PROBLEMS OF RELIEF PLANATION

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AKADÉMIAI KIADÓ, BUDAPEST

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RELIEF PLANATION

Studies in Geography in Hungary, 8

Edited by M. Pécsi

In this volume problems of planation processes in low mountains and their forelands and the resulting land forms are discussed.
The introductory paper gives information about the character, dynamics and trends of the recently discovered planation processes in the middle mountains of the Earth, and the variegated complexes of land forms brought about by these. With a view to clearing up terminological confusion, the paper points out contradictory usage and suggests new solutions.
The Hungarian authors concern themselves with the hitherto little-known form types of the planation levels in the Hungarian Mountains. They disclose up-to-date notions on the evolution of these forms and report on the latest methodological developments.
Authors from abroad interpret the climatic conditions controlling planation, provide analysis and model of the processes and forms of the semiarid zone so conducive to planation, and clarify the evolution of some special forms.
International scholarship calling for terminological clarity will find this book serviceable as a foundation of principles and methods of recent geomorphological investigations in Hungary. Research workers and teachers in all parts of the world, as well as cartogeographers following this new and practical discipline of physical geography, will be faced here with new ideas and challenges.

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Edited by

MÁRTON PÉCSI

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PREFACE

The present volume, eighth in the series "Studies in Geography in Hungary", presented by the *Geographical Research Institute, Hungarian Academy of Sciences,* has for its subject one of the more important problems of modern geomorphology which concerns the processes of planation in low mountains and their forelands, as well as the land forms resulting therefrom. In this book eminent experts on the subject from Hungary and abroad discuss the relevant theoretical achievements most worthy of attention. These contributions were originally read during the Symposium of 16–20 April, 1968, organized by the Geographical Research Institute.

The introductory essay contains information about the character, dynamics and trends of some recently discovered planation processes which are active in the middle mountain regions of the Earth, as well as about the variegated complexes of land forms brought about by these processes. In addition, detailed analysis is given concerning the present-day standing of the diverse research trends in this domain of themes. Particular interest may be attached to the paper inasmuch as it exposes the contradictory usage of various terms, providing at the same time some propositions with a view to clearing up the terminological confusion.

Contributions by Hungarian authors concern themselves with the hitherto little known form types of the levels of planation in the Hungarian Mountains interpreting their evolution according to the latest methodological developments.

Contributions by authors from abroad similarly expound special and general problems of planation. These include a novel interpretation of the climatic conditions controlling planation, a profound analysis and model of the processes and forms of the semiarid zone so conducive to planation, as well as the action of some peculiar processes and the evolution of certain special forms.

Finally, this book is a representative selection of the results of Hungarian geomorphological research — either unpublished so far, or published in a form difficult to obtain for scientists abroad — showing the international standing and the modern methods of this activity. Also discussing and evaluating the main problems of international research and urging terminological clarity, this book may hopefully serve as a foundation in the principles and methods of the subject for both research workers and teachers. Cartogeographers of such interest in physical geography also find here new ideas and chalienges.

M. Pécsi and *J. Szilárd*

INTRODUCTION

FUNDAMENTAL PROBLEMS OF RELIEF PLANATION

The great forms of the Earth's relief are sculptured by endogenic agencies. Their action, alternating in time and space, augments the relief energy of the surface. As a consequence, gravity compels the exogenic agencies to transport and deposit more waste over certain periods of time and certain areas than over others. The results of the exogenic processes are further modified zonally and locally by the particular ecologic conditions existing at the place and time under consideration; it is this interaction that determines the nature of the planation of the relief.

The unceasing but varying action of endogenic agencies brings about a differentiation of the repeatedly rejuvenated relief. The planation wrought by similarly unceasing exogenic agencies is, on the other hand, controlled by the alternation in time and space of the intensity of active gravity (i.e. slope angles) and of the given ecologic conditions. Locally and periodically, the exogenic agencies may also bring about a dissection of the relief. Hence, the action of the exogenic processes is invariably subject to outside control rather than being teleologic in nature. On the other hand, the process of relief planation is not strictly periodic, with a repetition of identical states; there is merely a rhythmic recurrence of similar states in the course of unceasing change.

The planated surfaces recognized in various regions are highly varied. The interpretation of their origin has long been controversial and has been a focal point, as it were, of many fundamental ideas and principles of relief evolution, and of geomorphology in general. On the other hand, it is also connected rather intimately with a number of problems of a more practical nature, such as the occurrence of shallow mineral deposits in deeply eroded regions, and of residual ores—bauxite, manganese—in correlate deposits, etc. It may further serve as a basis for a "continental stratigraphy" of regions where erosion has been going on uninterrupted for long spans of geologic time. A corollary of this idea is, for example, the method of determining the age of the relief during the geomorphological mapping of mountainous regions.

The topic includes in its theoretical aspect several problems of a general and fundamental nature.

(1) Planated surfaces are formed—in general—by the well-defined interactions of exogenic and endogenic agencies, with the exogenic agencies dominating (Chemekov, 1964; Filosofov, 1964; Klimaszewski, 1965). It is not, however, clear from this definition just how the agencies mentioned bring about the sculpture of planated surfaces. Is planation, or the stepwise system

of planated surfaces, a result of a continued or stepwise uplifting, or of the stability, or of the gradual sinking of the terrestrial crust?

(2) It was usual, in earlier times, to emphasize the role of linear erosion among the external agencies of planation; lately, although, the differentiated analysis of the specific combinations of exogenic agencies in individual climatic zones has become the rule. Our understanding of the effects of climate upon relief is, however, far from unequivocal. It is only clear, that in certain climatic zones external agencies are especially effective and may produce peculiar land forms.

(3) Still profoundly problematic is the interpretation of the origin of peneplain steps and pediment steps. Are they the result of the structural dissection of a previous contiguous surface; are they planated surfaces of different age, or the autodynamic results of an uninterrupted process of planation? [Some ascribe the development of stepped, truncated surfaces to a continuous structural uplifting (Penck, 1924); others attribute this to continuous exogenic processes, e.g. continuous stream erosion (Kádár, 1966); still others relate it to geophysical factors (Geyl, 1960).]

(4) The influence of lithology upon the planation of relief is not in general considered decisive, except in some local cases. Still, lithologic variety may result in deviations from typical forms and this is, in some measure, still open to further research.

(5) For the interpretation of the lowering of slopes, three comprehensive hypotheses have been developed:

(a) the rounding and overall lowering of divides by non-parallel slope recession (Davis, 1922; Philippson, 1931; Birot, 1949; etc.);

(b) parallel recession of slopes (Penck, 1924; Lehmann, 1933; Bakker, 1956; etc.);

(c) a combination of the above two has also been considered (Büdel, 1957b, 1965; Cotton, 1961; etc.).

(6) All in all, the interests of research, and of international scientific understanding and cooperation, in both principle and practice, make it indispensable to attain clarity of terminology, to identify synonyms and to define variants rigorously. The lack of such definitions has caused us no little inconvenience.

M. Pécsi

PLANATED SURFACES: PRINCIPAL PROBLEMS OF RESEARCH AND TERMINOLOGY[1]

by

M. PÉCSI and J. SZILÁRD

I. THEORIES OF RELIEF PLANATION

1. TRUNCATED, PLANATED SURFACES (RUMPFFLÄCHEN)

The genetic and topographic interpretation of the concept is rather diverse in literature. Taking into consideration all definitions, both narrow and broad, it emerges that truncated, planated surfaces are considered plane surfaces of considerable extent and low relief energy, usually in mountains, over a stable or gently rising base. They are sculptured by the processes of destruction, and by a well-defined equilibrium of uplifting and degradation.

While some authors consider truncated surfaces to be the results of sculpture by a single specific agency of destruction, others consider them polygenetic; that is to say, they result from the interaction of several agencies, with the intensities of the contributing agencies varying in time and space (Meshcheryakov, 1964; Klein, 1959a; Penck, 1924; etc.). According to the views of some, truncated surfaces are polygenetic also in space. Their complex of forms includes not only surfaces of degradation, but also of accumulation and accumulo-denudation, closely related to the surfaces of pure denudation (Meshcheryakov, 1964). Pécsi (1967) coined the term "surface of deplanation" for the former and "surface of applanation" for the latter.

(a) Abrasional planated surface

The earliest interpretation of planated surfaces was given by the British scientist A. C. Ramsay (1846). The idea underlying his interpretation was marine erosion, and the theory of peneplanation by abrasion was long paramount in England. In Germany, it found an exponent in the person of von Richthofen. Up to the final quarter of the last century it played a dominating role in the interpretation of planated surfaces fringing recent and ancient seas.

There are clearly quite broad terraces of abrasion, or stepped systems of this kind, along today's seashores, and fossil terraces of abrasion can be recognized also along the shores of ancient seas. The majority of researchers, however, reject the possibility of extensive abrasional planes of subcontinental size. Consequently, the term "abraded peneplain" should be rejected and the terms "marine terraces", "shore platforms" or "marine halfplanes" should be introduced in its stead.

[1] In the present paper the term "planated surface" is used in a very general sense for all kinds of *deplanated* surfaces.

(b) Peneplain (Endrumpf)

This term was coined in 1899 by W. M. Davis in reference to extensive, almost plane surfaces, sculptured by subaerial processes, such as stream erosion, and developed in various humid regions at the base level of erosion in the penultimate stage of relief lowering. The Davisian peneplain is due to a lowering of divides over periods of prolonged tectonic rest.

This concept has come to be widely accepted and has in the process gained a context much broader than that originally intended by Davis. The number of peneplains described by researchers from all over the world has become so large that—as recorded by W. D. Thornbury (1954)—Davis himself felt compelled to preach restraint to his followers.

The main point of controversy about this theory was whether it justified the assumption of quiet periods during which denudation attained the penultimate stage in the cycle of evolution. The cyclicity of relief evolution has also been contested, and as the peneplain is a necessary consequence of the Davisian theory of cycles, refuting the possibility of cycles is equivalent to refuting the peneplain concept.[2]

Modifying Davis's original theory, several authors came to the conclusion that peneplanation can also take place during a slow and constant uplifting, as long as the rate of rise is lower than the rate of degradation. Davis's polycyclic interpretation[3] of stepped peneplains was also widely accepted with more or less extensive modifications.

Even Davis's American followers accepted his theory of peneplanation with modifications of greater or less significance. According to W. D. Thornbury (1954), to preserve the original concept of Davis means to apply the term peneplain to the smoothed surfaces on divides developed towards the end of the cycle of erosion partially as a result of lateral planation by streams, and partially as a result of mass wasting on the slopes. This is a considerable restriction of the original Davisian idea. Surfaces similar to peneplains but sculptured by other agencies, or under different conditions, should be given other names (Bulla, 1954a; Thornbury, 1954; etc.). However, at the time the peneplain concept came into existence the necessary distinctive criteria and names were as yet lacking.

The opinion that under a temperate climate processes of erosion will never bring about a full smoothing or peneplanation is now gaining ground. Such

[2] In Davis's interpretation, the cycle of erosion is relief evolution returning invariably to the same initial state; it is composed of a long period of erosion and planation and a rejuvenation of the relief by a sudden uplifting. The lack of success of the Davisian theory was —according to geomorphological literature—due primarily to its anti-dialectic interpretation of relief evolution as a cyclic process.

[3] Davis assumed periods of long tectonic rest in the evolution of a mountain; the evolution during such a period produces a peneplain in the penultimate stage of the cycle of erosion, which subsequently undergoes repeated uplifting. On the mountain margin, at the baselevel of erosion, truncated surfaces, partial peneplains come into existence. Wherever and whenever the periods of tectonic rest were not long enough for the process of peneplanation to completely wear away the relief formed during the previous cycle and subsequently uplifted, there occur, according to Davis, remnants of older peneplains at higher altitudes, in a stepwise arrangement.

surfaces conserved in a temperate area are vestiges of a preceding period of tropical climate. Still, even in the face of these arguments, there are some who hold that peneplains can develop in humid temperate areas, for example, under a forest cover (Baulig, 1956), or as a result of fluvial erosion in general (Bulla, 1954b).

Several Soviet authors represent the view that in mountainous regions the rhythmic repetition of tectonic movements precludes the prolongation of smoothing processes up to the last stage of the cycle of erosion, that is to say that typical peneplains can nowhere develop. These smoothed, planated surfaces in the intermediary phase of evolution they call "denudational planated surfaces" as distinct from peneplains (Dumitrashko, 1954; Chemekov, 1964; Shchukin, 1948; and others).

According to Yu. F. Chemekov (1964), "denudational planated surfaces" develop in the phases of rest in the general process of arching. He considers the difference in forms between primary and final peneplains to be much less than advocated by Penck. He holds the two sets of forms to be genetically identical. In his opinion, the difference lies in the fact that whereas final peneplains are the result of a very long process of smoothing, the repeated phases in an orogenically mobile zone bring about only a partial smoothness which is delayed in an intermediate phase. In this sense Chemekov's line of thought is close to Davis's polycyclic interpretation of stepped peneplains.[4]

Also according to Chemekov, the longer the duration of relative tectonic rest, the more extensive and profound the sculpture of a denudational peneplain. Hence, he considers "denudational planated surfaces" to be results of the same downward relief evolution as peneplains proper, the processes at their origin being genetically identical. The difference is in depth and extent, depending on the duration of sculpture. He considers peneplains and pediplains to be the final surfaces of "denudational planation".

According to Chemekov, the denudational planated surfaces mentioned above can develop under various humid climates (warm temperate, subtropical or tropical). To support this statement he produces a great deal of analytical evidence.

(c) Equal peak heights

According to the Davisian theory of cycles, the levels defined by peaks of equal height, and by the tops and stepped flanks of divides, are remnants of peneplains formed at various baselevels of erosion during many successive

[4] According to Chemekov, conditions for the development of a stepped, planated surface are most favourable in the borderzone between mountains and basins. He distinguished zones of exclusive uplifting and zones of exclusive subsidence. Between the two, there is a zone of zero gradient which is essentially the theatre of the processes of deplanation. On the repetition of tectonic uplifting, that part of the planated surface formed in the zone of zero gradient which is adjacent to the foot of the mountain becomes part of the zone of uplifting, a relic, one of the steps of the stepped truncated surface. Subsequently a new phase of smoothing sets in at the level of zero gradient, in the foreland of the former, uplifted surface.

cycles. It was in opposition to and in refutation of this theory, and of the cycle theory in general, that A. Penck developed his own theory of equal peak heights. In his opinion, equal peak heights will result also from the simple uplifting of a mountain. The valley slopes of streams, incised to approximately equal depths into the body of the mountain, intersect the interfluvial plateaux at about equal heights without actually proving the existence of an ancient peneplain.

