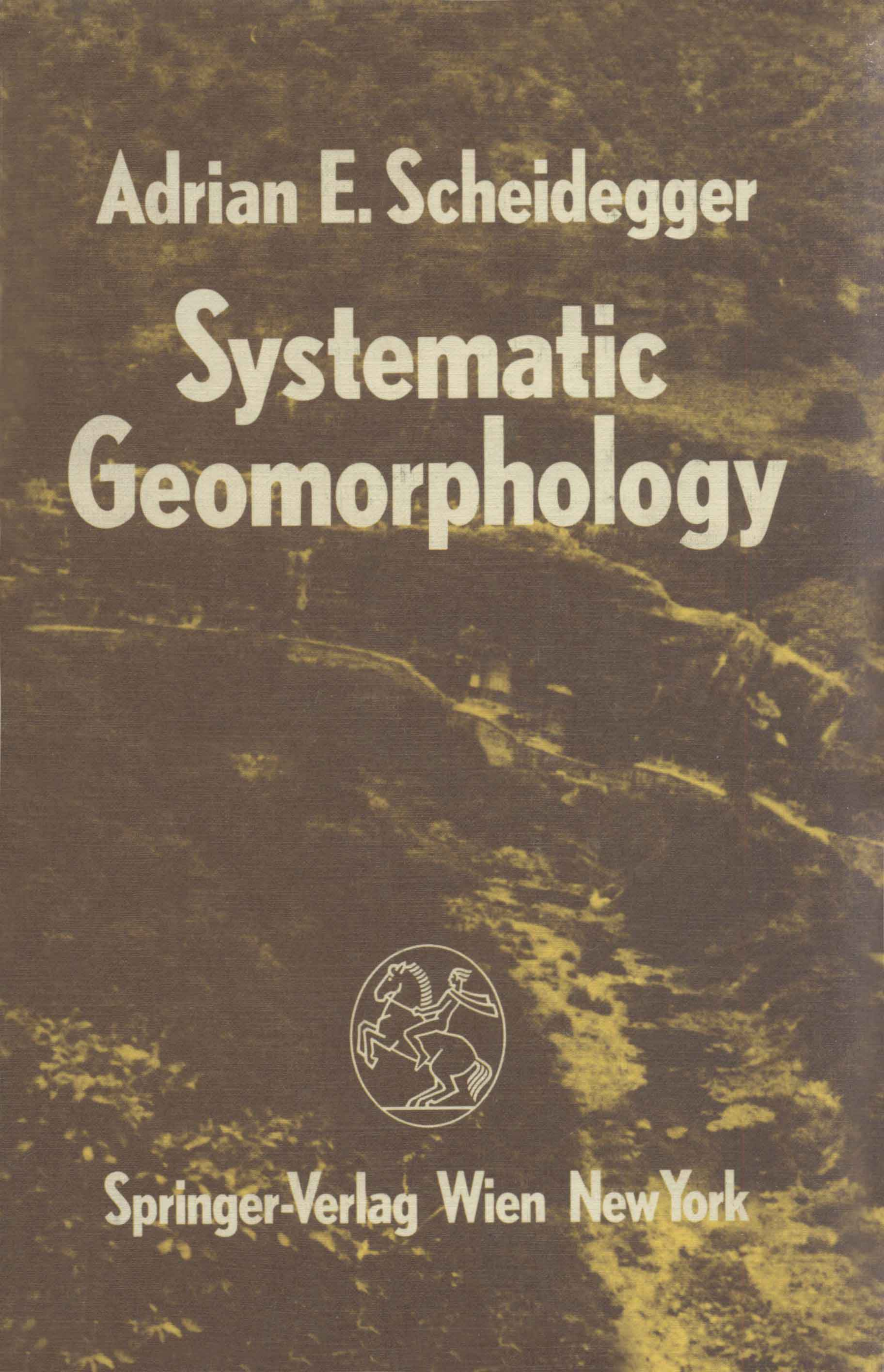

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Systematic Geomorphology

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To my Grandchildren

Preface

To most people, travel is an exciting experience. When one journeys around the world, one is struck by the great variety and beauty of the landscapes that one encounters.

