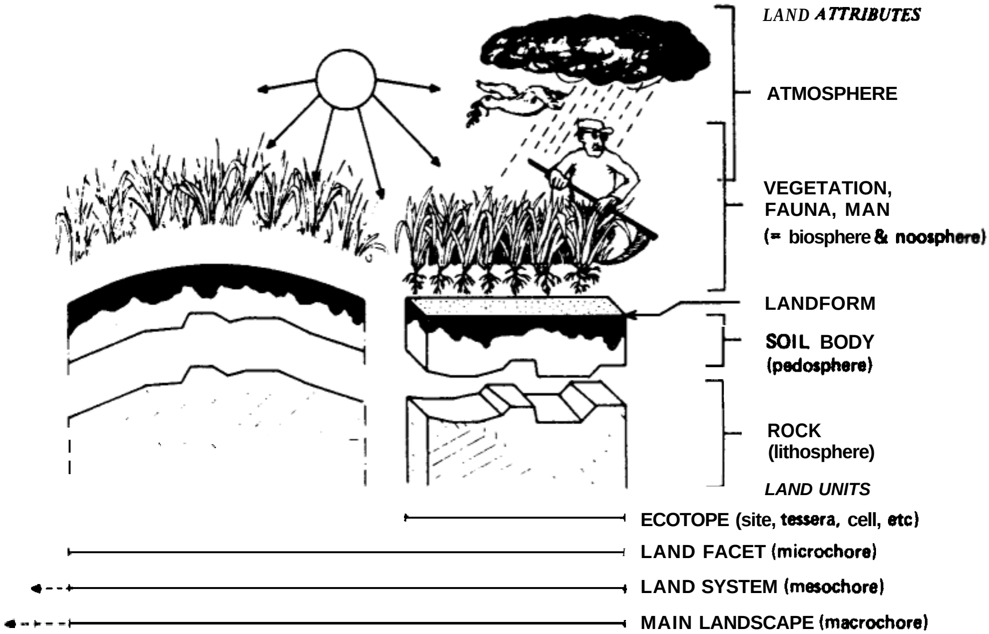

Fig. 3. Horizontal and vertical heterogeneity in landscape as the study subject of landscape ecology.

Operational and other factors

For a clear understanding of the following discussion, we should bring some order to the way relationships are usually discussed. The factors determining relationships can be distinguished as:

- Real operational factors
- Conditional factors
- Positional factors
- Hereditary factors

(see Wirdum **1981;** Van Leeuwen **1982).**

The only real relationships or real factors, in the pure sense, are the operational factors. Examples include the amount and composition of minerals that are actually ready to be absorbed by plant root tissues to serve as plant nutrients. They may be more or less correlated with certain soil analysis results but are by no means equal to them. CEC, pH, absorption capacity may partly describe them and these are controlled by texture, humus content and other aspects of the soil. Another example is the energy exerted by water on certain soil particles. This energy is conditioned by the total amount of water, its velocity, and several other factors that are in turn controlled by actual rainfall, slope and certain stability factors in the soil.

From these examples, it may be clear that the real operational factors are very difficult to measure directly. The conditioning factors, however, such as soil texture, absorption complex, slope, and soil cover can often be measured directly. Indeed, most of the study of the environment of organisms is done by measuring conditional rather than operational factors.

A still more indirect but important factor is the ***positional factor.*** The knowledge that water runs downhill and not the other way round can be used to speculate that a calcareous rock will influence its lower surroundings in a certain way; oligotrophic areas having a higher position influence lower richer areas. It is a well-known phenomenon (discovered by van Leeuwen, **1982)** that in the first situation a rather coarse-grained vegetation cover, relatively poor in species, develops in the transitional area. In the second case, however, nature develops a high diversity with a relatively low energy turnover. Such phenomena can be predicted and explained from the positions of the elements of concern.

Finally, hereditary factors relate to things that have happened in the past and persist in the present, although they cannot be explained by the measurable factors present. An example is the occurrence of certain relict plant species, introduced by no longer occurring natural or human activity, a human influence on soil conditions long ago that still persists.

Topological and chorological relationships

In the foregoing, we have seen that certain relationships occur within land units. Such relationships are vertical material exchanges via plant roots transporting minerals and water, or vegetation cover preventing raindrops from falling directly on the soil. These are called topological relationships (on the spot relationships). On the other hand, we have seen the influence of mineral-poor or -rich water transported from one land unit to another creating a transition zone or even a transitional land unit with a special character. There is also the special function of the boundary (or transition zone) between two especially low ranking land units for many animal populations (Opdam **1984;** Merriam **1988).** These are chorological relationships (between spot relationships). They do not necessarily exist between only adjacent units (see Figure **2).** The strong influence of many thousands of wild geese on European grasslands and arable fields (considered sometimes as damage that has to be compensated) is possible because of certain land units in the Arctic **(4000–6000** km north, separated by millions of km^2 of land and water).

The grazing in the dry season by cattle at certain floodplains that are flooded during the rainy season in Africa south of the Sahara is possible because of the existing low-productive but high-quality grassland, land units at the fringes of the Sahara, many hundreds of kilometers away, that can be grazed only in the wet season when there is drinking water available. The well-known land units of Alps (mountain grassland in Europe) exist because of spring and autumn grassland at lower levels and stables in the winter. So it is with many trekking animals, both wild and domesticated.

There is also the economic influence of a town on the land use which differs according to communication possibilities and so indirectly also with distance. It shows that land units as open systems are interrelated and often strongly dependent on each other. For an important group of landscape ecologists (*e.g.*, animal population scientists and hydrologists) the inter land unit fluxes are even their main object of study.

Related concepts

The concept of land units as ecologic expression of landscape is as old as the time human beings became aware of their environment and is also related to concepts used in modern science. Its history is revealed by existing toponyms, names of obvious, still-recognizable individual tracts of land with their own relatively homogeneous ecological character. Everyone can easily recall such names in his/her own language (fadama, erg, dambo, kwelder, ven, vlei, veld, heide, aue, alp, mor, paramo, savanne, the 'pastures green' of the bible stories).