A. Penck (1919) further considered it definite that erosion has an upper limit, arrived at through the interaction of the given exogenic and endogenic agencies, and above which the relief will not emerge. His "Gipfelflur theory", however, was accepted only for the interpretation of the equal peak heights of alpinotype mountains: its validity for low mountains and truncated surfaces was widely doubted. In our experience, on the other hand, A. Penck's explanation of divides of equal height merits some attention in the analysis of low-mountain regions as well.

(d) The primary peneplain (Primärrumpf) theory and the theory of piedmont benchlands or steps (Piedmonttreppen)

To replace the Davisian polycyclic explanation of stepped planated surfaces, and also as a refutation of the anti-dialectic theory of cycles, W. Penck (1924) gave an "autodynamic" interpretation of stepped planated surfaces.[5]

The basis of his hypothesis is the assumption of an arching, slow at first, but which accelerates and extends in time. According to W. Penck, an equilibrium surface, a so-called Primärrumpf, will then develop over the slowly rising region, its rise being compensated for by erosion. The evolution of the relief is exactly opposite to that assumed by Davis. On the rising piedmont surfaces, the slopes are not senile, but regress parallel to themselves in the direction of the valley flanks. Hence, the Penckian stepped surfaces are not decaying fossil forms, and the primary planes (Primärrümpfe) are not in the process of evolution.

Although the most emphatic point of Penck's Piedmonttreppe hypothesis was fully rejected by subsequent criticism, his thought-provoking theory gave an incentive to further research.

Several authors have made attempts at further developing and modifying Penck's ideas: H. Spreitzer (1951), for example, has attributed piedmont steps to a periodic arching, interrupted by phases of rest, and extending over

[5] In the Penckian interpretation of stepped Rumpfflächen, the initial surface is the "Primärrumpf", but it may be also the Davisian peneplain, the "Endrumpf", "Endpeneplane". As a result of arching, a process extending in area and accelerating in time, the river grades are broken and emphasized at the margins of the area being uplifted. Valleys incise themselves, and the valley flanks gradually retreat and broaden at the expense of the higher surface. The broadening arch embraces a wider and wider area and thus an ever increasing number of younger step surfaces is connected to the most highly elevated central arch. It is this system of stepwise repeated truncated, planated surfaces that was called "Piedmonttreppen" by Penck.

an ever broadening area, rather than to a protracted and constant-rate uplifting.[6]

The Penckian hypothesis was also adopted with profound modifications by several Soviet scientists (Gerasimov, Meshcheryakov, Piotrovsky). A. P. Dedkov (1965) has pointed out that planated surfaces occurring at various altitudes in the mountains are the results of a relief evolution continuing uninterrupted since the Early Tertiary period.

Although W. Penck, in motivating the evolution of his Rumpfflächen, pointed out the peculiar role of weathering, he attributed planation—under the assumed tectonic conditions—to normal fluvial erosion. His teachings were modified also in this respect by H. Spreitzer (1951). According to this latter author, the evolution of piedmont steps—and that is to say of planated surfaces—is restricted to hot, alternately humid and dry climates, with considerable slopewash contributing to stream erosion. He considers the piedmont steps of moderately humid regions as decaying fossil forms.

The concept of piedmont steps is rejected by some, together with the original Penckian idea as a whole, whereas others use it in a more or less modified form, often without pointing out any differences from the original Penckian definition. A further frequently arising problem of terminology is the indiscriminate use of the terms "erosional surface", "denudational truncated surface", "level of erosion", "level of denudation", "partial peneplain" and others, for the stepped surfaces of planation along the margins and also in the principal mountain masses. A uniform terminology based on a comprehensive agreement concerning these stepped surfaces of deplanation is much to be desired.[7]

(e) Pediplain

The concept was proposed by J. M. Maxson and G. H. Anderson (1935) for surfaces resulting from planation by extensive destruction and from the intergrowth of pediments in arid or semiarid regions. Later on, A. D. Howard (1942) proposed the term pediplain for the same concept. In his opinion, the planated surfaces called "Flattop" and "Rocky Mountain" in the Rockies for example, are pediplains rather than true peneplains. A similar view was expressed by J. H. Mackin (1947) in his interpretation of the "Subsummit" level of the Bighorn Mountains.

Pediplains have usually been deduced from pediments. It was in connection with these forms that American geologists and geomorphologists first came to attribute a decisive role to climatic factors. They reinterpreted as

[6] H. Spreitzer (1951) distinguished two variants of piedmont steps sculptured by slopewash and chemical weathering:

(a) Narrow ledge-like piedmont steps on uplifted blocks, formed at the openings of valleys issuing from the mountains in periods of relative tectonic rest;

(b) Piedmont steps sculptured in the episodes of rest of broadening and accelerating arching. It is these latter that are typical piedmont steps: also, they are more widespread than the preceding ones, which are restricted to funnel-shaped valley mouths on the mountain margin.

[7] Since the stepwise arrangement of "planated surfaces" occurs not only in the marginal —piedmont—zone of the mountains, but also in their interior, we propose for them the name *planated mountain step* (Gebirgsrumpftreppe).

pediplains a number of extensive planated surfaces held to be peneplains by Davis. L. C. King (1962) has lately expressed the view that pediplanation is the most general form of relief smoothing, substituting, as it were, the pediplanation concept for the Davisian peneplain concept. In this way, however, King (1950, 1962) gave an unduly broad context to the term pediplain, under which heading he included all the extensive planated surfaces of all the continents as far back as the Cretaceous. In King's opinion pediplains are typical of semiarid tropical zones, but may also develop at lower intensities under moderately humid climatic conditions. He considers the differences between forms developed in arid, semiarid and moderately humid climatic zones to consist merely of the intensity of development.[8]

The pediplain concept has, with certain restrictions, been applied by several authors to the interpretation of various surfaces (Grachev, 1962; Dedkov, 1965; Bigarella, 1965; Cotton, 1955; Pécsi, 1966; and many others). According to M. Derruau (1956), however, pediplains may develop under tropical climates only, whereas A. Cailleux restricts the climatic connotation of pediplain development to the semiarid zone. Hence, the pediplains outside the semiarid zones of today would all be fossil landscape forms.

Another open question concerns the criteria of identification for the pediplain, as a remnant of some planated surface outside the semiarid zone.

(f) Tropical planated surfaces

Since the qualitative and quantitative effects of external agencies in the existing morphologic zones of the Earth have been studied in sufficient depth (Bulla, 1954a, b; Büdel, 1948, 1957a, b, 1965; Dresch, 1957a; Kayser–Obst, 1949; Krebs, 1933; Tricart, 1950, 1961; and others), the view that extensive planated surfaces are most readily formed under humid or alternately humid and arid tropical climates has become more and more widely accepted. The initiators of the theory explained the smoothing of these areas by extensive colloidal and subcolloidal weathering as well as by large-scale slopewashing (Bulla, 1954a, b, 1958; Büdel, 1957a, 1965; Louis, 1957, 1964; Bakker, 1957a, b; Cotton, 1961). The mechanism of denudation in the alternately arid and humid tropical regions (Flächenspülzone) was analyzed in the greatest detail by J. Büdel (1957a, 1965), C. A. Cotton (1961), H. Louis (1957, 1964, 1968), J. A. Mabbutt (1961, 1965). Büdel interpreted the evolution of tropical planated surfaces by developing the theory of "duplicate planation surfaces" (doppelte Einebnungsflächen).[9]

[8] L. C. King refutes the separate existence of humid, semiarid and arid cycles of evolution as proposed by Davis, since all cyclical forms—those of the glaciated regions excepted—are fundamentally identical. King considers pediplanation to be a general process and the formation of pediplains to have taken place simultaneously all over the world.

[9] In the zone of tropical slopewashing, the surfaces are thickly covered with products of weathering, underlain by a less thoroughly smoothed but still hummocky relief of unweathered rock (e.g. granite). This deeper interface is the basal front of planation, smoothed by weathering. Double planation takes place, on the one hand, by slopewash on the surface cloak of weathering products (Spüloberfläche) and, on the other hand, by subsurface weathering on the deeper interface.

B. Bulla (1954a, 1958) emphatically extended the theoretical area of the formation of these tropical planated surfaces to cover the zone of tropical rain forests, whereas Büdel (1957a) considered it only probable that such an extension is justified. According to Bulla, planated surfaces regularly develop in the tropics on every rising or stable crustal segment, up to altitudes where high temperatures and abundant precipitation result in heavy weathering and are still sufficient to bring about a rapid lowering of the relief. In Bulla's opinion it is this form of smoothing which is currently active in the tropical savannah and rain forest areas. Because of its considerable extent, he held this process to be the most frequent and most typical form of relief smoothing on the Earth. He called it "tropical truncation" and the smoothed area resulting from this he termed "tropical planated surface".

In Bulla's interpretation, the stepped and undulating surface elements of these tropical planated surfaces are essentially independent of the tectonic displacements of the region. He emphasized that the tropical planated surfaces of today cannot, except with the utmost caution, be used to interpret the age and amplitude of epeirogenetic or dictyogenetic displacements, as the development of such surfaces is independent of its relative altitude above the sea level; it may extend from the flat coastal plain to quite considerable altitudes (2,000 m), provided the climatic conditions are right. In this latter respect Bulla's standpoint is close to that of H. Louis (1958, 1964) although fundamentally different from that of Büdel, who connects—just as Davis did—the formation of smooth surfaces almost without gradient (2 per mille) to a well-defined baselevel of erosion, and holds the high tropical plateaux, for example the Deccan Plateau, to be uplifted Tertiary planated surfaces, which at the proper time developed in close connection with the current baselevel of erosion.

According to Büdel (1965), an active planated surface such as the South Indian Tamilnad Plain unceasingly penetrates along deeply recessed valleys into the higher surface (the Deccan Plateau) and, in the process, gradually digests it. In this respect, his views are close to those of W. Penck. Although Büdel considers his hypothesis of the "doppelte Einebnungsfläche" — "duplicate planation surface" — to be valid also for the Deccan Plateau. He holds, together with B.P. Radhakrishnan (1952), that this plateau is to be a fossil surface. On the other hand, Louis (1964), disputing Büdel's views, considers, similarly to Bulla, that recent tropical planation is also possible on high tropical plateaux. According to my own experience in the field, Büdel's view concerning the Deccan Plateau is justified inasmuch as recent planation proceeds on the plateau margins and along deep embayments of broad valleys, whereas the central portion of the plateau can indeed be considered a fossil stump of a planated surface. This is supported by the slow dissection of high-level laterites.

Büdel's hypothesis of the "doppelte Einebnungsfläche" offers an apparently plausible explanation for the stepped halfplains (or the so-called "Spülpedimente") with a width of several hundred metres and 20 to 30 m altitude differential on the slopes of isolated mountains (Inselbergs) and on the margins of planated surfaces.

The term "stepped planated surface" is justified for steps with an altitude of several hundred metres that separate extensive tropical planated surfaces with currently receding fronts and marginal zones dissected by valleys embracing tropical inselbergs. According to H. Louis (1964), although the process of regression of the step fronts is in harmony with the effects of the actual tropical climate, the marginal parts of higher planated surfaces and the step zone itself are dissected by the broadening valleys incised into them. Hence, the stepped surfaces are necessarily due to a repeated uplifting—or a repeated arching—according to Büdel. The step scarp recedes parallel to itself from the seashore or from any other baselevel of erosion, preserving its steepness between the two adjacent planes. The developing tropical planated surface of about 2 per mille slope is also lowered parallel to itself. All in all, this hypothesis applies to a tropical environment in accordance with the more fundamental ideas of the Davisian polycyclic theory and of Penckian recessive slope evolution.

The interpreters of tropical planation and their followers generally agree that this process was also in ancient times the most general process of relief smoothing. This is also the explanation they offer for today's extratropical planated surfaces which, in their opinion, represent remnants of Tertiary or even older fossil surfaces.

(g) Other planated surfaces

(1) The local baselevel of a planated surface frequently coincides with a rather resistant layer of rock. In such cases it is open to discussion whether the smoothed surface is a peneplain (a stump) or simply a dissected structural plain. The valley slopes are usually steep and in front of them there are inselbergs capped with hard rock.

(2) C.M. Crickmay (1933) suggested replacing the term "peneplain" as a form of denudation by the term "panplane". He held that Davis's cycle of evolution is not realized because only the initial stages of the cycle of erosion can be verified. The cycle theory is "a deduction by some of the grand masters of geography and geology, and merely blind submission on the part of the rest". The panplane is, according to Crickmay, a product of lateral stream erosion. Between the valleys broadened by it, the divides are gradually digested and lowered. However, it would be difficult to replace the peneplain concept by the above definition although there undoubtedly exist plains sculptured by broad lateral erosion.

This is why a restriction of the term panplane has been suggested (Thornbury, 1954), limiting it to bands smoothed by lateral erosion along the floodplains of rivers.

(3) The term etchplain has been used for some time by several researchers, e.g. by E. J. Wayland (1943) in Uganda, to designate some smoothed surfaces arranged stepwise below the Cretaceous planated surface. Wayland held these forms to have developed on the deeply weathered surface of a stepwise uplifted peneplain, by marginal downwearing in periods of tectonic rest.

(4) As not all remnants of erosional surfaces can be called peneplains or planated surfaces in the Davisian (or any other general) sense, the term "partial peneplain" has been used by various workers. The term was originally coined by Davis for forms of denudation that were held up in the early stages of evolution. The adherents of the cycle theory interpret this by assuming that, of the successive cycles of erosion in a gradually rising region, the later ones tend to be less complete than the earlier ones, that is to say that the succesion tends toward less and less complete cycles. However, even workers who do not accept the cycle idea use this term, firstly for partly smoothed surfaces arranged stepwise by gradual uplifting, and secondly for smoothed surfaces which geomorphologically or topographically do not fully merit the term "peneplain". In this latter sense, the terms "primary peneplain", "initial" or "local peneplain" are also in use. Yet others, who wish to avoid any use of the term peneplain, use various synonyms of rather diverse content for the above concepts: denudational level (Cys, 1965), erosion surface-level (Mazur, 1965), surface of planation (Czudek–Demek–Stehlik, 1965; Mishev–Popov, 1965). The present authors suggested the term "planated surface" or "surface of planation".

(5) On the margins of the mountains, or in the broad embayments of the valleys that penetrate into them, smoothed surfaces frequently form transitions towards forms of accumulation and denudation or of pure accumulation. These forms and their terminology will be dealt with in the section on pedimental half-planes and special half-planes.