The scientific mind, naturally, is not satisfied with admiring the various landscapes, but would like to understand how they were formed. The exact theory of landscape formation is a very complicated affair, but much can be learnt from accurate observation.

The need for the present little book became apparent to the writer during his studies of the mechanics of landscape formation. It turned out that there was, in fact, no systematic compilation of those surface features of the Earth available, that have to be explained by theory. In effect, even the taxonomic principles that have to be applied in a classification of landscapes have nowhere been clearly stated. Thus, this book is intended to present a pictorial taxonomy of geomorphic features based on the basic principles of landscape genesis, as they have recently been worked out.

The pictures have all been taken by the writer himself during many geoscientific studies and travels throughout the world. Some of these pictures had already been used in earlier publications of the writer's. Such previously used pictures have been duly referenced; the writer wishes to acknowledge his indebtedness to the Zeitschrift für Geomorphologie, to Rock Mechanics, to the Gesellschaft der Geologie und Bergbaustudenten in Österreich, to Physik in unserer Zeit, and to the Institut für internationale Architektur-Dokumentation (Arcus) for the permission to republish them.

Vienna, June 1987 **A. E. Scheidegger**

Contents

1 Introduction

Systematic geomorphology is the science of the classification of landscapes. Inasmuch as the surface features of the earth are of a bewildering complexity, the task of classifying them is not an easy one.

Traditionally, this task has been tackled on the basis of some evolutionary hypothesis. Thus, Davis (1924) noted that erosion and degradation by water, ice and wind represent some of the most effective agents in landscape evolution. However, since "erosion" can only have a destructive effect in a landscape, he assumed that all development would involve the degradation of forms that had been built up previously by endogenic (tectonic) processes. Thus, Davis supposed that every landscape would be passing through progressive stages of youth, maturity and old age, after some cataclysmic geological event had initiated this process. For each one of these stages, specific characteristics were postulated; thus in "youth", valleys were supposed to be narrow and steep, in "maturity", broad and gentle, and in "old age" all that would remain was supposed to be a plain, corresponding to the base level of erosion. A new "cycle" of landscape evolution would be initiated after a new tectonic cataclysm would create a new topographic relief. Characteristic cycles had been postulated according to whether the climate was humid, glacial or arid.

Unfortunately, the cycle theory of Davis contains a fundamental misconception. None of the evolutionary landscape cycles could ever be followed through on a single object. "Young"-looking forms are seen in one place, "mature" ones in another, "old-age" ones yet elsewhere. The very existence of "cycles" as postulated by Davis is therefore to be questioned. If a classification of landscapes is to be attempted, this can evidently not be done on the basis of an evolutionary theory that is patently false.

Therefore, if a taxonomy of landscapes is to be established on the basis of their genesis, the latter must first be described correctly.

Davis (1924) was certainly correct in his view that erosion (exogenic) and tectonic (endogenic) processes are involved in landscape evolution. It is also clear that the primary initiation of landscape dynamics has to come from endogenic processes, inasmuch as exogenic degradation (erosion) can only occur if a relief is already in existence.

Nevertheless, endogenic uplift and exogenic degradation do not occur in sequence as supposed by Davis, but concurrently. In this manner, a landscape represents a "system" affected by two antagonistic processes: tectonic build-up and exogenic degradation. If a landscape shows any sort of permanent character, these two antagonistic processes are in dynamic equilibrium ("*principle of antagonism*"; Scheidegger, 1979).

In the light of the above remarks the concepts of "youth", "maturity" and "old age" introduced by Davis for the classification of landscapes, attain now a new significance: If the activity level of the two antagonistic processes mentioned above is high, the landscape has the character of "youth", if the activity is medium, the landscape has the character of "maturity", and if the activity is low, the landscape shows the features of "old age" in the terminology of Davis.