In forestry, such names as site and standort are very narrowly related to the term land unit, especially when these terms are used in a spatially tangible way. Soil surveyors use the term land type as a wide (high abstraction, small map scale) unit. If they use it not only as a mapping unit but in a more conceptual form, it is related to a complex large-scale land unit (depictable only on small-scale maps). Holdrige's life zones (mainly climatologic differences) and UNESCO's bioclimatic zones and others can be considered as kinds of large-scale (mappable on small scales) land units. The set of terms used by the Australian, British, Canadian and other schools of ecologic land surveyors *(land system, land facet, main landscape, bio-physical landscape)* are of course narrowly related and, in fact, are pure land units at different scales in the sense used here (see also Stan Rowe (1988), who gives a clear description of the land unit concept under the title 'terrain ecosystems').

Our concept of land unit could even better be called land system, being land as a system. Christian and Steward (1964), however, defined their 'land system' as a system of land units, hence something at a certain scale level (depictable cartographically on scales of 1:100,000 to 1:1,000,000). The term land unit is restricted to another (lower) scale level by these authors. Both expressions are thus contaminated. Still it would be unwise to not use the common term 'unit of land', hence 'land unit' as a general term, not restricted by scale. It is clear that the Australian land system could be such a land unit (in the sense of the definition in this paper) provided it is an ecologically homogeneous unit (compare, for example, surveys in Australia and Papua New Guinea). Unfortunately, however, sometimes these land systems are more geomorphologically than ecologically defined and cannot be called land units as defined in this paper. Criticism of the Australian method by practical land evaluation experts (mainly in oral communication) clearly stems from this problem.

The units of the potential natural vegetation maps of Germany, Holland and Japan are narrowly related to such land units but are expressed in vegetation terms and are indeed ecologically homogeneous (see Kalkhoven 1988). We should mention here also the vegetation landscape units of Doing developed for coastal dune landscapes (see Doing **1974).** Finally the term 'ecotope', as used by modern landscape ecologists, is a pure land unit of lowest rank, very similar to standort, site, tessera, landscape cell (see Fig. **3).**

Other terms neglect the biotic part of land, but are still related because they point to the same tract of land. These include:

– Soil body (the three-dimensional bottom) of an ecotope as far as soil condition is concerned.
– Physiotope, somewhat wider, also including the atmosphere and the rock and hydrosphere below*.

* We could also mention in this context the term 'biotope'. This term is used inconsistently, however. It is sometimes the ecosystem minus life (the physical environment of a plant community) or the total environment including animals and man. More often, it **is** synonymous with the 'habitat' of one animal species or even the niche of an animal. We avoid this term in landscape ecology, however.

- Terrain unit, usually geomorphologically defined, is very much related to physiotope and could in fact be considered as a physiotope but is more often a complex (mosaic) of physiotopes.
- Physiographic units, according to certain geographers and soil scientists pointing to pure geomorphic features, are strongly related to the former. The author, educated by Edelman (the founder of physiographic soil survey) grew up in the tradition of physiography being the landscape *including life!* In that tradition, a physiographic unit is a kind of land unit as defined here.
- The catena concept used in soil survey schools deviates from those mentioned above. Originally, it was used to describe a continuous chain (catena = chain) of soil types, developed from the same parent rock under different topoclimates on a mountain slope. **As** such it is a combination of soils which have only the parent rock in common. It is, in fact, a series of soil bodies of land units, each belonging to a rather high-ranking climatologically-determined, hierarchical level of land units, and thus by definition does not form one single land unit.

Catena is confusingly also used in the sense of a soil association, a complex map legend unit. **As** such, it may have the character of an intermediate-scale land unit as far as the soil part is concerned. Because of the confusion that surrounds this concept (it is also used for complex sites or zonations with different groundwater levels), it is advisable to leave it out of land unit descriptions.

The reality behind the (visual) reality and the task of classification

The foregoing could be summarized by stating that the concept 'land unit' is used to express a system of operational factors acting upon each other naturally. Because it is too difficult to detect them without disturbing their action and because they work in an integrated action synergistically, these factors cannot be depicted in a pure sense.

We see a certain tangible relief, vegetation structure and (after digging a pit) a series of colored layers of soil forming a profile with different textured and structured layers. We can describe that configuration, even the conditional and positional factors, and draw it on a piece of paper as a mapping unit. The real operational factors that we want to know and eventually use for land evaluation are behind the visible, observable ones. There might be factors that have no visible evidence as such but (by indirect research) may appear to be correlated (at least statistically) with a land unit as a 'holon'. By mapping land units, such factors can be inventoried or, after having been detected by further study, more concretely analyzed by experiments.

Fertility of soil, influences of topoclimate, synergistic effects of minerals, soil fertility and soil humidity on plant growth, and mutual biotic influences belong to those indirectly observable operational factors.

In this way the 'land unit' concept does not differ from any other classification of natural bodies such as organism, pedon, coenon, and holon. For classification, we abstract a limited number of properties as diagnostic characteristics from those individually-observed wholes (*e.g.*, by statistical treatment of many descriptions of those individually-observed specimens).

If these individuals really are 'natural' bodies, then a few diagnostic characteristics are sufficient to characterize the wholes. Soil scientists believe that soil classification units describe such bodies. Vegetation scientists assume the same of vegetation communities as classification units. Land(scape) ecologists suppose that land units do indeed describe such correlative complexes and as such combine at least the factors represented by soil, vegetation and landform types, but as one whole and not separated artificially into different subsystems*.

In the following, we will discuss the consequences of this hypothesis for:

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* There is a modern trend to abandon these 'old fashioned' classification principles and go back to point observations. The modern **GIS,** in combination with geo-statistics, would give (in principle) possibilities for this. Especially in reconnaissance **sur**veys, the problems with internal variation of units, the inaccuracy of analysis methods (see Pleijsier 1989), however, will force retention of the benefits and achievements of classification.