2. PEDIMENTAL HALF-PLANES

(a) Pediment (Gebirgsfussfläche)

The interpretation and definition of pediments in geomorphological literature are also rather varied. The term was originally coined by W. J. McGee (1897) who meant by it a gently sloping plane sculptured out of hard rock, foreset to the steep mountain slopes (Thornbury, 1954). In his opinion, the surface of the pediment is covered by just as much detritus as can be transported by slopewash in a semiarid climate.[10]

D. W. Johnson (1932a) also included under the heading of pediment all surfaces of accumulation which connect the baselevel of erosion to the truncated rock surfaces of the mountain, the thickness of whose detrical cover increases away from the mountain. Under his influence, even surfaces standing more or less under the regime of accumulation on the mountain margins were interpreted as pediments.

In North American literature, four general groups of pediment have been distinguished:

(a) (typical) pediment
(b) dissected pediment
(c) buried or cryptopediment
(d) coalescing pediment.

Bilateral pedimentation results in a gradual digestion of the mountain mass or of the residual mountain. In this sense, when pediments coalesce after having digested the entire mountain mass, a pediplain comes to exist (Howard, 1942).

Lately the study of the regional extent, the interpretation of the origin and the clarification of the terminology of pediments has been undertaken largely by European workers (Birot, Bobek, Chichagov, Dresch, Joly, Mensching, Piotrovsky, Raynal, Spiridonov, Wiche, and others).

According to Dresch (1951, 1957a), French literature makes a sharp distinction between (1) pediments proper—surfaces sculptured in hard rock, often the crystalline, in the forelands of mountains, and (2) glacis, sculptured in soft rock and loose deposits.

[10] In American morphological literature, the process of pedimentation is attributed to various agencies:

(a) Sheet erosion (McGee, 1897): the detritus moved by slopewash works a strong corrasive planation on the hard rock of the mountain foreland.

(b) Lateral planation (Blackwelder, 1931; Johnson, 1932a) planation is due to lateral erosion and corrasion by rivers and torrents in semiarid regions; two components of this process are assumed:

(i) lateral erosion at the mouths of valleys on the mountain margin,
(ii) deposition of alluvial fans by rivers issuing from the mountains.

(c) The combination theory (Davis, 1930; Rich, 1935; Sharp, 1940) considers as the most important factors of pedimentation

(i) the mechanical comminution of hard rocks,
(ii) slopewash and
(iii) so-called lateral planation.

In Rich's opinion, pedimentation, together with the production of detritus and the formation of alluvial fans, is the normal and general form of planation in arid and semiarid regions. He considers the role of lateral erosion to be inessential to the sculpture of pediments.

Pedimentation is considered by L. C. King (1962) the most general process of planation, not only under arid and semiarid climates but also in the tropics with one rainy season and under Mediterranean, and to some extent, also under temperate climates. He holds that once the steep scarp of a retreating pediment step has developed against the mountain flank, it stays that way until the advance of the gently sloping pediment digests the entire mountain. As a result, the pediment becomes a pediplain.

(b) Glacis

Although the French authors (Birot, Dresch, Dumas, Tricart, and others) sharply distinguish the soft-rock glacis from the pediment, authors from other countries (Mensching, 1958 b; Wiche, 1963) use the term pediment in a broader sense, as a synonym of the German "Fussfläche" and the French "glacis". However, there seems to be a fairly wide consensus of opinion that half-planes foreset to mountains fall into several groups of different position, origin and constitution. Birot and Dresch (1966) distinguish three main groups among the glacis sculptured in soft rocks, or in loose deposits:

(a) Glacis of erosion or ablation. The truncated soft rock crops out on the surface, or is covered by just a thin sheet of alluvial–proluvial deposits.

(b) Buried glacis or ancient glacis of erosion, covered by a sheet of alluvial–proluvial deposits: accumulation is faster than denudation.

(c) Glacis of pure accumulation, or, as some call it, glacis fans. They frequently resemble gently sloping alluvial fans and develop out of garlands of alluvial cones of torrents, leaning against the mountain slopes. Some workers distinguish also glacis slopes and glacis terraces. The former rise steeply above the erosional glacis covered by a thin sheet of waste, and join the rock ledges on the forefront of the mountains. On the other hand, glacis terraces develop far from the mountain front, near the lower part of the half-plane foothill, and constitute forms of transition between glacis of accumulation and stream terraces.

There is presently a fairly lively discussion about whether it is necessary to make a genetic distinction between glacis and pediment. The conditions of glacis formation as indicated by the French authors are an arid–semiarid climate, with intense physical comminution, periodic mass wasting and slopewash, to which some authors add lateral erosion. According to Dresch, however, the evolution of a glacis is bound to the baselevel of erosion, whereas a pediment is much more independent in this respect. On the other hand, H. Mensching and R. Raynal (1954) have pointed out that, the half-planes in the forelands of mountains being of a highly complex origin, it is better to avoid concepts having a connotation of a single external agency (glacis d'érosion). They hold the terms piedmont surface, glacis de piedmont or piedmont-glacis, meaning waste-covered half-planes in the forelands of mountains, to be most convenient. The term "glacis terrace" should refer to terraces developed by streams incised in foreset half-planes (piedmont-glacis or glacis of accumulation), reaching from the mountain front towards the main valley. These forms are not identical genetically with valley terraces in the usual sense.

(c) Valley pediments

In geomorphological terminology and literature there has recently cropped up a special term for rather narrow half-planes (of a few hundred metres' width), joining the alluvial-plain or terrace surfaces of broad valleys and the lateral slopes of interfluvial divides. Such planes are often sculptured in hard rock, but they also occur in soft rock. The oblique slope of the half-plane is occasionally covered with a thin sheet of deluvial, colluvial or eluvial deposits. These "valley pediments", pediment-like surfaces about the higher portions of river valleys in the temperate zones,[11] have not yet been studied in sufficient detail to permit a genetic comparison with typical glacis or pediment forms. It is, however, an open question whether it is at all justified to distinguish "valley pediments" from these latter.

The process of evolution of "valley pediments" sculptured in hard rock is unclear as yet. In some cases this slope is already dissected into lateral ridges of equal height. In some mountains such forms occur in several generations at different altitudes, that is to say, in the form of lateral ridges issuing from the larger interfluvial divides.

Some "valley pediments" converge with the older, early Pleistocene, others with the younger, late Pleistocene terraces (Pécsi, 1959). In the case of the former, the assumption of an early Pleistocene origin is justified. In some cases, the presumably oldest — Upper Pliocene — "valley pediment" (or the glacis in hilly regions of loose deposits) passes with a gentle break into the surface of the interfluvial divide. In the absence of suitable regional comparative studies it is difficult to tell how the so-called "valley pediments" are related to F. Bascon's term "berm" (1931) or to W. H. Bucher's "strath" (1932) or the forms denoted by these terms. Both concepts were applied by their authors to surfaces of planation, "initial" or "partial peneplains" developed in broad valleys of erosion, owing to the interruption of a cycle of erosion. According to Bucher, a "strath" in the strict sense is a half-plane developed by lateral erosion on the valley bottom; after emersion, it can be developed further by any other agency. Such surface remnants have already been described as "strath terraces". Hence, in a general way, the terms "berm and strath terrace" are restricted to the planated surfaces merging into the valley flanks.

(d) Marginal ledges

Under a temperate climate there occur, mainly around funnel-shaped valleys penetrating into blockfaulted mountains, some narrow marginal ledges sculptured in hard rock. These forms are usually restricted to the mountain margin looking down upon the funnel-shaped valley. In other places, however, where the interfluvial ridges are narrow or the openings of the valleys are close together, they extend also to the forefronts of the interfluvial ridges. On the other hand, in sections where valley openings on the mountain front are wide-spaced, the frontal slope is undissected and steep.

These stepped ledges, or occasionally stepped pedimental half-planes, can be considered each as the root of an earlier pediment surface or piedmont-glacis, preserved on the margin of the mountain block uplifted since (Pécsi, 1963b, 1966).

[11] In some tropical regions these are much more conspicuous, e.g. west of Poona on the Deccan trap basalt surface.

Their evolution is due to a set of peculiar conditions:

(1) lateral erosion by streams issuing from the mountain, under certain climatic conditions (seasonally dry and wet) in periods of relative rest intercalated into the stepwise rising of the mountain,

(2) the lowering of a surface sculptured from hard rock or unconsolidated deposits in the foreland of the mountain,

(3) the deepening due to erosion of a valley or basin in the foreland of the mountain, or the stepwise local subsidence of the foreland, more generally the subsidence of the baselevel of erosion in the foreland.

On the basis of the morphology of the foreland and considering the nature of the correlate sediments, the stepped remnants of pediments, the marginal ledges of the Hungarian Mountains, and particularly of the block-faulted limestone and dolomite ranges of Transdanubia, developed during the semiarid periods of the Upper Pliocene and/or of the Lower Pleistocene.

(e) Points of controversy concerning half-planes

(1) The most controversial point is the evaluation of the climatic factor. Although an ever increasing number of authors are emphasizing that the mechanisms of evolution of planated surfaces exhibit differences controlled by the fundamental climatic zones of the Earth, the role of the climatic factor is still assessed in a number of different ways. Most authors agree, however, that a warm dry or semiarid climate is most suitable for pediment evolution.

In the last few decades, some authors have attributed a similarly favourable role to periglacial aridity and comminution (Bashenina, Cailleux, Dedkov, Pécsi, Tricart, Wiche, and others). Although some researchers restrict the classification of true pediments to semiarid regions, several others hold that pediments can and could develop also in temperate subarid regions (Berg, Cailleux, Gerasimov, Tricart, and others). Still others consider the development of pediments possible even in a tropical climate of alternating wet and dry seasons (Büdel, King). According to L. C. King (1962), the difference between the forms developed under all these various climates is merely one of intensity. On the other hand, Cailleux, Louis and Wiche emphasize that tropical pediments must be distinguished from extratropical ones, because the chemical weathering typical of the former is replaced by physical weathering in the case of the latter. It is on these grounds that H. Louis (1957, 1964) criticizes Büdel's term Spülpediment. The latest research tends to prove that pediments or piedmont-glacis cover a much broader climatic range than hitherto believed (Tricart, 1968).

The presence of pediments in the forelands of the Hungarian mountains was first pointed out by M. Pécsi (1964a, b,), who interpreted them as forms of denudation created during the dry periods of the Upper Pliocene and Early Pleistocene, as fossil elements of the landscape. Earlier geomorphological literature in Hungary made no mention either of pediments or glacis, nor of their origin for that matter.

(2) However, the interpretation of the mechanisms of evolution of these forms and slopes is not yet unequivocal. According to the most widely accept-

ed view, the frontal slope of the mountain retreats parallel to itself during pedimentation; as a result the pediment slope advances against the main mass of the mountain to the detriment of the latter. The forms for occurrence of pediments and the processes of evolution are also influenced by lithology, but to an extent unknown because of the lack of suitable comparative material.

(3) The main phase of the evolution of pediments occurs after the intense deepening and subsidence of the basins, divides and valleys in the forelands of the mountains, that is to say, into the Upper Pliocene and verging on the Pliocene–Pleistocene (Büdel, Fink, Klimaszewski, Mensching, Pécsi, Simonov, Tricart). Numerous researchers (Dedkov, Dumas, Pécsi, Simonov, Tricart, Starkel, Wiche, etc.) have proved with concrete examples that pedimentation, as well as the formation of glacis, also occurred in the dry and pluvial phases of the Pleistocene. On the other hand, King traces back to the Cretaceous the extensive surfaces, or pediplains, that were formed as a result of pedimentation.

In the opinion of several authors, the Quaternary as a whole was not long enough, nor did it provide the necessary climatic conditions, for the development of extensive pediments. They do not deny, however, that the pediment surface also continued to evolve by mass wasting during the Pleistocene. In this sense the North African pediments, and glacis, e. g., are interpreted as transitional Tertiary–Quaternary forms (Büdel, Dresch, Mensching, Raynal).

The assumption is justified, on the basis of numerous convergent opinions, that in Europe the climatic conditions of pedimentation were satisfied in the Upper Pliocene or at least in certain parts of it. However, crustal dislocations at the Pliocene–Pleistocene boundary on the one hand, and intensified erosion during the humid interglacial phases of the Pleistocene on the other, dissected some of the Pliocene pediments into flat interfluvial divides. The relatively short periglacial phases of dryness resulted in the continued evolution of pediments. On the flanks of the interfluvial ridges of the rising mountains, and of the dissected pediment, lesser half-planes—terraces of cryoplanation, pediment-glacis and "valley pediments"—came into existence (Pécsi, 1963b, 1966).

(4) The above points of controversy, as well as the genetical interpretations annexed to them, and the clarification of terminology require comparative regional studies of great detail in the future, and suitably organized international cooperation.

3. SPECIAL HALF-PLANES

The smoothed surfaces and half-planes mentioned above are in the opinion of the majority the result of a combination of exogenic agencies rather than of one single agency. There are, however, types of special planes each sculptured by a single agency, such as river terraces, terraces of cryoplanation or abrasion,[12] which are also in some way or other connected with

[12] The planation by inland ice—"glacial truncation"—is a strongly contested problem: in the opinion of a majority of researchers, it merely remodels—overemphasizes—the pre-existing forms without leading independently to the formation of a planated surface. Consensus of opinion is no less negative concerning the so-called "planation by deflation". The possibility of "karstic planation", raised by J. Cvijić and A. Grund, is also dubious. The

the smoothing of the relief. Further to be classed with the family of special planes or half-planes are forms controlled by litho-tectogene elements. These structurally controlled half-planes are, however, modelled by several exogenic agencies.

Of course, all special half-planes are exposed to subsequent remodelling of a polygenetic nature. In such cases, entirely different forms may be derived from one and the same category, depending on the intensity of remodelling. These can be classed with the forms of relief smoothing in the more general sense. Their terminology and genetics, as well as their classification on the basis of these, is still a task of the future.

II. APPLICATION OF THE THEORIES

The interpretations of the planation of the relief by subaerial processes on rising or stable crustal segments can be divided into two main groups.

1. THE EVOLUTION OF PLANATED SURFACES (TRUNCATION OR PLANATION)

Criticizing Davis's and Penck's interpretation of the evolution of planated surfaces, Bulla (1954a, 1958) found that neither the "peneplain", indicating the penultimate stage of the stream erosion cycle, nor the "Primärrumpf" developed as a product of equilibrium between emersion and largely normal stream erosion is the most general planated form on Earth. This he attributed to a third form, the so-called "tropical planated surface".[13]

In the last decade, the results of geomorphologists working in the humid tropics—in the zones between the wooded savanna zone and the zone with two rainy seasons—have shed new light upon the planation under tropical conditions of extensive surfaces. The possibility of planated surfaces as a result of heavy tropical weathering and intense slopewash has been accepted by numerous researchers. The idea is actually being applied even to planated surfaces formed in the Mesozoic and Tertiary in what are now the temperate zones.