In the above qualitative description, quantitative values have to be assigned to the concept of activity level as well as to the concept of "landscape character".

The activity level is best described in terms of tectonic uplift rates, which must equal the exogenic denudation rates in the case of dynamic equilibrium. The former can be measured by repeated precise levelling operations, the latter by determining the total load carried by a river per unit time at a certain point and dividing it by the total area drained above the point. Experience has shown that there is indeed a rough balance between these two rates (cf. Scheidegger, 1987); in humid, high mountain areas ("high activity"), they are of the order of (nearly) cm/year; in low mountains, they are of the order of mm/year; and in plains regions, they are much below one mm/year.

The second concept, that of landscape "character", was quantified by Strahler (1957) through the introduction of the *hypsometric curve*. The latter is obtained by calculating the fraction of the area under consideration that lies below a certain height-level. In geomorphology, it is customary to consider *relative* hypsometric curves: the heights and areas are divided by the total height (difference between the highest and lowest point in the area) and by the total area under consideration, respectively. Then, Strahler (1957) had shown that the hypsometric curves are convex for "youthful" landscapes, more or less straight for "mature" landscapes and concave for "old age" landscapes. This qualitative statement has been further quantified (Scheidegger, 1987) by the introduction of a "hypsometric index": This is the quotient of the area under the hypsometric curve and the area of the isosceles triangle obtained by drawing a straight line from the point (0, 1) to the point (1, 0) in the hypsometric graph.

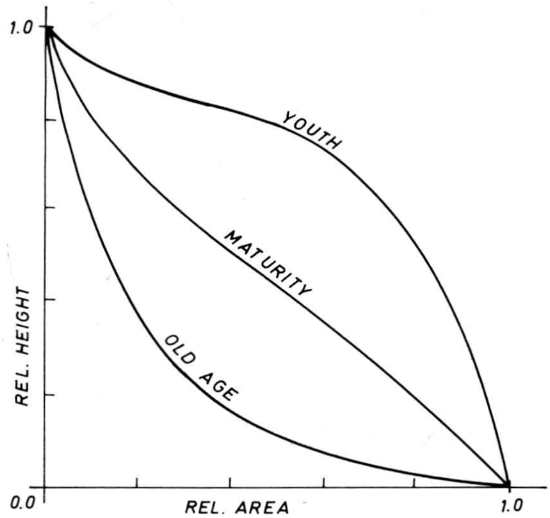

Fig. 1. Hypsometric curves after Strahler (1957)

Now, one has two quantitative measures for describing the landscape dynamics: The uplift/denudation rate, and the hypsometric index.

In view of the above remarks the terms "youth", "maturity" and "old age" should be abandoned in the characterization of landscapes and should be replaced by "high-activity", "medium activity" and "low-activity"-type landscapes. Clearly, one has a hypsometric index of between 2 and 1 for high-activity ("youth"), of around 1 for medium-activity ("mature"), and below 1 for low-activity landscapes (see Fig. 1).

Furthermore, it has been remarked (Scheidegger, 1979) that the two antagonistic processes active in landscape dynamics have a different character: Since tectonic (endogenic) processes act in consequence of plate tectonics, their statistical character is *systematic* over large (plate-size) regions. In contrast, since exogenic processes have their origin essentially in atmospheric processes that are best described by the statistical theory of turbulence, they present the aspect of being stochastic processes on a small scale. The result is that exogenic processes produce features that are *random* (such as meander trains, random drainage nets etc.) on quite small scales. Consequently, the statistical character of geomorphic features can be used in order to obtain an indication of the actual origin of such features.

The configuration of forms in a landscape can generally be characterized by a set of parameters (such as hypsometric index, drainage density, mean slope angle etc.). Inasmuch as a particular configuration in a landscape is the result of a dynamic process, it stands to reason that, if one or more of the parameters are changed, the others must "respond" for there to be an equilibrium. In this connection, a large literature has sprung up discussing and describing the process-responses that take place in the wake of natural and anthropogenic changes in a landscape (cf. Terjung, 1982; Scheidegger, 1988).