1. Techniques for land attribute surveys (soil, vegetation (land cover), landform, certain geologic surveys) preferably using aerial photography and other remote sensing techniques.
2. The delineation and definition of mapping units.
3. The units to be chosen as a basis for land evaluation.
4. The application of modern GIS (geo information systems).

For the time being, however, it should be clear that the land unit is not simply a mapping unit. On the contrary, it is a conceptual unit and as such is also the concept underlying a mapping unit. Survey mapping is the main method for studying land units, detecting them, describing them, and trying to understand them.

How to delineate and classify land units

Mapping and photo-interpretation as study methods

An important method for studying land units is to map them. Surveyors among soil scientists, geomorphologists and vegetation scientists will understand this. The visual pattern on a map reveals much of the positional aspect and so helps in understanding the units as tangible bodies and by this (in combination with the data from the field) also the truth behind the reality.

All study begins by observing the object and looking for similarities and differences among specimens. The only feasible method for preliminary comparison of land units is to view them synoptically from above. The land unit concept in landscape ecology was born after the possibilities were created to do so using aerial photographs, and later other remote sensing images (Troll 1950).

Many land units, as described above, can be clearly seen on such images. **A** skilled photo-interpreter will be able to delineate units that are ecologically relatively homogeneous. His skill is based on knowledge of landform (and geomorphic processes), of vegetation structure in relation to the environment and forming various cover types, and of relationships between soil and physiography.

One recognizes the units on an aerial photograph as one recognizes a person depicted by just the density of silver grains on a piece of paper. This may happen without conscious detailed analysis or reasoning, but in a glance, based on previously collected knowledge that usually may be unconscious.

It is not the place here to give details of the art of photo-interpretation, but it should be noted that differences in opinion or misunderstandings are created by the sometimes necessary separate treatment of photo-interpretation for soils, landform and vegetation (land use). This is partly unavoidable, but each interpretation, in most instances, gains in value if it is as integrated as much as possible with other disciplines.

The oldest wide-spread systematic survey system using photo-interpretation is the so-called ‘physiographic soil survey’ of Edelman (1950). In those days ‘physiographic’ was synonymous with the landscape approach. This means that the geomorphic landform, including the vegetation cover (natural and cultural), was used to help delineate the soil units. ITC teachers, such as Buringh and Venenbos (see Goosen 1967; Zonneveld 1979) worked this system out for use in aerial photo-interpretation. Doing (1974) developed a vegetation survey method based on landscape principles, transitional to a land unit survey. The present land unit approach is strongly influenced by this physiographic approach. It deviates from it in that units are not reduced in the final stage to soil types only, but also takes into account other attributes including vegetation types, and may define the physiographic units in the final map legends as land units.

Which land attribute is dominant?

The question of dominance has three aspects:

1. Which attribute determines (in the first place) the character of the unit.
2. Which attribute determines its quality for a certain purpose.
3. Which attribute determines the map image, or the pattern?

The first question is not very relevant. The unit is supposed to be a holon, hence all attributes are important. The second question can, for most agricultural aims, be answered with: several or all of the operational soil, water and climate factors. None of these is usually directly observable or directly visible in the map. In designing a map legend, one should, if the pattern allows, take this into account. For example, if irrigation or erosion plays a role, slope becomes more important. The third question deals with the chorologic aspects of a land unit and becomes more important the higher the hierarchical level. For monothematic maps, it is purely a question of cartographic generalization. For land unit maps, it is also a question of the character (especially the homogeneity) of the higher units.

Of those attributes that are at the scale (hierarchical level) at issue, the most readily depictable according to size, shape and visibility tend to determine the map image. This may be irrespective of the meaning of that attribute in relation to question **2.** If several units are equally depictable, the choice is relative to the purpose, since the purpose should determine which attribute will determine the highest hierarchical level in the map image. Hence on small-scale maps, the map image may be strongly influenced by the decision about dominance. On a more detailed map, it is mainly the hierarchy in the legend, and by that the color selection that is influenced by it.

Experience teaches us that knowledge of geomorphic processes in many cases improves the delineation of units. Units may often be delineated by relief form and the vegetation that marks them on the photo. This is especially true on sedimentary rocks and recent sediment. The geomorphic pattern is not always the most important feature on the highest levels, however. On igneous rocks, the landforms of a landscape may differ without change in soil or vegetation. There the chorological aspects, as well as map generalization, and the quality in relation to aim, may demand another land attribute as the 'dominant' diagnostic characteristic (see also van Gils 1989). Especially in areas with steep climatic gradients, such as in mountains and desert fringes, climate is the dominant factor on a high hierarchic level. Climate as such cannot be seen, but vegetation as an expression of it can be used to delineate climatic features.

Vegetation as dominant and as subordinate criterion

The requirement of ecological homogeneity demands criteria that as much as possible reflect the ecological position at the scale concerned. This means bio-indication (for a treatment of bio-indication see Zonneveld 1988). In the landscape, this would give priority to vegetation in making a choice between readily visible land characteristics. In a pure natural landscape, one could conclude that, as a simple rule, the first criterion of subdivision of the Earth's surface was vegetation. This does not mean that all relevant differences can be readily seen directly. Often they can only be inferred from landform and drainage pattern, and later (after the photo-interpretation stage) be confirmed by description of floristic vegetation characteristics in the field.

Therefore, photo-interpretation, even if focused on vegetation, needs to always take into account not only such aspects as tone, texture and micro pattern, but also other land aspects such as drainage pattern and relief. The latter can be observed only on stereo images. On non-stereo images (such as those from satellites) geomorphology can be delineated only by some shade effects and those patterns in vegetation cover that are determined by landform.

Not all geomorphologic boundaries coincide with vegetation boundaries, however, even in pure natural landscapes. Climate boundaries in mountain areas cause vegetation zones that often do not coincide with clear geomorphic processes or forms (an example are the zones on large volcanos).

In Mali (ITC 1977) we described clear but gradual boundaries occurring between Sahel and Sudan zones, where such vegetation as characterized by Acacia's, Bombax, Cordyla and others define the main land units. These boundaries are somehwat at an angle to the latitudes and cross major geomorphologic and geologic zones.