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existence of subaquatic planated surfaces as opposed to surfaces of subaerial planation — terraces of abrasion and planated bands — has of course to be reckoned with, since these have been recognized not only along the shores of actual lakes and seas, but also in Tertiary zones of transgression.

[13] Bulla based his interpretation on the examinations of geomorphologists working in tropical regions (Krebs, 1933; Mortensen, 1929; Kayser–Obst, 1949; Jessen, 1936; Sapper, 1914) and on climato-morphological evaluation by Büdel (1948) and himself (1954a). It was primarily Krebs' research into recent planation in the Indian Tamilnad Plain that moved him to interpret tropical planation as a form not due to the related stream erosion and valley evolution, since in the climatic zones of the savannah and the tropical forest, linear erosion plays a very subordinate role in planation. As these zones are still fairly extensive on the Earth, Bulla considered tropical planation to be a most general process both currently and in the geological past. Bulla put aside, or did not evaluate, earlier theories concerning the evolution of pediments and pediplains in arid and semiarid regions. Neither did he mention them in his textbook "Általános természeti földrajz" (General physical geography). This was probably why he considered tropical planated surfaces to be in the same, even more general, class as the planated forms postulated by Davis and Penck.

Besides these, however, many still adhere to more or less modified forms, of some variant or other of the original Davisian or Penckian ideas, including the emphasis on the role of uneven structural evolution, or emphasis on the climatic factor.

2. PEDIMENT FORMATION (PEDIMENTATION AND PEDIPLANATION)

This process was originally defined as the process of planation of arid regions in areas of origenically displaced or stable crust. The main factors involved were physical comminution, slopewash, and lateral stream erosion.

The formation of planes and half-planes of degradation by pedimentation has lately been extended also to the actual and ancient periglacial and dry-cold zones (Bashenina, Boch and Krasnov, Cailleux, Pécsi, Tricart, Troll, Wiche, and others) as well as to the semiarid and Mediterranean climate zones, for both recent and fossil forms (Büdel, King).

Some hold pedimentation to be possible also in the temperate zone (King, Penck, Gerasimov, and others). Moreover, L. C. King has attempted to prove, in a fairly general way, that pedimentation or pediplanation in the broader sense is the most general process of planation of the present, as well as of the geological past. In his opinion, pediplanation is apt to replace the entire process and concept of peneplanation. The overemphasizing of pediplanation by King and the extension of this concept to the domain of peneplanation gave rise to some mistrust among researchers. This does not, however, mean a refutation of the pediplain concept, only the assertion that pediplanation cannot be invoked to interpret all extensive smoothed surfaces of the Earth.

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Today, detailed research in almost all climatic zones of the Earth tends to prove that *planation truncation* and *pedimentation*—the two main types of subaerial relief smoothing—differ in conditions of origin, form features and correlate deposits, owing to differences in their fundamental ecologic make-up.

As ecologic conditions can, however, be of a transitory nature, undergoing more or less gradual changes over geological periods of time, there can develop also transitional and superimposed forms between the two fundamental types, as well as fossil and decaying forms. The interaction of these circumstances with the diastrophic evolution of the Earth could result in compound complexes of forms, differing more or less profoundly from the fundamental types.

The contradictions of interpretation are largely due to these circumstances, as well as to the lack of comprehensive regional and synthetic studies.

In our own program of detailed regional research we have initiated a study of the processes of surface smoothing—truncation, pedimentation—in the Hungarian Mountains, together with the complexes of the correlate landscape forms and deposits (see the next paper by M. Pécsi).

SURFACES OF PLANATION IN THE HUNGARIAN MOUNTAINS AND THEIR RELEVANCE TO PEDIMENTATION

by

M. PÉCSI

1. STRUCTURAL EVOLUTION OF THE HUNGARIAN MOUNTAINS

Hungary is at the middle of a basin surrounded by the Alpine, Carpathian and Dinaric mountain chains (Fig. 1). The relatively young Carpathian Basin is a result of the Tertiary folding and uplifting of the surrounding wreath of mountains and of the simultaneous subsidence of the Variscan basement. The Variscan basement was faulted rather intensely at the end of the Palaeozoic period; and early in the Mesozoic, it was furrowed by parallel marine troughs of SW–NE extent. It was in these that the Triassic, Jurassic, and to a lesser extent, the Cretaceous rocks, which make up the near-surface parts of the Hungarian Mountains, were deposited. These marine troughs reached their maximum extent in the Triassic; in the Jurassic and Cretaceous they became substantially narrower. The limestones and dolomites deposited in the Triassic lay dry and, in a tropical climate, underwent a planation of the cone needle karst type during most of the Cretaceous period, and also to some extent in the Eocene. This was accompanied by the formation of laterite and bauxite.

In the Upper Cretaceous, extensive volcanism preceded the formation of the Carpathian belt, the mosaic-like faulting, and the uneven subsidence of the Mesozoic blocks within the Carpathians. In the Eocene, some of the Mesozoic blocks were inundated by the sea and their surfaces, planated and laterite-covered in the Cretaceous, now became covered with Eocene limestones, marls, etc. During the evolution of the Carpathian mountain frame, the Variscan basement remained a more or less coherent unity, although parts of it were also inundated by the sea in the early Tertiary. However, most of the Variscan still formed low hills of planated surface in the Oligocene; indeed, the areas which form the Little Plain and Great Plains of today rose even in the Miocene above the zones of block-faulted Mesozoic intercalated between them. The most intense Tertiary subsidence of the crystalline and also partially of the Mesozoic, basement was likewise preceded by intense volcanism. The evolution of a basin subdivided by low mountain ranges was initiated by a geostructural-morphological change beginning at the Helvetian–Tortonian limit in the Miocene.

Intense volcanism along the deep faults outlining today's basin produced one of the largest belts of young volcanic mountains in Europe. The Hungarian members of this intra-Carpathian fire belt, the Visegrád and Börzsöny Mountains, the Cserhát Hills, the Mátra and Tokaj–Zemplén Mountains were produced by outbursts of volcanic activity, repeated up to and into the Pliocene, younger as a rule in the East than in the West. This process was simultaneous with the folding and uplifting of the Flysch Carpathians, and with the repeated, and gradually accelerating, subsidence of the Pannonian Basin. Dividing the Pannonian Basin into two separate sub-basins (the Little Plain on the one side and the Great Plains plus the hill region of Transdanubia on

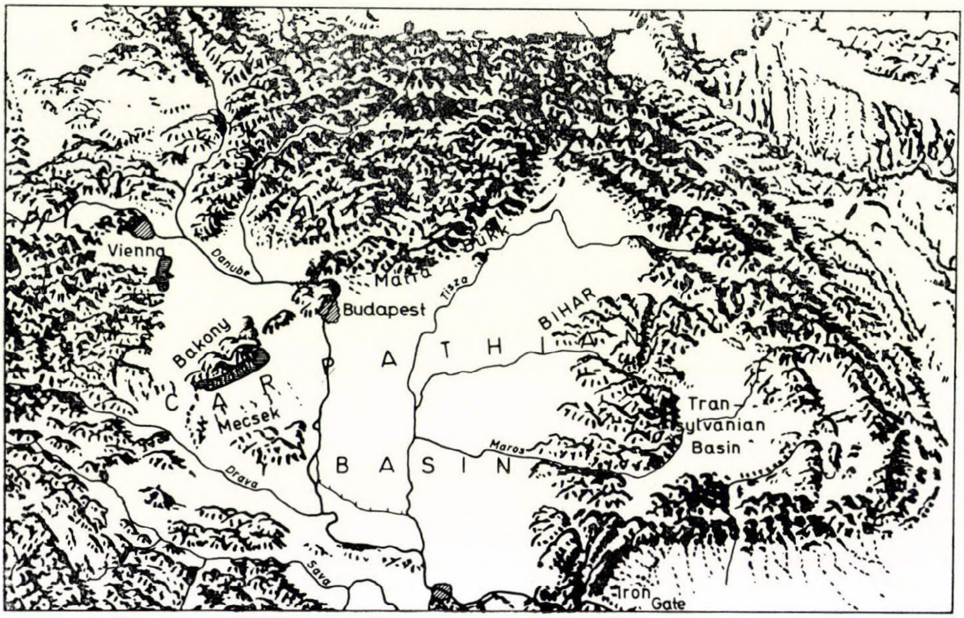


Fig. 1. Position of the Hungarian Mountains within the Alpine–Carpathian range system

the other), the Hungarian Mountains form two structural and morphological groups: (a) Mesozoic block ranges overlying a crystalline Variscan basement and (b) mountains built up as a result of young, Miocene–Pliocene volcanism. Since the two groups underwent substantially different processes of morphogenesis, their forms of degradation are also of necessity different. Still, there were also occasions for the development of similar traits, during the Pliocene (Pannonian) transgression when the forelands and feet of both groups of mountains were washed by the Pannonian sea. The Pannonian deposits (and locally, the Pannonian levels of abrasion) are elevated to about 300 m above the present sea level in the border zones of our mountains; that is, all mountains were uplifted by about equal amounts (300 to 400 m) during the Upper Pliocene and the Pleistocene. In the two groups of mountains, the nature and efficiency of the exogenic landscape-forming agencies can be assumed to have been largely identical during the Pliocene and Pleistocene, in spite of differences in structure.

2. FORMS OF PLANATION IN THE HUNGARIAN MOUNTAINS

One encounters surfaces of planation at summit-level in both the Mesozoic fault-block ranges and the young volcanic mountains. Still, their ages and modes of origin exhibit some quite substantial differences.

Besides the summit levels, the individual fault blocks feature mountain-front ledges likewise sculptured by planation. Some of these planated ledges (of which there are two in most cases) can be interpreted as terraces of abrasion formed in the littoral zone of the Lower and Middle Pliocene sea, as they have been observed together with the corresponding littoral deposits in the forelands of the Bakony and Vértes Hills and of the Mecsek Mountains (Lóczy, 1913; Vadász, 1935; Lovász, 1968). In other cases they can be classified as remains of Upper Pliocene foothill or Fussfläche (Pécsi, 1963b). A detailed interpretation of these latter forms will require further careful analysis.

In the forelands of the individual fault blocks, the most extensive forms include broad belts of foothills and footslopes. This belt also divides into two parts: (a) an ancient pediment or glacis of erosion dissected into interfluvial plateaux in the proximity of the mountain front, and (b) the transition of these into alluvial-fan slopes farther from the mountain. Locally these latter slopes are dissected by broad valleys or they may penetrate wedge-like into the previous zone.

Extensive planated summit levels have been variously interpreted as Davisian peneplains or Penckian Primärrümpfe (Cholnoky, 1929; Láng, 1955; etc.). B. Bulla (1958, 1962) interpreted them as the remains of a tropically planated surface. In his opinion the Palaeozoic and Mesozoic fault blocks underwent a continuous tropical planation from the Upper Cretaceous to the Middle Miocene, which also acted, of course, on the crystalline Variscan which was uncovered up to the late Tertiary. Bulla supposed also another phase of tropical-subtropical planation, from the Upper Miocene to the end of the Pliocene, as a result of which the late Tertiary volcanic mountains were also tropically planated. The planated summit-levels of these latter mountains were interpreted in a similar way by Z. Pinczés (1960), A. Székely (1964), and M. Pécsi (1964a).

More recently Pécsi (1968) contested the hypothesis that tropical planation in the Hungarian Mountains had been a continuous process prolonged over the entire Tertiary. The uplifted planated surfaces of the Hungarian mountains had been sculptured by several differing processes rather than by a single, long process of denudation. These planated surfaces are, then, of a polygenetic origin.

The considerable volumes of correlated gravelly Tertiary deposits (Lower Oligocene gravel and conglomerate, Upper Oligocene gravelly sand, Lower Miocene [Aquitanian–Burdigalian] gravels, also Helvetian and Tortonian gravels) covering large parts of the summit-levels and mountain-front ledges of certain fault blocks, suggest that planation attributed to a humid, tropical weathering played no dominating role in landscape sculpture, at least not at the time of deposition of these sediments. In some stages of the Eocene, Middle Oligocene and Miocene, one also encounters kaolinite-bearing varicoloured and red clays, the correlate deposits of weathering under a hot tropical climate. Hence, the Tertiary planation of this minutely block-faulted surface was not a tropical process, except subordinately and for relatively brief periods. As far as can be judged from the surviving forms, the dominating process was an intense and repeated pedimentation (pediplanation).

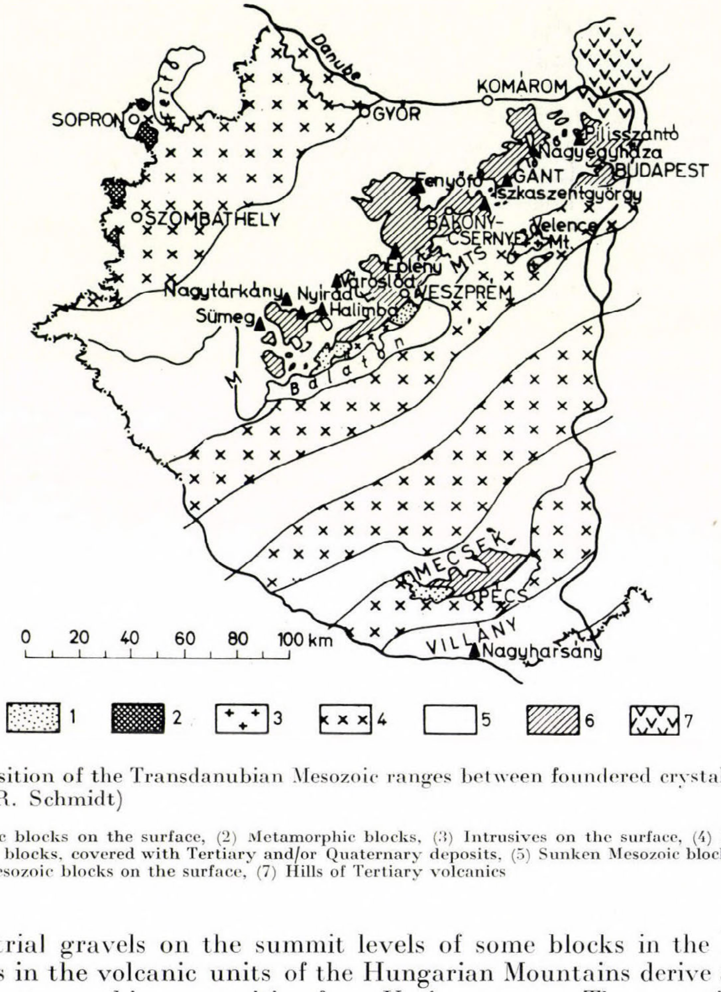


Fig. 2. Position of the Transdanubian Mesozoic ranges between foundered crystalline ranges (after E. R. Schmidt)

(1) Palaeozoic blocks on the surface, (2) Metamorphic blocks, (3) Intrusives on the surface, (4) Intrusive and metamorphic blocks, covered with Tertiary and/or Quaternary deposits, (5) Sunken Mesozoic blocks, covered as above, (6) Mesozoic blocks on the surface, (7) Hills of Tertiary volcanics

Terrestrial gravels on the summit levels of some blocks in the Mesozoic, as well as in the volcanic units of the Hungarian Mountains derive according to their petrographic composition from Variscan areas. They constituted the foreland (or possibly the foothill or pediment) of a crystalline massif that up to the late Tertiary stood higher than the Mesozoic regions. Indeed, some minor intramontane basins, for example, in the Bakony Hills, filled to a considerable degree with gravel from crystalline rocks, temporarily played the part of accumulatory basins (Fig. 2).