In general, the processes respond to changes in the parameters in a gradual way. However, at times, the reponse may lead to an instability.

One reason for an instability to occur may lie in the existence of a positive feed-back mechanism: if a parameter is slightly changed, the adjusted process may further change this same parameter in the same direction. The initiation of this process may lie in natural statistical fluctuations in the system (Taylor instability).

Another reason for the occurrence of an instability of the system may lie in a multivaluedness of the dynamic equilibrium parameters: Thus, the state of the system may suddenly change from one possible equilibrium configuration to another. Furthermore, the various branches of the curves that represent equilibrium states in parameter space can possess singularities; if one of these is approached, an instability threshold is reached (a "catastrophe" occurs; cf. the catastrophe theory of Thom, 1972).

The effect of a Taylor-type instability expresses itself in the fact that geomorphic deviations from uniformity tend to grow. Thus, meanders become bigger (until they are cut off), erosion cirques grow etc. This type of evolution has been described as the consequence of the operation of an "*instability principle*" (Scheidegger, 1983) in geomorphology.

The existence of multivalued dynamic equilibrium parameters expresses itself, for instance, in the presence of reaches with streaming and with shooting flow in a river, in the presence of flat-steep-flat sections on a slope etc. This has been called the "*catena principle*" in geomorphology (Scheidegger, 1986).

We have seen that endogenic processes are the primary agents in geomorphology: Without tectonic activity, no degradation can take place. Thus, there is a "structural background" to all landscapes, which expresses itself in the systematic nature of many features (Scheidegger and Ai, 1986).

In addition to the primary systematism due to endogenic control, there are, however, additional systematic features that are the result of a certain directedness of the exogenic processes. This directedness has been considered as the result of the operation of a "*selection principle*" (Gerber, 1969) in geomorphology which states that the processes of degradation and erosion occur preferentially in such a fashion that statically stable forms are "selected" by them. The stability, of course, is with regard to the stresses induced by the weight of the developing forms themselves. Because the gravitational field is also homogenous over large areas, like the tectonic stress field, the resulting forms equally show a certain systematism. Specifically, the evolution of triangular peaks, towers and similar features can be ascribed to the operation of the selection principle.

From the discussion given above it should become clear that it is not possible to give a "linear" classification of geomorphological features. Since there are several criteria possible as a basis for classification, the result must be a (multidimensional) matrix.

In the light of the principle of antagonism, the most fundamental classification is evidently obtained according to the activity level. Depending on the prevailing climatic conditions, specific fundamental landscape types are the result.

Furthermore, the type of tectonism and of the material present leads to a consideration of the structural and petrological background of a landscape.

Next, specific systems can be considered, of which slopes are the most fundamental ones. In slopes, the operation of the various principles of landscape evolution afford a further classification.

Specific types of landscapes can then be considered individually, depending on their mode of genesis. Thus, chapters will be devoted to fluvial effects, to the ocean-land system, to glacial geomorphology, to desert features and, finally, to volcanic landscapes.

To sum up, the taxonomy of geomorphic features can be presented in form of a systematic table, to which the pictures in this book are keyed. This table is given as Table 1 on the following pages.

Table 1. Taxonomy of geomorphic features in tabular form (figures are keyed to this table)

2 Basic landscape types

We have seen in the Introduction that the most fundamental principle active in landscape genesis is the principle of antagonism. A fundamental division of landscapes is thus obtained by considering whether the activity level of the antagonistic processes is high (Figs. 2.11 to 2.13) medium (Figs. 2.21 to 2.23) or low (Figs. 2.31 to 2.33).

At each activity level, a further distinction is obtained by considering the prevailing exogenic agents: This may be water (in a humid climate), ice (in a glacial climate) or wind (mainly, but not exclusively, in an arid climate). Additional subdivisions may have to be introduced on account of the material underlying a landscape. In this fashion, the taxonomy illustrated by the pictures now following was arrived at.