In west Java (Udjung Kulon), the telescope effect was clearly demonstrated by Hommel (1987) at the low Pajung hill (600 m) showing the same zones (landscape units) that farther inland (Mt Gedé) are observed at a much larger altitudinal scale, clearly showing local topoclimatic influences. Clear examples of this telescope (or 'Massenerhebungs') effect are also well-known from European mountain areas.

Topoclimatic influences that determine proper ecologically characterized land units at a relative general scale are regularly used by the author and his students in Thailand, Indonesia and Latin America to determine agro ecological zones in a kind of global land evaluation (see Zonneveld and Surasana 1988).

In all these examples the soils also have a relationship with the different climates but their boundaries are not always where the vegetation scientists put them, because diagnostic differences in soil may be inherited from climates of the past or at least related to fewer operational or actual factors than vegetation reflects.

It should be emphasized that not only topo- but also macroclimatic boundaries, as in the areas in the desert fringe that do not follow clear geomorphic features, are nevertheless dominant features for biophysical land evaluation. This and the telescope effect in mountains (as well as cool air fluxes) show that the meso and topoclimates are not simply bound to certain landforms but to complex positional factors in which the positions of certain landforms, such as isolated hills and mountains, also play a role.

The requirement of ecological homogeneity at the scale concerned demands that climatic similarity indicated by vegetation should be a dominant characteristic high on the hierarchical scale, especially in areas with strong climatic gradients, such as in all mountainous and desert fringe areas. For application in land evaluation, this requirement is clear enough and need not be explained further.

It should be emphasized here that for proper use of vegetation as an indicator, as comprehensive as possible flora lists, subdivided into sociologic or ecologic groups (at least the phanerogames and forest floor bryophyta and lichens), should be considered. I have argued elsewhere (Zonneveld 1988) that this can be done for any scale if the land unit approach is used, even in tropical rainforest. The use of only some structural or physiognomic features is not sufficient, nor is the distinction of just some indicator species.

One needs so called 'sociological species groups' (groups of plants that behave relatively similarly by statistical frequency) to assess classification units. It is not always necessary to know the scientific names. It is the author's experience that one can work very well at local scale with vernacular names that eventually can be translated into scientific ones if such are known.

Climate may coincide with geomorphologic boundaries and also with those of soil classification units. Problems occur if vegetation differences are not immediately visible in remote sensing images. Where climatic boundaries are gradual, records of vegetation transects and point observations can be combined with data of climatic observation stations (if available), interpolating between them and using contour lines and altitudinal positions with structural aspects of vegetation (see Fig. 4 and explanatory text). Remnants of natural vegetation should be used if present. Secondary vegetation also has climatic indicator value, although it is usually less detailed (see Zonneveld and Surasana 1988).

Vegetation as a criterion also has special problems in land unit classification and delineation: it varies not only in space, but also in time, reacting quickly to all kinds of environmental fluctuations. Soils also vary considerably with the same factors, but soil scientists have solved that problem by neglecting those fluctuations, for example by taking the top 20 cm (the plow layer that often is disturbed) for various measurements as one (mixed) unit. Thus soil classification units are to be considered to represent potential rather than actual land ecological factors and, moreover, because of disturbance of the A-horizons, are less sensitive ecologically. For land unit classification, we should preferably have vegetation data extending over a certain period of time. We can then describe a 'pattern' in the time dimension as we do in the spatial dimension on small-scale maps. The most easy and accepted time distinction is the seasonality of vegetation, the yearly cycle of various seasonal stages in which the vegetation may vary. It is therefore sometimes necessary to visit a site at just the right moment or even several times during the cycle.

Human influence is more complicated. Fortunately, this is often not random, but adapted to the environment. The details of boundaries often