There is no conclusive proof for the continuation of tropical planation beyond the early Eocene. The cone karst, the laterites and bauxites formed under the tropical climates of the Jurassic and Cretaceous, are preserved today at the bottom of fault grabens, covered by Eocene limestones or younger sediments (Fig. 3). An analysis of the structure of the Mesozoic mountains of Transdanubia and the position of the correlate deposits which suggest certain modes of destruction, has proven tropical planation to have probably extended over the entire Transdanubian Mountains area in the Cretaceous. This broad expanse of low-lying tropical peneplain was uplifted to varying altitudes by differentiated structural movements from the Upper Cretaceous onward. The Tertiary morphogeny of the separated fault blocks was determined firstly by the amplitude and the continuity of their uplifting or subsidence, and secondly by the processes of destruction, generally controlled by the climatic conditions of the relevant periods.[1] The Mesozoic blocks, having undergone polygenetic evolution since the Upper Cretaceous and vertical movements into various morphological positions, are classified into the following main structural and morphogenetic types.

BURIED SURFACES OF PLANATION

Undisturbed surfaces of tropical planation are restricted to blocks which subsided in the Eocene and were covered by limestones which saved them from subsequent destruction. Some blocks sinking further during the Tertiary made it possible for small intramontane or foreland basins to develop.

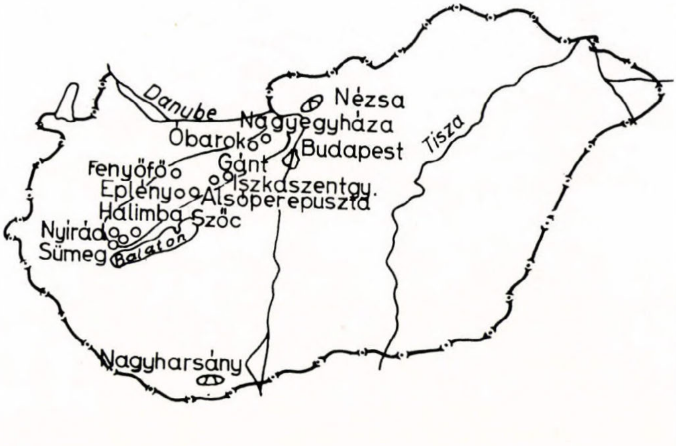
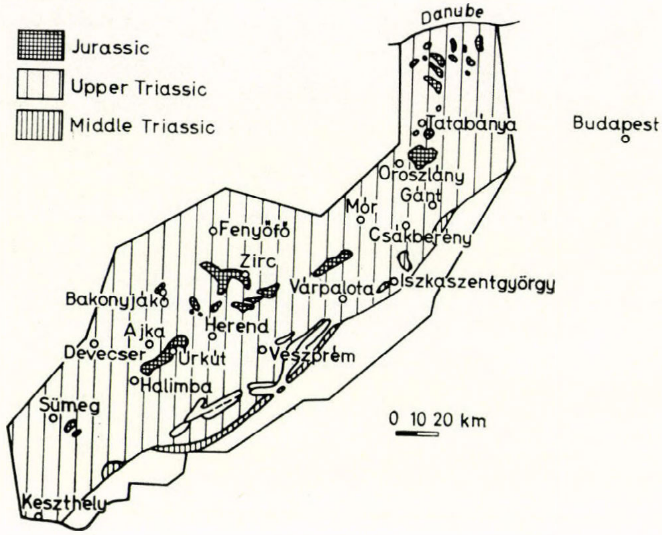


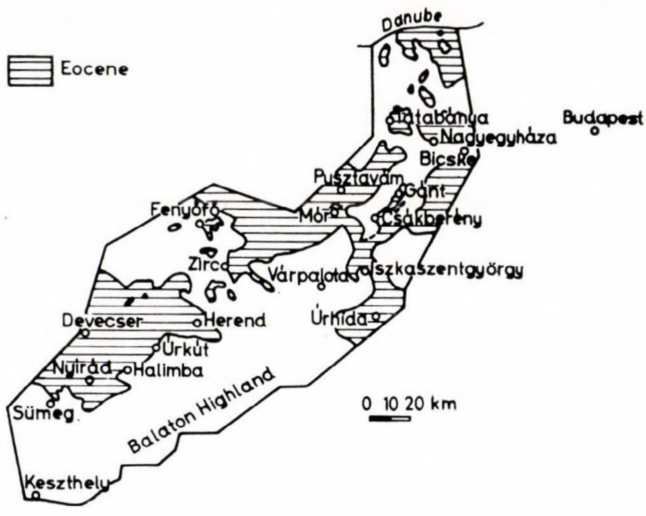
Fig. 3. Eocene-covered and buried blocks of the Transdanubian Mountains

(a) Position of the Transdanubian Mountains and the more significant bauxite deposits

[1] These polygenetic factors were decisively influenced by the geological and climatomorphological conditions on the surface of the crystalline basement, which at that time still rose high above the surrounding landscape.



(b) Extent of Triassic and Jurassic, mostly dolomites and limestones, in the Transdanubian Mountains



(c) Eocene-covered and buried Mesozoic blocks

It is these groups that we call crypto-surfaces (Fig. 4a). The depression of the Eocene-covered cone-karst crypto-surfaces hold bauxite deposits, in the Bakony and Vértes Mountains in particular. The position of these deposits gave the necessary evidence for distinguishing the various types of crypto-surface of planation.

REMAINS OF TROPICAL SURFACES OF PLANATION IN THRESHOLD POSITION

In the Bakony and Vértes Hills and also in the Gerecse Hills, there are certain blocks with tropically planated tops which either stayed at the level of the present foothill or were raised to form low thresholds. The low blocks of the South Bakony and of the Balaton Highland also belong to this category. The forms and products of tropical weathering had largely been destroyed here but a few odd remnants still remain to prove the case. It is only in the fissures of the underlying rock that tropical laterite or red clay were preserved. Elsewhere there are scattered remains of Tertiary gravel, most often of red-tinted quartzite. This suggests that a subsequent process of pedimentation took place on the ancient tropical surface of planation (Fig. 4b).

REMAINS OF TROPICAL SURFACES OF PLANATION, UPLIFTED TO SUMMIT-LEVEL POSITION

This category includes blocks uplifted into summit position in the Bakony and Gerecse, whose surfaces bear no trace of tropical weathering either in morphology or in correlate sediments (Kőris Hill, Papod, Tés Plateau, Nagy-Gerecse, etc.), although traces of redeposited tropical red clays can be found in dry valley apertures at 400 to 500, and at 200 to 250 m height a.s.l. The planated summit-levels, sculptured presumably by the processes of tropical weathering in the Upper Cretaceous, also continued to decay in the Tertiary (Fig. 4c). Evidence concerning the depth and the mode of their destruction is, however, as yet insufficient.

BURIED BLOCKS IN UPLIFTED POSITION

This type includes the remains of tropical surfaces of planation in uplifted positions, covered by more or less thick sheets of gravel or other sediments (Fig. 4d). Buried in spite of their elevated position, they are termed *semi-exhumed surfaces*. Gravel coming from the adjacent exposed crystalline could accumulate on the lower-lying parts of the tropical surface of planation up to the Upper Miocene, presumably as part of a process of pedimentation. These gravels were subsequently uplifted in the Pliocene or Pleistocene (for example, at Farkasgyepű in the Bakony, on certain blocks of the Buda and Pilis Mountains, in the Romhány block of the Cserhát Hills, etc.).

EXHUMED BLOCKS IN SUMMIT-LEVEL POSITION

It is in the Buda and Pilis Mountains and east of the Danube bend, in the Cserhát Hills, that one encounters Mesozoic blocks, which although once

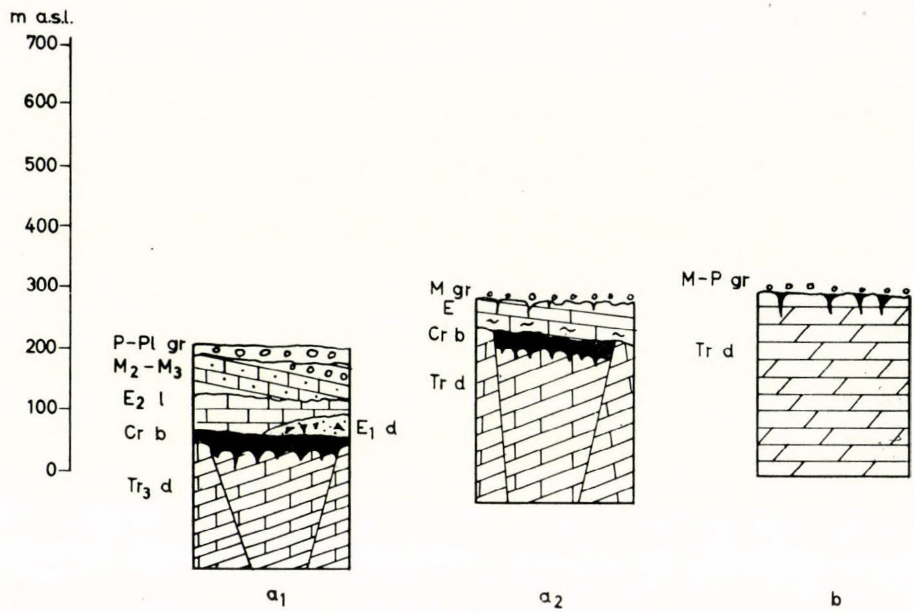


Fig. 4. Surfaces in various positions and forms due to younger dislocations and Tertiary

(a_1, a_2) Buried surface on a mountain border or in an intramontane graben basin, (b) Low marginal surface surface pedimented in the course of the deposition over it of a Tertiary gravel sheet, (d) Uplifted surface fully cene) in the forelands of the crystalline massifs, with conglomerate covers over their subsided portions. P–Pl gr.: E_1 d: Lower Eocene dolomite detritus, Cr b: Upper Cretaceous bauxite, Tr d: Triassic dolomite, M gr: Miocene and limestone, O cong.: Oligocene sandstone and conglomerate.
1. Remains of a tropical weathering, with kaolinite and red clays; 2. Unconformity; 3. Needle-karsted remnant of

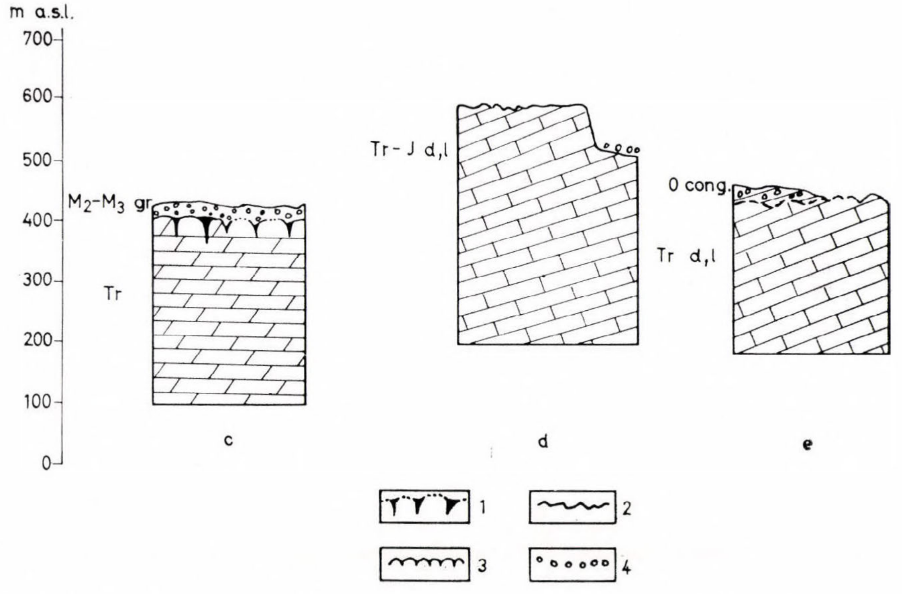
covered by Oligocene sandstone and conglomerate, have since been completely laid bare and uplifted above their surroundings (Fig. 4e).

The conglomerate had directly overlain the tropical cone karst locally, and so contributed to its destruction. The petrographic composition of the conglomerate implies transportation from the nearby crystalline.

3. DISSECTED UPPER PLIOCENE PLANATED SURFACES

The fronts of the individual mountain blocks, usually bearing two more or less narrow ledges of denudation, are joined to the surfaces of the basins surrounding them by extensive sloping foothill (Fig. 5). Their breasdth though highly variable, may, in cases where there is a hilly landscape foreset to the low mountains, be as wide as 10 km. The slope angles of such broad planated surfaces do not exceed a few degrees.

These surfaces are covered with little-rolled, and scattered detritus of very coarse nature from nearby sources, covered in turn by younger slope loess or loam. The exposures reveal these fossil "pediments" or "glacis d'érosion" to be likewise truncated, planated surfaces. In the forelands of our moun-



remodelling of the Cretaceous tropical peneplain of the Hungarian Mountains

with traces of tropical weathering, truncated by subsequent pedimentation, (c) Uplifted but still covered
destroyed in the Tertiary, (e) Uplifted, semiexhumed surface, pediplanated in the Tertiary (e.g. in the Oligo-
Pliocene-Pleistocene gravel, M_2-M_3: Middle Miocene marl, limestone and gravel, E_2 l: Middle Eocene limestone,
gravel, M_2-M_3 gr: Middle and Upper Miocene gravel and conglomerate, Tr-J d, l: Triassic and Jurassic dolomite

a tropical surface; 4. Gravel remnants on the surface

tains they intersect the Pannonian deposits with planes gently sloping from 350 down to 200 m a.s.l. The deposits of the earlier Tertiary and Mesozoic and also of the Palaeozoic in local cases, are not infrequently cut down flush with this planated surface (Fig. 6).

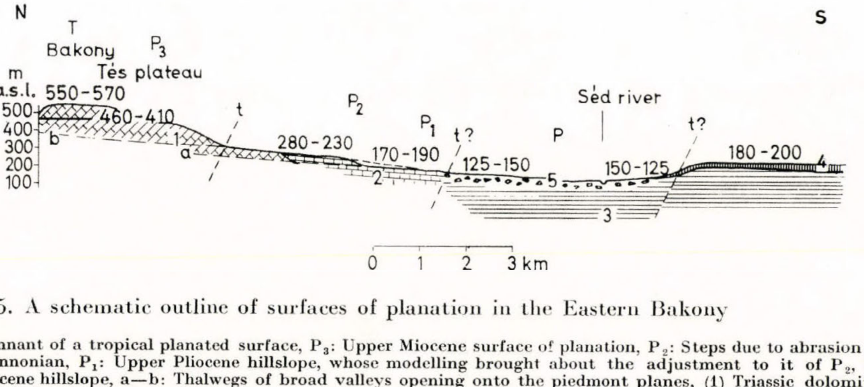


Fig. 5. A schematic outline of surfaces of planation in the Eastern Bakony

T: Remnant of a tropical planated surface, P_3: Upper Miocene surface of planation, P_2: Steps due to abrasion in the Pannonian, P_1: Upper Pliocene hillslope, whose modelling brought about the adjustment to it of P_2, P: Pleistocene hillslope, a—b: Thalwegs of broad valleys opening onto the piedmont planes, (1) Triassic dolomite, (2) Lower Pannonian limestones and sands, (3) Upper Pannonian clays and sands, (4) Slope loess, (5) Slightly worn dolomite detritus, t: Hypothetical fault lines

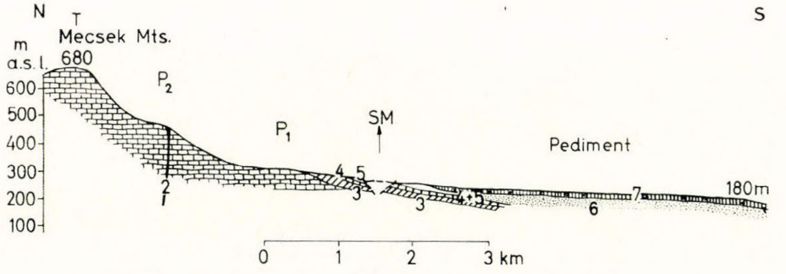


Fig. 6. The foothill in the southern foreland of the Mecsek Mountains

T.: Remnant of a tropical (?) planated s urface, P_2: Late Miocene-lower Pliocene surface of abrasion (?), P_1 Upper Pliocene foothill, further sculptured during the Pleistocene glaciations, SM: Submontane basin, (1) Jurassic limestone, (2) Trachydolerite, (3) Helvetian, (4) Tortonian, (5) Sarmatian, (6) Upper Pannonian sands, (7) Pleistocene slope loess mixed with scree

Farther from the mountain front these planated surfaces are dissected into digitating interfluvial plateaux. Along the rivers crossing the Hungarian Mountains (Danube, Ipoly, Hernád, Zagyva) the pediments and glacis slopes joining the uppermost terraces are narrower and steeper, with slope angles up to 8°. It is such a planated surface that verges into the highest, late Pliocene terrace No. 7 of the Danube (Fig. 7) and into the surface of the oldest alluvial-

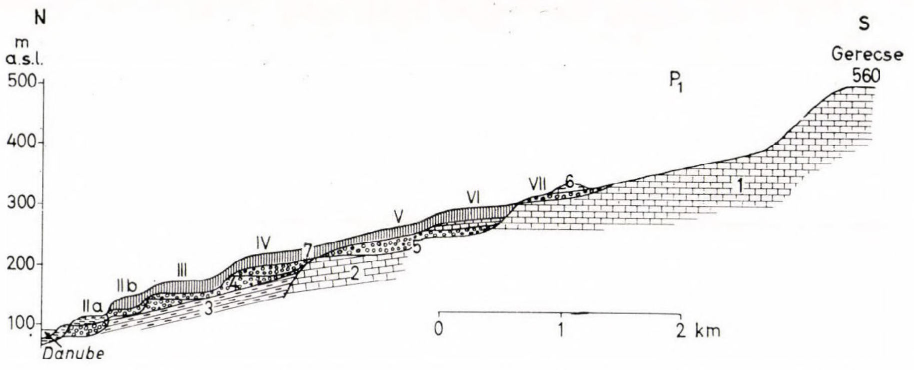


Fig. 7. Relationship between Danube terraces and the Upper Pliocene foothill at Lábatlan, on the border of the Gerecse Mountains

P_1: Upper Pliocene foothill, IIa—VII: Danube terraces, VII: Travertine-covered terrace, late Upper Pliocenel VI: Pre-Günz terrace of the Danube ("Donau" glacial episode), with travertine, V: Günz terrace, IV: Mindel terrace, III: Riss terrace, IIa and IIb: terraces of the Riss-Würm interglacial and of the Würm glacial, (1) Mesozoic at large, (2) Cretaceous sandstone, (3) Eocene marl, (4) Oligocene conglomerate, (5) Terrace gravel, (6) Travertine, (7) Slope loess

fan surface at Budapest (Pécsi, 1959). A similar situation is observed in the eastern foreland of the Alps, on the borders of the Little Plain, and in the Graz Basin, where the lower margin of a very broad planated surface is overlain by alluvial-fan terraces of the rivers of the Alpine foreland (Fink, 1960; Pécsi, 1964a, b).

Within limits, this morphological position of the Hungarian Upper Pliocene planated surfaces is indicative also of the period of their origin. They are older than the highest river terraces, which have been placed in the uppermost Pliocene or the Pre-Günz (Pécsi, 1959), but younger than the Upper Pannonian (Middle Pliocene) deposits which they truncate. Their evolution can therefore be placed into the Upper Pliocene, all the more so since there are travertine sheets at these levels, for example, on the borders of the Buda and Pilis Mountains, which have also been placed in the later Upper Pliocene or the pre-Günz (Schréter 1951; Kretzoi, 1953).

4. PROCESSES MODELLING THE UPPER PLIOCENE PLANATED SURFACE

Remains of lynx, camel, panther, lion, ostrich, giraffe and horse (Hipparion) in the Pliocene sands of the world-famous Baltavár site in Western Transdanubia (Sümeghy, 1923) reveal a once hot climate with alternating dry and wet seasons and with semiarid episodes which continued into the Upper Pliocene. This assumption is also borne out by the correlate sediments. The extensive and voluminous Upper Pliocene deposits are almost exclusively coarse sands. The argillaceous deposits, if any, are very subordinate. This also suggests a semiarid comminution and denudation. It is these Upper Pliocene sands that we regard as the correlate deposits of a pedimentation that continued over most of this period.

The modelling of the Upper Pliocene planated surface is attributed on the one hand to planation subject to a semi-arid climate, with alternating wet and dry seasons, and on the other, to a large-scale uplifting of the Carpathian region which resulted in, and continued after, the withdrawal of the Pannonian sea. Uplift in the Upper Pliocene was far from uniform; the surrounding circle of mountains, and the range of low mountains in the basin proper, rose more rapidly from the end of the Upper Pliocene on, whereas the Great Plains and the Little Plain embarked, after a transitory uplift in the Upper Pannonian, on a strong, though interrupted subsidence.

In Hungary the crustal movement since the Upper Pliocene can be characterized by the following figures. The late Upper Pliocene gravel of the Danube terrace lies at an altitude of 300 to 350 m a.s.l. in the mountains, and 200 to 250 m above the plain, whereas in the Little Plain it lies at a depth of 200 m, and even as low as 300 to 400 m below sea level in the Great Plains. The biggest post-Pannonian depression in the Great Plains (about Szeged and Hódmezővásárhely) is locally deeper than 1,000 m.

As a result of the slow subsidence of the basins and of favourable climatic conditions in the Upper Pliocene, *pediments* or, even *more frequently*, *glacis*, came to exist in loose sediments and soft rocks below the mountain-front ledges. Since the conditions for this process were optimal for a relatively long time, the gently sloping Upper Pliocene planated surface foreset in our mountain could develop to a considerable width.

5. PLEISTOCENE HILLSLOPES, GLACIS, PEDIMENTS

The joint result of Pleistocene cryogenetic processes in the Hungarian Mountains was a planation of the relief. The most important forms of periglacial destruction include terraces of cryoplanation, periglacial foothills and oblique foot slopes in the forelands of the mountains.

During the Pleistocene, the older mountain-front ledges and even the broad belts of Upper Pliocene planated surfaces were substantially remodelled by cryoplanation in the gradually rising Hungarian Mountains. Besides this, far from insubstantial effect, another Pleistocene hillslope foreset to the Upper Pliocene surface could develop along the margins of the rising mountains.

Elsewhere, the Upper Pliocene planated surface is only suggested by a few more elevated surfaces, whereas the lower and more generally narrow interfluvial plateaux are actual remnants of the Upper Pliocene surface remodelled and lowered in the Pleistocene. These lower plateaux also display some smaller steps of cryoplanation.

The evolution of Pleistocene periglacial hillslope pediments and glacis along the borders of the Hungarian Mountains was closely connected with the formation of derasional valleys[2] (Pécsi, 1964a). This means that the origin of these forms in the Carpathian Basin differs from the processes of pediment and glacis formation in the classic sense. The similar forms in the Carpathian Basin represent a different "form facies". I am of the opinion that "form facies" similar to the classic type forms could also develop under semiarid climates in other regions, under a set of somewhat different specific conditions. These will have to be considered "*form facies*" of the well-defined and well-documented *type forms*, both to emphasize differences, and to indicate the fundamental genetic and formal similarity.

Although the Hungarian Mountains of the Pannonian basin are of a small areal extent when measured against the entire continent, they offer, thanks to their peculiar morphological and geological conditions, some quite conclusive examples of some important problems of morphology.

Of these, I should like to call attention to the development of the peculiar "form facies" of periglacial pediments and glacis and to the substantial remodelling of the relief by cryoplanation.

In summary, it appears that the forms of planated surfaces in the Hungarian Mountains include denuded remnants of tropical surfaces, uplifted or subsided to various pediplains; mountain-front ledges from Later Tertiary or Pliocene abrasion or pedimentation; dissected or remodelled pediments or glacis from the Upper Pliocene in the forelands of the mountain blocks; and finally, Pleistocene periglacial hillslopes or piedmont glacis and pediments.

[2] With the epigenetic type of derasional valleys — in contradiction to the fluvial erosional ones — we place generally these smaller valleys of from several hundred to some thousand metres long, which were shaped predominantly by the processes of slope mass movements. The linear fluvial erosion streaming in the bed, or the trenching gully erosion either did not take place in shaping the present-day valley form at all, or had only secondary roles in it. Up to now in the literature of geomorphology the individual types of the derasional valleys had names — local ones: dell, balka, corrasional valley (W. Penck), corrosional valley (J. Büdel), denudational valley (Klimaszewski) — which could give rise to misinterpretation.

LAND FORMS OF THE MÁTRA MOUNTAINS AND THEIR EVOLUTION WITH SPECIAL REGARD TO SURFACES OF PLANATION

by

A. SZÉKELY

1. INTRODUCTION

Highest among the mountains of Hungary, the Mátra is one of the members of the intra-Carpathian volcanic belt attached to the Northwestern Carpathians.

The main mass of the mountain was produced by a huge Middle Miocene stratovolcano. About the middle of the Miocene (at the Helvetian–Tortonian boundary) volcanic activity surged along the enormous fault system separating the subsiding Carpathian Basin from the rising Carpathian Range by a number of centrolabial andesite stratovolcanoes, the ancient Börzsöny, Cserhát, Mátra and Jávoros (Javorje), and covered an area of almost ten thousand sq. km with volcanic rodes several hundred metres thick.

A detailed geological map and description of the Mátra was prepared in the early twenties by J. Noszky (1927) who considered the mountain to be the strongly decayed ruin of a Lower Tortonian centrolabial stratovolcano originally developed along numerous large faults. After a cursory examination J. Cholnoky (1929) thought he recognized the traces of a vast ancient caldera and of several centres of eruption in the central part ot the Mátra. He considered the main mass of the Mátra to be the coalesced product of four large volcanic centres. On the other hand, S. Láng (1955) proved that no original volcanic forms have been preserved except in the form of a few well-worn remnants. In his opinion, the hot humid subtropical and tropical climates of the Upper Miocene and Lower Pliocene degraded the Mátra down to the final stage of erosion, into a slightly undulating, flat peneplain. He interpreted this peneplanation "partly in the Davisian, partly in the Penckian sense", without producing any detailed proof. The mountain was then uplifted in several blocks in the late Pliocene and early Pleistocene, undergoing in the process a structural and erosional dissection.

In the middle fifties, an up-to-date geological and lithological survey of the Mátra was initiated. E. Szádeczky-Kardoss (1959a) in his first synthesis based on the new results, stated the Mátra to be the stump exhibiting a collapse structure of a stratovolcano "having once had the height of the Etna of today." In his opinion, the centre of the giant caldera was situated in the ore-bearing region about Gyöngyösoroszi whereas the taller summits surrounding it (Tóthegyes, Galyatető, Kékes) are remains of the caldera rim. The southern part of the caldera foundered owing to the subsidence of the Great Hungarian Plains: only a few traces of it remained above the surface.

B. Bulla (1958, 1962) considered all the low mountains of Hungary to be remnants of a Miocene–Pannonian tropical planation surface, developed by profound weathering and sheet wash ("tropical planation") under a tropical climate up to the middle of the Pliocene and a subsequent subtropical climate. These mountains did not, according to Bulla, necessarily wear down to the last stage of erosion: they are tropical surface of planation rather than fluviatile peneplains.

The present author in the course of his detailed morphological investigations—continuous since 1962—placed, besides an analysis of the relationship between structure and forms, and also in particular upon the detection and analysis of correlate deposits deriving from the degradation of the mountain (Székely, 1960). Concerning the first point he studied in particular how far the actual forms (slopes and planes) follow the original volcanic structure, and to what extent they truncate it. This gave him first of all an indication as to the depth of destruction, proving the removal of several hundred metres of volcanics all over the northern part of the Mátra. On the other hand, the evaluation of the horizontal and vertical extent, composition, sorting, grain size and coloration of the correlate deposits provided some concrete evidence as to the processes, age and duration of destruction. The number and altitude of planated levels were determined on type profiles selected with a great deal of circumspection. These profiles have proven that the levels of planation lying above one another did not develop in the same measure and at the same altitude all over the mountain. Hence it is not justified to mechanically connect all levels of about equal altitude; on the contrary, it is necessary to divide up the mountain into structural units on the basis of the various type profiles.