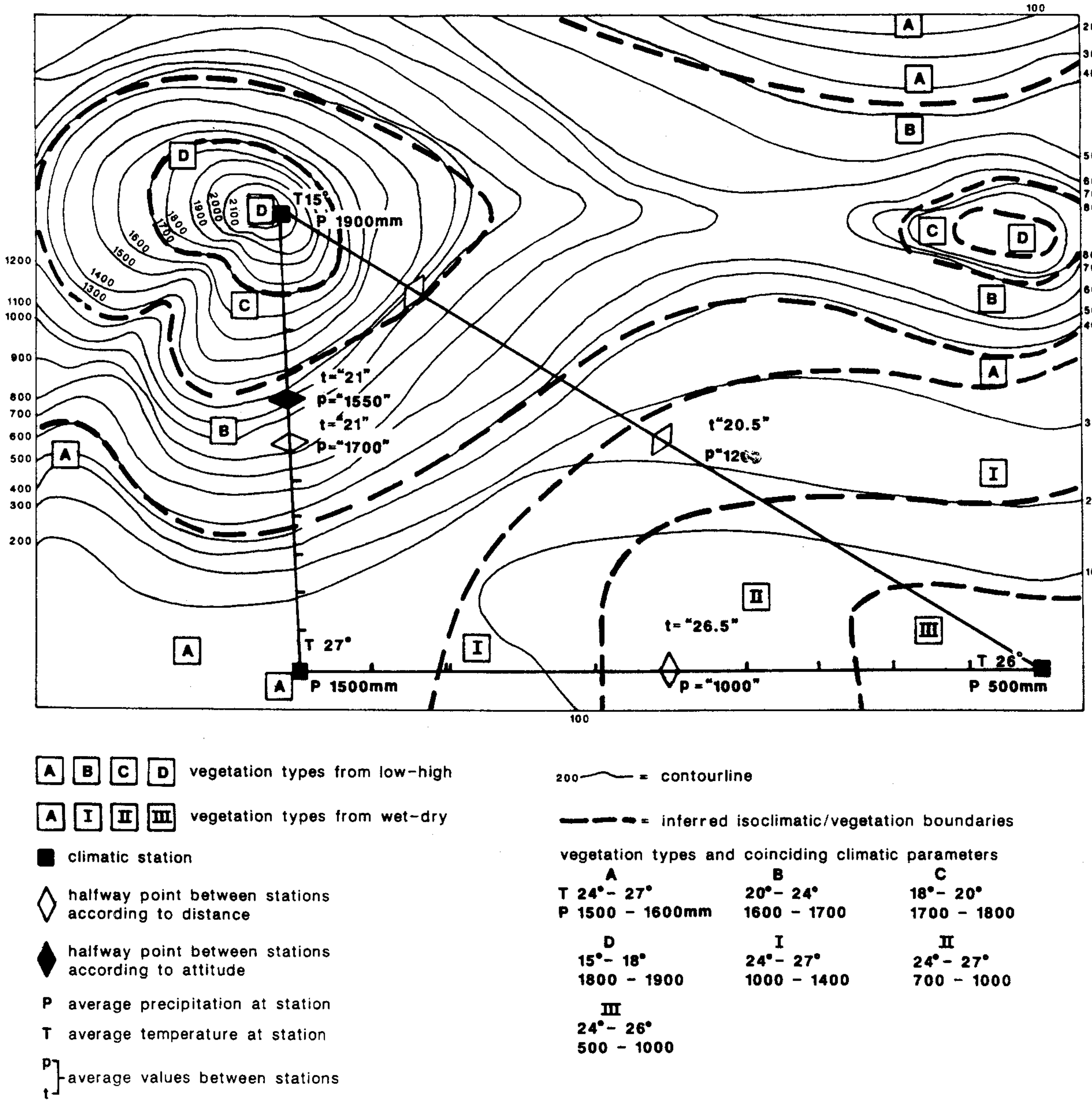

Fig. 4. Example of delineation of vegetation boundaries on the basis of vegetation and climate point observations (using contour lines): The vegetation differences are in this instance not readily visible in the remote sensing (aerial photo) image. The point observations are accurately assessed in the field and allow a classification in four classes according to altitude, and also four classes in the low land according to coincidence with humidity. The structure of the plants indicates that drought-resistant forms occur in III, unlike A. Equidistant lines in the plain do not violate the indication by point observations of vegetation zones, so are taken as inferred boundaries of vegetation (and climate). From the plain towards the mountain summit, however, the altitude is a more accurate criterion than distance to estimate the climate (especially temperature). The altitude is used to locate clearly the boundaries indicating climatic vegetation zones between the four point observations. According to the point observations of vegetation, however, the same zones occur at the much lower mountain to the right at much lower absolute altitudes. This is apparently caused by the telescope effect ('Massenerhebung'). Thus the climatic vegetation zone boundaries can (by consequence) not coincide or be parallel to the contours but intersect them at a certain angle. In this way, the boundaries in the figure are designed taking into account the vegetation point observations in relation to the contour lines.

cause problems because modern land use, with mechanical management and tillage, does not very accurately take natural boundaries into account. The geomorphology and field observations of weeds and soils have to be used to find boundaries, especially on detailed scales. The crop sequence (possibly including a semi-natural stage as fallow or part of a shifting cultivation system) can help define strong human influences.

Permanent cultures of at least a decade (orchards, vineyards), however, are to be considered as individual land units. Planting an orchard or a forest has such an ecologic and economic impact on the land that it can also for practical reasons be considered as important as a soil or natural vegetation factor. Human influenced vegetation (and soil) differences, however, do not need always to define land unit boundaries on a high hierarchical level. This depends very much on the type of area and the special aim of the survey. In areas with little human influence, they tend to be of higher rank than in fully cultivated areas, but certainly not as a rule.

The concept of ‘potential natural vegetation’ (originated by Tüxen, see Kalkhoven **1988)** can be used to characterize land units with a cultural land use/cover that is less adapted to the environment. Thus potential natural vegetation has to be derived from local correlation studies of remnants of natural vegetation and the environment. For monitoring vegetation cover, this potential natural vegetation can be used together with land form and soil to characterize the basic land unit*.

Intensive human action usually aims at changing the environment, especially the vegetation. One wants not only to follow but also to predict what the result will be. There we need the whole complex character of the land unit: the vegetation for general environmental indication and especially for climate and the present situation; the geomorphology for the positional factors; and the soils for edaphic factors in relation to future fertility (chemically as well as structurally, such as water-holding capacity).

Especially in detailed surveys, special soil surveys (even of single variables) may be necessary. There the use of potential natural vegetation is often impossible or at least not accurate or detailed enough. This does not mean that actual vegetation features would not also be useful in predicting potential situations. **A** good example is the characteristic natural vegetation of sites where acid-sulphate clays are being formed, partly under the influence of that vegetation and the environment that it indicates.

At intermediate scale in cultivated areas on sedimentary rocks, geomorphologic boundaries tend to have a high priority in the higher hierarchical levels and climatic differences are less important. Vegetation and land use are therefore more dependent on the terrain and, as stated above, vegetation boundaries are more difficult to assess than are terrain boundaries, so the latter are used.

Soils as dominant criterion

The role of soils in land unit classification is just as important as landform, climate and vegetation. Soil classification (just as vegetation classification) based on field observation is a major means of determining the *character* of land units, especially also their *potential qualities.* On intermediate scales, soils (just as floristic vegetation classification) play a less important role in determining detailed *boundaries.* Terrain form, in combination with vegetation cover (structure), tends to be dominant here. In detailed scale surveys with intensive field work, however, soil classification, just as vegetation classification, may also play a role in determining boundaries in the field (see van Gils, in press).

Soil classification may also play a role in assessing climatic-determined land units (see above) provided the climate, for obvious reasons, has been constant for at least a few thousand years. This requirement makes the task of soil science in this field doubtful. Inside the broad climatic zones, however,

* Vegetation can be considered as a dynamic part of a land unit that may have a different appearance not only in several seasons but also over the years. For example, in a GIS system, the mapping units to be used as a permanent basis for indicating change can be characterized in this way via land units. For other purposes, it may be useful to consider the land unit as less permanent and classify it differently if considerable changes in vegetation have taken place, especially if these also strongly influence the soil and hydrologic situation.

the soil indication of climate is still important (soil catenas, in the classical sense, represent different climatic soil types in the same parent material on mountain slopes). The incorporation in a soil classification of criteria derived from atmospheric/climatic data instead of pedologic diagnostics, as is done in the USDA soil classification system, introduces a land unit concept in what is meant as a pure morphometric soil classification. It is far better to incorporate climate in land units by vegetation, as described above.