The author succeeded in establishing the *existence of two prominent planated surfaces* in the Mátra. He attributed the evolution of the planated surface that dominates the central part of the mountain to areal erosion under the subtropical climate of the Lower Sarmatian. The broad zone of low piedmont planes about the mountain and the retreat of the interfluves between the valleys by comminution and weathering more or less parallel to the slopes, tending to broaden funnel-fashion towards the foreland of the mountain, he attributed to Upper Pliocene lateral erosion. Between the two dominant levels, narrower and less conspicuous ledges were recognized between 400 and 600 m of altitude (Székely, 1960). Later on, the author separated these into a middle and an upper ledge level at 400 and 600 m altitude, respectively (Székely, 1964). He stressed them as more than simple faultscarp benches, since the lower ledges clearly penetrate funnel-fashion along the larger valleys into the main body of the higher surface.

2. PHASES OF RELIEF EVOLUTION IN THE MÁTRA

The intensely worn-down andesite masses of the Mátra bear no sediments at all: consequently, the phases of relief evolution had to be reconstructed from correlate deposits explored in the foreland of the mountains. It was, then, by confronting these deposits with the land forms in the mountain that conclusions about the processes and dates of planation could be arrived at. The analysis of the correlate deposits permitted the identification of six phases of surface evolution. The deposits corresponding to the individual phases are separated by structural and erosional unconformities, which indicates that the phases were separated by quite substantial structural displacements, among other causes. The joint evaluation of the products of destruction, including the animal and plant fossils contained in them, and of the land forms permitted the formation of certain conclusions concerning also the climates of the six phases.

(1) In the Tortonian, the Mátra was still characterized by young, primary volcanic forms, with elongate fissure volcanoes, huge volcanic cones, craters and calderas. The mountain was then much more extensive than today; its low foothills spread over most of its actual surroundings and were contiguous

with the neighbouring volcanic mountains. It was at this stage that the most intense post-volcanic activity took place, giving rise to hydroquartzite veins and ore lodes as well as to an extensive decomposition of the andesite. Post-volcanic subsidence resulted in marine ingression into the Western and Southern Mátra area. On these shallow shores and embayments accumulation was, it seems, still the dominant process, while the Central Mátra still rose several hundred metres above the Tortonian sea and witnessed the first stages of its destruction. It is, however, remarkable that the deposits in this shallow sea around the mountain are largely biogenic (Leitha limestone) or if detritic, then of a rather distant origin (sandstones); products of wear came down from the Mátra (redeposited tuffs, andesite pebbles), yet they are—apart from beds of tuff deposited in the sea—negligible in quantity. Tuff beds 3 to 25 m thick intercalated between the marine deposits prove that the last volcanic eruptions took place at that time; that is, the mountain was still in the process of construction. Although the destruction of the Mátra began already during the build-up of the enormous stratovolcano, this phase was nevertheless mainly one of construction, insofar as the big stratovolcano was concerned.

(2) At the end of the Tortonian, local volcanism ceased and the entire region was slightly uplifted (regression). As a result, destruction grew intenser in the Lower Sarmatian phase and covered a more extensive area. The dominance of areal destruction is suggested by reworked tuffs, clayey, bentonitic and clayey-marly littoral deposits. The primary volcanic forms were strongly worn down and remodeled and the relief was planated to a considerable extent. The result of this process is the summit-level of today.

(3) In the second half of the Sarmatian, the western part of the Mátra was uplifted somewhat: as a result, the correlate deposits of the Upper Sarmatian and Lower Pannonian are found to be coarser. Intensified uplifting and a drop in temperature resulted in an emphasizing of linear erosion, as proved by much andesite gravel and even boulders on the border of the mountain, in particular at the mouths of the largest western valleys. This phase destroyed the primary volcanic forms of the Mátra and initiated the dissection of the summit-level simultaneous with the uplifting. Even with the new baselevel of erosion in the foreland, a new planated surface began to develop backwards from the mountain border. This is the "high surface" of today.

(4) In the Upper Pannonian, under a changing climate (episodes of temperate traits intercalated into the warm subtropical climate plus an alternation of wet and dry periods), the slow, repeated displacement of the foreland resulted in a slow destruction of the deeply worn very low hills. It is in this way that the clayey and sandy littoral deposits of the Upper Pannonian came into existence: according to mineralogical examinations, even the sediment in the shallow lagoons immediately adjacent to the mountain border derives from more distant Palaeozoic and Mesozoic mountains. Substances furnished by the destruction of the steep mountain of today occur only locally (in the southwest) and even there, only in very subordinate amounts.

(5) In the Upper Pliocene, uplifting was again accelerated, especially in the North, unbalancing the symmetry of the mountain and augmenting the

rate of valley incision. A hot climate reminiscent of the tropical border zones of today was characterized by alternating wet and dry periods. These conditions intensified the processes of erosion (as proved in particular by the laying bare and denudation of some Pannonian deposits) and promoted *the evolution of a "piedmont plane"*, i.e. *zone of foothill.*

(6) The Quaternary is characterized first and foremost by intense valley incision due respectively both to strong uplifting and to subsidence in the foreland, resulting eventually in the profound dissection of the Tertiary surfaces of planation and in the evolution of a young, colourfully accidented relief. The Mátra itself rose more rapidly than its immediate foreland (the Mátraalja), and consequently the deep incision of valleys in the mountain was paralleled by the extensive development of thick alluvial-fan fields on the deeply eroded foothill surface. At the same time, the Upper Pliocene piedmont plane was dissected and lowered. Here, the general phases of Pleistocene uplifting could be demonstrated for the entire Mátra: the strongest one had been early Pleistocene, with profound valley incision, whereas uplifting and incision in the middle and late Pleistocene had been relatively weaker. The phases of accumulation intercalated between the phases of uplifting are characterized by intense gravel deposition and alluvial-fan formation in the foreland, interrupted by brief and rather insignificant episodes of erosion. As opposed to incision in the interglacials, the main agencies of relief sculpture in the periglacials were cryofraction, gelisolifluction and slopewash by meltwaters and infrequent precipitation. In the Mátra, these processes gave rise to boulder fields, scree slopes and cryoplanated steps, and in the foreland to alluvial fans (cryoglacis of accumulation), valleys of corrasion, to loess and loessoid deposits.

The main features of this phase were, then, controlled by periodic alternations of the climate which resulting in a special set of forms differed from those of all preceding phases. This is manifest also in the correlate deposits, coarser than before, as well as the extensive alluvial fans. The most regular alluvial fan is the Tatármező of Markaz, disclosed by the open-cast lignite pit of Gyöngyösvisonta to a depth of 20 to 25 m. The coarse deposits of the Upper Pleistocene are sharply distinct here from the finer Lower Pleistocene waste. This suggests that, by that time, uplifting entailed a considerable increase in relief, as a result of which the periglacial climate was most pronounced in the upper Pleistocene.

The lower regions surrounding the mountain were largely covered with rhyolite tuff before the Pleistocene uplifting. Under the Pleistocene deposits, directly on top of the intensely eroded Pannonian, there are rather thick extensive layers of redeposited tuffs (mostly of rhyolite), light-coloured and, for the most part, without gravel.

In the periglacial phases, areal denudation was again intensified. Its results are concentrated on two levels. The necks and cones emerging from the high surfaces are intensely worn by comminution, indeed, they are frequently buried in their own detritus, whereas the flats between them are covered with thick detritus: that is to say, the high surface was further smoothed and cryoplanated. The Upper Pliocene "foothill surface" was largely digested by a lower, Pleistocene surface. The cryoplanation of the high surface took place largely under the dry cold climates of the younger glacial periods, whereas the evolution of the Pleistocene surface had begun earlier in the Pleistocene, under a somewhat warmer but already dry climate, as proved by its height and its correlate deposits, and was only developed by the Upper Pleistocene periglacials.

3. STRUCTURE

The macroforms of the Mátra are structurally controlled to a rather considerable extent: the mountain developed in the first place along a set of faults between the subsiding basin and the emerging Carpathian mountain frame. The most marked macroform, the pronounced asymmetry of the mountain, was due to this process (Fig. 1). On the north side, the internal

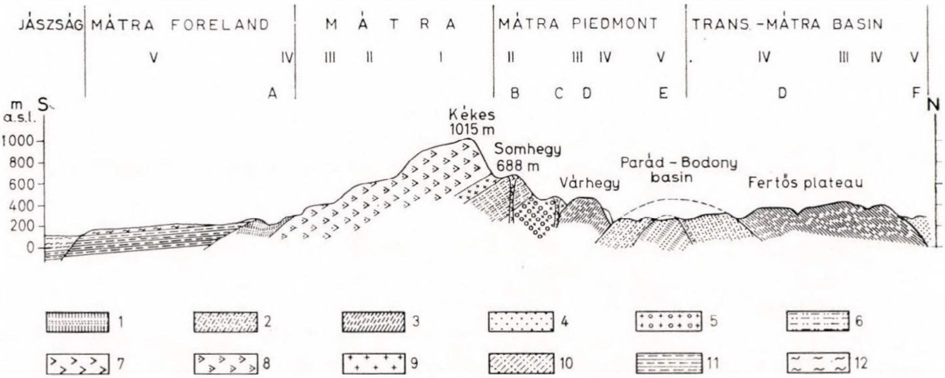


Fig. 1. A comprehensive synthetic profile of the Mátra

(1) Middle Oligocene schlier, (2) Upper Oligocene (Lower Chattian) schlier, (3) Upper Oligocene hard sandstone, (4) Upper Oligocene (Upper Chattian) schlier, less thoroughly consolidated, (5) Lower Miocene varicoloured clays, soft sandstone, Lower Rhyolite tuff, lignite formation, (6) Helvetian schlier, (7) Etched-out subvolcanic bodies (laccoliths, dykes), (8) Tortonian volcanics (andesite, agglomerate, tuffs), (9) Middle Rhyodacite tuff, (10) Sarmatian clay, marl, reworked tuff, etc., (11) Upper Pannonian clays, sands, deposits of the Pannonian Basin sea, (12) Quaternary alluvial fans, slope deposits, etc.
Planated surfaces: I. High surface, II. Upper step, III. Middle step, IV. Upper Pliocene pediment-like lower step, V. Lower Pleistocene glacis of erosion and of accumulation.
(A) Structurally controlled small basins of the Mátraalja, (B) Upper string of laccoliths, (C) Lower string of laccoliths, (D) Plane on Upper Chattian sandstones, (E) Basins of denudation of the Mátralába, (F) Basins of denudation beyond the Mátra

structure of the mountains is disclosed by steep scarps developed on the hard rocks of the volcanic stratification. These scarps are often diversified by frequent slumps and rockslides. For structural reasons, the northern border had always retreated more or less parallel to itself, with permanently steep slopes. This is why the main ridge is so close to the northern border. On the other hand, the divides running south from the main ridge are much gentler and have steep slopes only at their ends facing the foothill planes. It is this great asymmetry of the relief which is reflected in the conspicuous asymmetry of the drainage pattern. Whereas there are long, well-developed valleys and even valley systems running south from the main ridge, the steep slopes of the northern side carry but insignificant short steep-profiled torrential valleys. We shall see that the great asymmetry of the relief and of the drainage pattern is responsible in the final reckoning also for the piedmont planes. Structural displacements have brought about also a conspicuous threefold north–south subdivision of the Mátra from both the geomorphological and the general physiographical viewpoints (see Fig. 1). The northern foreland of the mountain, the Mátralába (Foot of the Mátra), has been worn away to its roots as a result of uplifting since the Sarmatian. From a field of erosional and corrasional hummocks, developed over prevolcanic deposits (Oligocene, Lower Miocene and Helvetian clays, sands and sandstones) there emerge, proving the depth of destruction, a double row of dike ridges, subvolcanic bodies, laccolith humps and the etched-out stumps of volcanic necks.

The southern foreland of the mountain, the Mátraalja (foothill of Southern Mátra) a subsiding area up to the end of the Pannonian, exhibits many contrary features. Here the sunken volcanic base is covered over most of the area with several hundred metres of poorly consolidated post-volcanic deposits (Tortonian, Sarmatian, Upper Pannonian clays, marls, sands). The destruction and dissection of this region commenced as late as the Upper Pliocene. From its low gentle rises there emerge just a few relatively high blocks of andesite (e.g. the Sár Hill). It is consequently only in the middle zone intercalated between the northern rising and the southern sinking regions that the worn-away ruins of the ancient volcano emerge over the surface to form the Mátra proper, but even this portion is strongly tilted to the south and hence markedly asymmetric.

The gradual extension of the uplifting over greater and greater areas, as revealed by the phasing of relief evolution, and the threefold subdivision just outlined suggest an arch-like uplifting with a west–east axis (see Fig. 1). This process was presumably accompanied by substantial structural displacements along both longitudinal and transverse faults. As a result, the Mátra consists of several structural units, displaced to various heights, which fact strongly affected the modelling of the surfaces of planation and also their present-day altitude. Such units include the Pásztó Mátra, the Mátrabérc, Mátra Plateau, the Galyatető and Kékestető groups, the Eastern and the Southwestern Mátra. Their altitude differences can be derived globally from the present altitudes of the index horizon called the middle rhyolite tuff and from the altitude differences of the surfaces of planation.

4. INFLUENCE OF VOLCANIC FORMS UPON RELIEF AND MINOR SURFACE FORMS

The primary volcanic forms of the Mátra have long been converted into forms of denudation by destruction going on since the Tortonian, but have not been effaced altogether. The strongly worn down remnants of the main centres of eruption still rise above the high surface in the form of peaks and cones (Ágasvár, Világos) or tall broad mounts (Kékestető). Most of the peaks are, however, erosionally or structurally defined forms (Koncsur and Óvár, respectively) or combinations of the two (Nyikom). Even the traces of some lava sheets can be recognized (southern slope of the Kékes). The really important phenomenon is, however, the indirect influence of the primary volcanic forms upon the actual set of forms. This influence was essentially a certain preferential redirection of the processes of destruction. Although worn down quite thoroughly, the largest one-time centres of eruption still rise conspicuously above the high surface, whereas the oldest and most important valleys are most often incised into the lower surface between the centres of eruption, because the first watercourses naturally developed there. Indeed, on the Mátraalja, even a twice-removed influence of the primary forms can be established. The sunken volcanic mountain is in a buried position here, under a cover of Neogene deposits. The thicker sediments over the valleys compacted more intensely and gave rise to shallow depressions on the surface. It was these which started some of the first watercourses which, owing to their aconsequent directions, were considered structural valleys by some (Láng, 1955). Drilling data prove, however, that they follow by and large the buried valleys under the sedimentary cover.