Land Attribute Classification Units as Diagnostic Land Unit Characteristics

A word should be said on classification units and their boundaries as characteristics of land units. Despite the fact that most classification systems are built up in such a way that their units will coincide with integrated environmental factor complexes, the schematization and the lack of proper diagnostic criteria often result in soil, vegetation and geomorphologic units (that are supposed to characterize the same land unit) not having exactly coinciding boundaries in any tangible situation in the field. In such instances, professional ad hoc judgment must determine (via photo-interpretation and field observation) where the boundary will be placed on the map.

Physiographic soil surveyors and landscape-guided vegetation scientists usually have no problem with such a procedure; they tend to place a higher value on landscape boundaries than minor (usually arbitrary) deviations in classification systems. This is one of the most important reasons why a direct land unit survey at reconnaissance scale, where fieldwork per area has to be reduced as much as possible and boundaries cannot be checked every kilometer, has to be preferred to single land attribute surveys. The latter require an extra stage in which all separate attribute map patches have to be combined into land units, with all the associated boundary registration problems. This can also be a problem in modern GIS.

In determining the hierarchy for the various land attributes in classification of land units, the same priorities apply as mentioned about delineation.

Climatic (hence vegetation) boundaries dominate at general scales (even world ecological maps and higher hierarchical levels in vegetation and soil classification systems focus on the climatic aspect). At intermediate scales, geomorphologic boundaries tend to be so obvious, and are often so clearly correlated with soils, land use and vegetation, that they naturally will dominate. On very detailed scales, the soil differences defined by augering and still in combination with physiography and (semi) natural vegetation may be more important.

Exceptions are possible at all levels in all attributes, depending on the special character of the land and also the special character of the survey. As an example, a survey very narrowly focused on irrigated agriculture may place in one legend unit all too-steeply sloping land, never mind what interesting features of geomorphology, vegetation, climate or soils may occur; geomorphology (slope) dominates fully here on any scale.

How to finally assess land units

Where the aim of the study is to describe land units (as a basis for land evaluation, in whatever the survey method used), the final description (and usually cartographic expression) of a land unit can still, in principle, be prepared in two different ways, with various transitional procedures in between. One is the more analytical way, starting from an intensive analytical stage in which each land attribute is studied intensively and mapped separately by its own scientists. This means, in general, that soil surveys are executed by only soil scientists, usually working from a special (soil survey) institute. The vegetation is then studied in the same way by vegetation scientists and sometimes also rangeland specialists. All have their own equipment for the field survey and travel separately to the same area. Geomorphologists and certain geologists and hydrologists also work independently in the field. (This was quite commonly done in many of the older **FAO,** UNESCO and World Bank surveys.) This method has its value for special purposes and routine mapping programs for a single land attribute (such as national soil surveys) and can also result in reasonably described land units by later combining all data. The special character of this method compared with the comprehensive land unit approach includes:

- Each specialist concentrates on his own work and discipline and is not disturbed by scientific or logistic activities and constraints of others, which can be an advantage indeed.
- Data combination afterwards is a special activity for which special skills, time and money are required.
- Boundaries and the method of generalization (especially a problem in reconnaissance surveys) are different on all maps. Combining them requires intensive study of all separate survey results, which will give to the person doing it the opportunity to gain much knowledge about correlation (and non-correlation) of land attributes. In some instances, extra fieldwork is required to solve problems that could not be resolved in an office. Boundary problems may be many and frequent.
- For detailed, purely scientific studies with very detailed attribute classification systems and intensive field survey, it can be the best way. Land ecological relationships can be studied objectively and intensively, provided all parties are in contact with each other before and after fieldwork and realize that they all study the same system.
- The method, however, is relatively *very time-consuming and expensive* in personnel and transportation costs – the more so the smaller the scale.

The other method is the land unit survey. Here, following the basic principles of physiographic soil survey and landscape-guided vegetation survey, and using aerial photography and other remote sensing means, preliminary land units are interpreted directly as such on photos. Geomorphologic evidence, as well as vegetation pattern interpretation, is an absolute requirement. The interpretation and the subsequent field survey are carried out preferably by several persons, having together sufficient knowledge of at least landform, terrain, soils vegetation and land use. In the field, at the same sample spot, at least soil, vegetation and landform (terrain) aspects are described. In special cases, separate geomorphologic transects may be necessary. The same holds for specific soil and vegetation observations, The bulk of the work in the field and office is carried out by representatives of these sciences working in close contact and even with some exchange of tasks. In practice, the vegetation scientist, in areas where his task is light, may help the soil surveyor in writing or augering (and vice versa).

A main advantage, in addition to logistics, is that each science gains from the other: a feature observed in one science may stimulate observations of special correlations in another that otherwise would not be so obvious. Also, a clear boundary in one attribute may make it superfluous to look intensively in the other, depending on past evidence that such boundaries are correlated. This is obviously a less analytical approach, but is more practical and economical.

Cooperation in such a land unit survey may still vary depending on the type of people and aim of the survey. A general characteristic, however, is starting with one preliminary photo-interpretation map made from a combination of photo-interpretation efforts in all contributing disciplines. During the following stage, a representative of each discipline is responsible for a specific classification. In the final stage, boundaries are assessed by mutual agreement. In the field, all participants make their observations simultaneously at the same plot; other, independent field data collection is carried out only incidentally.

The joint point sampling is essential. The variability in soil and vegetation means that correlation studies need to be based on data collected at exactly the same point and at the same time. Problems in the separate analytical method arise especially from the internal variability in soils and vegetation and its influence on map generalization.

Classification

Theoretically, for land units as for any other type of natural body, a taxonomic classification (typification) system could be made. As far as application

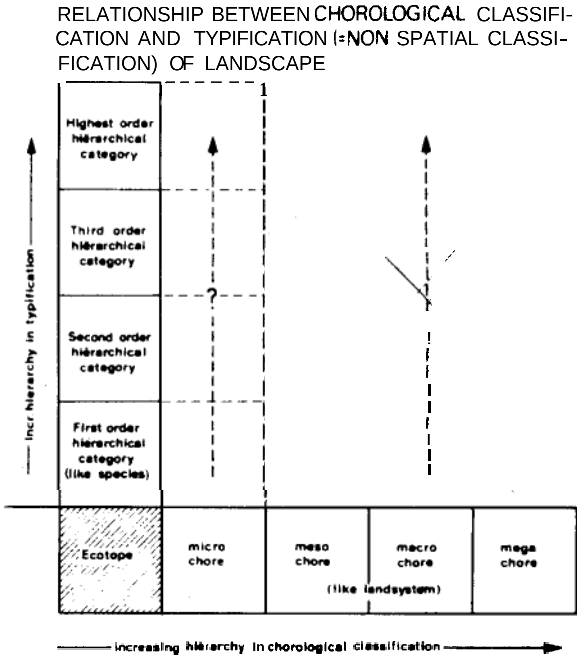

Fig. **5.** Topological and chorological classification.

is concerned, we are not in favor of this because it may make the procedure unnecessarily complicated. This may be clear from the following explanation: analogous to soil and vegetation units, such a classification (typification) can be made only for the smallest tangible bodies that can be called land(scape). This is the ecotope. For all land units of higher ranks, the horizontal (chorological) arrangement plays an important role and that role is often so site-specific that it does not lend itself well to a general hierarchical classification system (see Fig. 5).

In fact, such higher rank units are in this aspect identical to legend units of a map and are usually unique for a region. **A** legend description suffices for one region. The legend, however, needs a classification of the basic elements, in this case the ecotope (the smallest possible land unit). So why not a classification (typification) of ecotopes? Such systems indeed do exist for Russian circumstances and also to a certain extent in The Netherlands. To make a world-wide system would demand much effort and probably can never be so detailed that it can serve all local purposes. It would, however, be an interesting exercise that would serve the development of science. In this context, Phipps (1981) and Kwakernaak (1986) proposed the introduction of information theory in characterizing land units.

For any local survey, however, it is more practical to describe the units with a combination of the classification systems of the composing subsystems – the land attributes (soil taxon, vegetation taxon, landform and land use, and, if possible and/or appropriate, climate, hydrology, animal population data).

This does not mean that the land unit is just an addition of these separate attributes! It is just a way to describe, with existing, generally-known names or symbols, a ***whole*** (holon). To emphasize the holon character, however, we should give the land unit its own ***ad*** *hoc* name. Such a name is very important. Too often the land unit is considered as a mere mechanical addition of land attributes instead of what it really is supposed to be: a SYSTEM, including a series of subsystems (soil, vegetation, landform, topoclimate). To use only the names of the attributes could stimulate this erroneous mechanical view. To use only one attribute (‘Cretaceous’ or mountain or forest) would also lead to misunderstanding. The name can be derived from vernacular names (alp, paramo, kwelder, aue, marsh, etc.) with the addition of a characteristic plant, soil or land form. Examples include Arenga plateau, Festuca kwelder, Espeletia-paramo, Combretum-pediplane, Oak rolling land. At least two attributes or a holistic vernacular land unit name is used here (see *e.g.*, Hommel 1987; Etter 1985).

Here we may emphasize the form of a land unit map legend in general. This legend should explain as clearly as possible the composition of the various units, the relationship of land factors within these units and the ecological interrelationships of the land units in the total mapped landscape. Maps tend to live a life separate from reports. Also the modern GIS puts a special demand on land unit maps. They provide the basic data for the GIS and remain the basic reference document for GIS applications. The total complex land unit legend can be stored in a GIS, preferably as an expert system (see Zonneveld and Surasana 1988). Format, shape and text design of legends for land unit maps must therefore receive the highest attention.

Are land units just mapping units?

The careful reader of the preceding already knows our answer to this question. Remarks are sometimes made in the sense of 'why all this fuss about a practical trick to have just feasible mapping units (colored patches on a piece of paper)?'

Indeed, land units as described here can and should be used as mapping units, at least in reconnaissance maps that serve land ecology aims. It is clear, however, that this capacity to be a feasible mapping unit depends on the hypothesis of the land unit as a SYSTEM.

Hence land units are more than just mapping units. Otherwise land units and physiographic units should not be used as preliminary photo-interpretation and/or mapping units for soil, vegetation or landscape maps, nor for land evaluation. It is my experience that some daily users of the land unit concept in their practice of survey and photo-interpretation are not always aware of this truth.

Application aspects and conclusions

G(eo) I(nformation) S(ystems) and land units

The term geo information systems is used here for those computerized systems that are able to store and reproduce spatial information. One of the inherent basic technologies is automated cartography. **A** GIS can be used to integrate cartographic (spatial) and temporal point data by adding, selecting and combining. From the preceding discussion, it may have become clear that the distinction of land units is a top-down process, and not a simple selection and addition of separate surveyed features of the land. The integration involved requires mental activity that cannot be readily programmed in the software of such systems. Such systems are very useful, however, *for adding, subtracting and recombining existing, separate biophysical data,* and for *integrating spatial social and economic data with the biophysical land unit qualities* as is required in land evaluation (see Meijerink *et al.* 1988; Zee and Huizing 1988; Hielkema *et al.* 1986). A GIS, however, cannot be considered a basic tool for land unit assessment nor will it make the land unit approach during survey superfluous. The arguments for this statement follow.

- The land unit as a system is not a mere compilation of independent building stones.
- The boundaries of separately-surveyed land attribute mapping units rarely coincide.

There are four major reasons for boundaries not coinciding: orientation errors, classification errors, real classification differences, and no correlation between the land attributes (see Banning *et al.* 1973 and Fig. 6).

Land unit surveys *(sensu stricto)* avoid the first three errors. The fourth one is detected during the survey and is important information in and of itself. When boundaries do not coincide, the surveyors have to judge which boundary of which land attribute defines the status of a land unit. **A** GIS may help here only in exceptional cases, and it is probably more efficient to reserve map input to a GIS until a final map has been prepared. In land unit surveys, a GIS has a very important use *after* the survey and final map preparation (see Zonneveld and Surasana 1988).

This final map (including final boundaries, final legend descriptions) is then available for *analysis,* that is, selection of certain land attributes or values of attributes as described in the legend. The GIS can then recombine those selected values into new derived maps for comparison, using modelling algorithms and expert systems. **A** GIS can also be used to integrate pure biophysical land units with social and economic data.

Finally, a GIS can be used for land evaluation and land use planning (see Zee and Huizing 1988; Andrade *et al.* 1988). This facility is still being developed, but by using more sophisticated algorithms (*e.g.*, crop yield simulations) and expert systems, the real holon character of land units can be combined with objective automated evaluation procedures. We also expect much of a GIS in the study of the chorological (horizontal) relationships between land units in the land evaluation context.

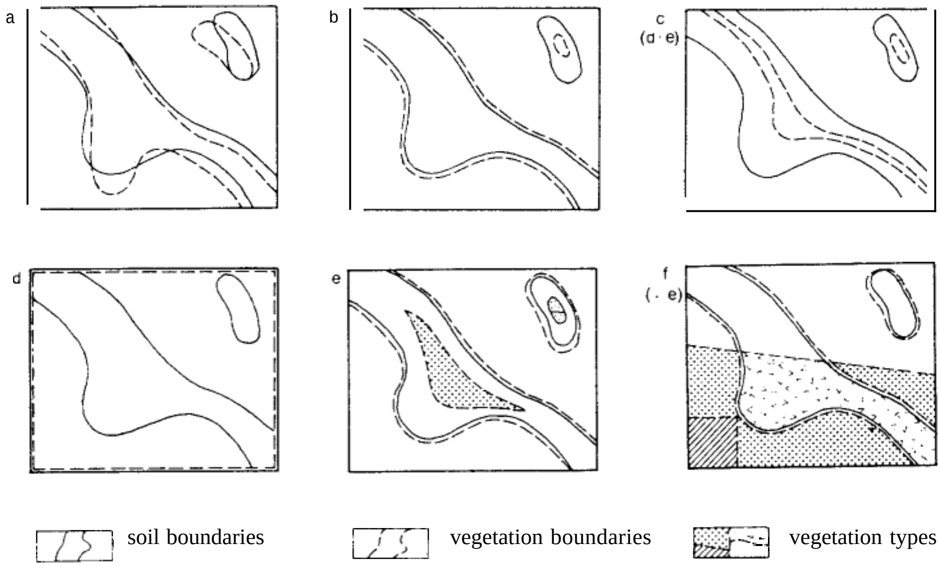

Fig. 6. Examples of differences between soil or vegetation caused by:
Technical errors in surveying:
a. faulty determination of location
b. faulty determination of the soil unit or vegetation type in the field
Differences in classification:
c. arbitrariness of delimitations between recognized soil or vegetation units
Genuine differences
d. 'analogue' soils (cf. Pallman), different soil units but obviously ecologically identical for the vegetation
e. unclassified difference in the soil, evident in the vegetation but as yet unknown or not sufficiently apprehendable to warrant recognition of separate soil units
f. non-pedological ecological factors, e.g. in the climate, or due to the influence of man.
(From: Bannink, Leys and Zonneveld, **1973.)**

When and why land unit surveys and when and why not?

From the foregoing, it may be concluded that, compared with single attribute and especially single value survey methods, land unit surveys are less analytical, use an hypothesis as the truth, stimulate scientists and disciplines to benefit from each other, lead more directly and completely to a result for development purposes if land evaluation is the final aim, and are cheaper (the more so the more global the scale).

For pure academic study to develop a discipline and also for systematic routine survey of a country, soil surveyors may better make pure soil maps, and vegetation scientists pure vegetation maps. This, however, should be done without the landscape hypothesis, using it only for assisting in choosing sample points and transects which indeed should preferably be guided by some physiographic features in the field. The boundaries should be based on pure fieldwork, however, using the aerial photo mainly as a field map. This corresponds to the photo-guided field survey (as described by Zonneveld **1988).** This is feasible only in large-scale study-surveys and for systematic routine mapping in a relatively detailed survey. **A** good example is the time-consuming systematic survey of The Netherlands (a rich country with a relatively small area and a dense population) with multipurpose land uses, where a whole institute has worked for more than 20 yeaers on a series of pure soil maps of 1:50,000 that cover hardly more than **30,000** km^2. Compare this with a 1:200,000 scale map of Mali also of **30,000** km^2 by a small ITC group in **18** months, all aimed at land evaluation for general development (land use, including roads) (ITC, **1977).** The land unit approach was the only feasible method, although the final result was published at the request of the receiver in separate attribute maps, the latter derived directly from the original land units.

Hence the more the development of a discipline is the aim and the smaller the area, and the more direct field observation is necessary, the more reasons there are for single attribute surveys. If the final aim is to delineate the overall ecological character of an area and if the constraints of time and money are great, the more necessary it is to use the land unit survey method.

These are trends! We know of 15,000 scale land unit maps of great usefulness with important results for science, made to use and test the holon hypothesis. We know also of pure soil and vegetation maps of the world on scales of many millions in atlases. They are useful for scientific and educational purposes. Finally, the choice of the survey method depends very much on the education, experience and even character of the responsible scientists. There are, however, cases and areas where relevant ecological information of land unit type is urgently needed and the situation does not permit the luxury of indulging in time, money and manpower-consuming separate, perfectionistic surveys by each discipline. Thus the rescue of the tropical rainforest, rapidly dwindling away at present (and also the now overused farmland), requires overviews on reasonable scales giving needed vegetation and soil information for effective conservation planning that can be feasibly obtained only by land unit surveys within the coming decade. After that, if no serious conservation measures are taken, there is no more need for surveys because the forest (and the currently still productive land) will have disappeared.

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