5. THE INFLUENCE OF VARIOUS ROCKS ON THE FORMS OF THE RELIEF

The most important lithologic contrast is between the volcanics in the mountain and the less resistant sediments in the foreland. In the mountain proper, there is a marked contrast between the hard andesite lavas and the more readily weathering tuffs. The tuffs are largely worn down wherever exposed. The differences in resistance due to hydrothermal postvolcanic activity in the Western Mátra are of still more importance. It was these processes that produced the hardest and most resistant hydroquartzites and silicified andesites, most often etched out as ridges and divides today, and on the other hand the variously decomposed andesites over which valleys and valley basins have often developed.

Moreover, leaching by the hydrotherms altered large masses of the original lava sheets into pseudoagglomerates (endometa volcanics, E. Szádeczky-Kardoss, 1959b). Under a hot subtropical climate, pseudoagglomeration by solutions circulating along joints could take place to a lesser extent also near the surface (exometa volcanics). The large-scale pseudoagglomeration of the lavas prepared huge volumes of rock for rapid removal. Hydrothermal activity was the fundamental cause for the evolution in the Western Mátra of fairly broad valley basins, absent from the eastern half of the mountain.

6. PLANATED SURFACES OF THE MÁTRA

The Mátra of today has two conspicuous surfaces of planation (Figs 2 and 3). One is the "high surface" (see subsection 1) dominating the mountain, from which there emerge insular remnants of the summit-level (see subsection 1a).

The other is the broad zone of "foothill surface" about the mountain, likewise twofold: its higher element is Upper Pliocene (see subsection 2); the lower one is Pleistocene (see subsection 2a). Between the two dominant levels, the mountain is locally fringed by narrow ledges.

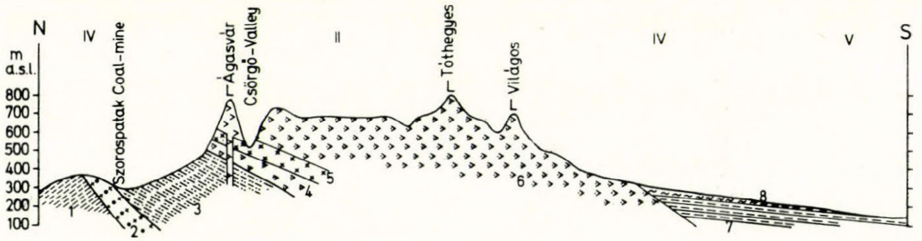


Fig. 2. Cross-section through the Western Mátra and the Mátra Plateau. (For the symbols of geological formations and planated surfaces cf. Fig. 1)

L = St·ongby decayed remnants of one-time centres of eruption

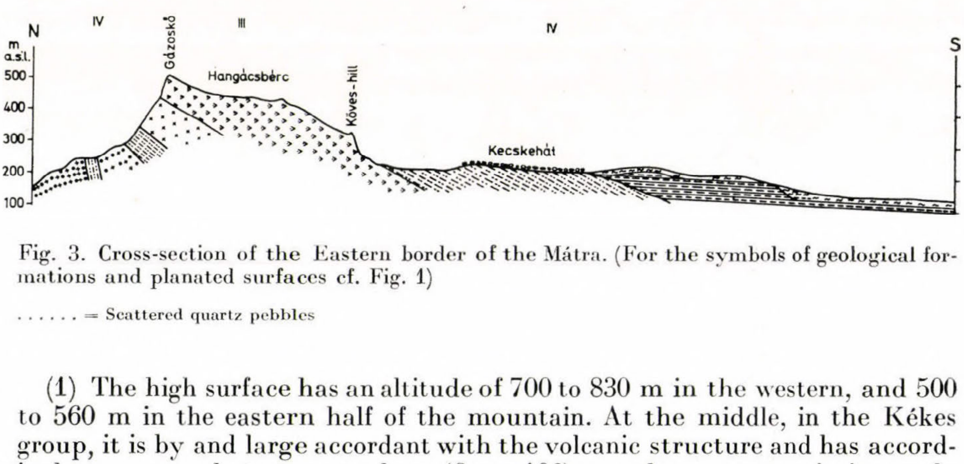


Fig. 3. Cross-section of the Eastern border of the Mátra. (For the symbols of geological formations and planated surfaces cf. Fig. 1)

. . . . . . = Scattered quartz pebbles

(1) The high surface has an altitude of 700 to 830 m in the western, and 500 to 560 m in the eastern half of the mountain. At the middle, in the Kékes group, it is by and large accordant with the volcanic structure and has accordingly a somewhat steeper slope (6 to 10°); on the contrary, it is nearly horizontal where it transsects the volcanic structure. Its evolution is presumably to be correlated with the coarse Upper Sarmatian and Lower Pannonian deposits on the borders of the mountain (phase 3 of destruction). This surface was much more extensive in the Lower Pannonian: it was proved by drilling to have covered also the northern part and the entire northwest of the present Mátraalja (crypto-planated surface). Its above-surface part has, however, been substantially remodeled, dissected by the deepest valleys of the Mátra, whereas the peaks rising above it have been worn down by cryofraction. Its only more or less unaffected portions are divides between valley systems intensely retreating from all directions (Mátra Plateau), otherwise it is reflected only in the equal heights of the gently sloping ridges between the centrifugal valleys.

The smoothness of this surface is broken first of all by stumps of ancient centres of eruption and certain tilted fault blocks (Óvár).

(1a) On the northern border of the high surface there are large islands of a summit-level of about 900 to 1,000 m altitude, coinciding by and large with the ancient centres of eruption, and also along the main divide least affected by erosion (Piszkés, Galya and Kékes peaks). Their flat tops, for structural reasons gently dipping towards the south and more steeply towards the north, are sculptured in the youngest dark, basaltic andesite.

(2) The other dominant surface is the piedmont plane. Forming a broad belt with gently concave slopes around the mountain, it has a centripetal dip of about 2 to 5°. It is most conspicuous in the south where it starts from the mountain foot at an average altitude of 300 m in the southeast and of 350 m in the southwest, and descends gradually to younger and younger deposits. Outside the andesite, it truncates in many places the Tortonian and Sarmatian of 6 to 12° dip and, more generally and extensively but very shallowly, also the very gently dipping (1° on the average) Upper Pannonian. This fact fixes the age of this surface in the post-Pannonian. In the southeast, it is separated by steep andesite slopes (20 to 22°) from the high surface, whereas in the southwest it penetrates in some basins and half-basins to depths of several kilometres into the andesite mountain; also, it forms a narrow ledge level along the larger valleys, which rises above 400 m of altitude upstream (see Fig. 2). In these higher reaches its slope is steeper, up to 7°, whereas above 400 m it becomes gentler again and is separated from the high surface by a less steep (10 to 12°) and less marked step. These deeply penetrating surfaces bear peculiar small low andesite "inselbergs" of concave slopes, most of them right in front of the high surface, witnesses of gradual slope retreat.

On the north flank of the mountains, on the other hand, the foothill surface starts at 450 to 480 m and, truncating older and older prevolcanic formations, descends to 340 m. For structural reasons, the slopes which separate it from the high surface are steeper (20 to 40°) and more uniform here than elsewhere. As opposed to the southbound valleys of 6 to 20 km length, this steep flank bears but torrent valleys 1 to 1·5 km long. This is why the foothill surface does not penetrate into the body of the mountain here.

Narrowest in the east and west, the foothill is nevertheless conspicuous enough there, dipping 4 to 6° towards the highest terraces of the Zagyva and Tarna rivers, respectively, and descending to them in a somewhat steeper step.

The age of the foothill surface can be much more definitely established than that of the high surface. We have already adduced evidence as to its being post-Pannonian, and since it is dissected by valleys accompanied by Pleistocene terraces and alluvial fans, it must have developed in the Upper Pliocene. This is confirmed also by reddish tuffaceous sand and clay, locally overlying the piedmont in 1 to 3 m thickness. On the andesite mass rising above the retreating Pannonian sea, however, its evolution had begun already at the end of the Upper Pannonian, as suggested by its gentler-sloping parts above 400 m altitude. In the northern foreland (the Mátralába), on the other hand, which rose above the sea ever since the Sarmatian, the entire Pliocene was available for its evolution. This is why the foothill is so extensive here.

It is essentially a product of the remodelling and the continued evolution of the Lower Pannonian surface of planation (epigenetic piedmont plane), which in the southern subsiding foreland (Mátraalja) became covered with deposits of the Upper Pannonian sea (cryptopiedmont).

Uplifting intensified in the Valachian phase of orogeny and dissected the foothill in the Quaternary with narrower valleys: furthermore, in the Lower Pleistocene, broad younger, lower embayments wedged themselves into this surface. This is why its more or less well-preserved portions are restricted to the interfluves between the larger valleys. Its best-preserved and most extensive portions are flanked and sheltered by the broadest plateaux of the andesite mountain; in such sections, on fronts 4 to 8 km wide, not one young valley emerges from the mountain into the foreland (e.g. on the western and eastern margin of the Mátraalja). The surfaces are by and large parallel here to the volcanic stratification. These are essentially structural planes remodelled by denudation. The original form of the Upper Pliocene surface was preserved well enough in the southwestern foreland, in the form of relatively broad divides, particularly on the more resistant sandstones between the shorter valleys of intermittent streams. However, even the remnants of the Upper Pliocene surface bear everywhere traces of continued wear and remodelling during the periglacials (thin cloaks of gelisolifluidal waste, etc.).

(2a) In the forelands of the valleys emerging from the mountain, the foothill surface was eroded to a deeper level as early as the Upper Pliocene; it was of course fundamentally remodelled in the Pleistocene by an alternation of erosion and accumulation in these areas. The lower, Pleistocene surface is not so uniform and broad all around the mountain as the Upper Pliocene surface, obviously because during the Pleistocene the semiarid climate necessary for piedmont evolution was available only for a relatively short time; it is consequently restricted to valleys and ledges, where it occurs in several varieties:

(i) In front of the gates of the mountain, its root region developed over andesite as a rock surface (pediment), whereas it continues to the south, most often flush with the said pediment, in coarse alluvial fans, several kilometres long glacis of accumulation (e.g. at Markaz and Domoszló). These often broaden funnel fashion in front of the valley mouths, and sometimes narrow down again farther away. The lower finer-grained layers of the thick alluvial fans indicate the low surface to have commenced developing under a still warm climate, whereas the higher, coarser deposits show that evolution continued under a periglacial climate: this is how the present surface flush with the root region of the andesite (cryoglacis of accumulation) came to exist.

(ii) In the flanks of the Upper Pliocene surface they are cut back in the form of half-planes of steeper slope, gradually digesting the Upper Pliocene foothill. Along the broader valleys—particularly of the two border rivers, the Zagyva and the Tarna—they merge in the form of a flat marginal plane (valley glacis) of some hundred metres width into one of the terraces, most often the Würm II/b. This proves their Upper Pleistocene age and—together with the gelisolifluidal or oryonivational slope deposits—their periglacial origin.

(iii) On the outer margin of the Upper Pliocene foothill they occur as steeper but much longer half-planes, likewise descending gradually towards the young terraces of the border rivers, or in the south towards the surface of the Great Plains. In this latter case their length often attains 4 to 6 km. Their age is as above.

The half-planes reaching to the valleys and the mountain borders bear numerous filled-up corrasional valleys. These prove just as elsewhere in the forelands of our mountains (Pécsi, 1964a) the periglacial origin of these half-planes.

Between the two above-described dominant surfaces of planation there are just a few narrower and vaguer steps whose margins are often less well defined. In general, there is one more, intermediate marginal level of planation at 400 to 460 m altitude in the eastern, and at 400 to 500 m in the western part of the mountain. On the eastern and western borders of the mountain it is a well-developed flat surface of a few hundred metres width, whereas in the south it most often forms just a narrow ledge in the larger valley mouths. On the northern flank, on the other hand, there are at this altitude narrow ledges (structural benches) invariably connected with the hard-rock surfaces of the subvolcanic bodies (laccoliths). In the west this surface truncates the Upper Sarmatian–Lower Pannonian correlate deposits, so that it may have developed towards the end of the Upper Pannonian and risen to its present altitude during the Upper Pliocene and Lower Pleistocene.

Besides this step, the slopes of the high surface bear several other steps of various altitude, size and origin, of a purely local importance, however. In the High Mátra, the most frequent such forms include narrow cryoplanated steps, and broader stepped interfluves near the borders. The latter were once somewhat of a problem as they often resemble to the point of confusion the marginal surfaces of planation. However, they occur only where valleys are spaced close enough, and divides are locally lower as a result. In the Central Mátra, the marginal slopes of the surfaces of planation often also bear structural steps a few tens of metres high due to the lava sheets (andesite flows) of the ancient stratovolcano.

Owing to the strong structural, relief and drainage-network asymmetry, the planated surfaces of the Mátra are rather asymmetrically developed. The high surface and the marginal level of planation are rudimentary or missing in the north. On the other hand, the Upper Pliocene foothill surface is just as well developed in the northwest and even better preserved than in the south, naturally to the detriment of the lower, Pleistocene surface plane. In the northern foreland, earlier uplifted, it is presumably the foothill plane, developed throughout a longer span of time, that may have encroached upon the older surfaces of planation. On the northern border, the structural and cryoplanated ledges are also missing in most places: nor could the interfluvial steps so typical of the southern border develop between the shortish valleys of the north.

7. ORIGIN OF THE PLANATED SURFACES

The data now available seem to prove the surfaces of planation to be connected with the stepwise uplifting of the individual mountain units (fault blocks), or more precisely with the intercalated phases of relative rest, which matched them to the changed baselevel of erosion. The arch-like uplifting extended over greater and greater areas. The more recent, lower plane had invariably been initiated by an episode of intensified structural uplifting, but the planated surfaces subsequently truncated the structural lines.

Structural control is particularly conspicuous in the root zone of the foothill, on the andesite border. Still, the foothill surfaces now cross the fault lines without breaks, as the present author was the first to emphasize (Székely, 1960) in the face of earlier views which attributed the flights of planated steps to purely structural causes (Bulla, 1954b, 1958; Láng, 1955); indeed, these planes have penetrated into the main mass of the andesite mountain to several kilometres depth. This also goes to prove that we have here, rather than simple structural treppen, true surfaces of planation developed by the lateral erosion of creeks emerging from the mountain and by the gradual retreat of the interfluves. This is proved among others by the presence of detritus, even today produced by comminution at the feet of the interfluve slopes.

Hence we are faced here with a structurally preformed piedmont—a pediment on hard rocks and a glacis on softer ones. We consider this distinction essential since the foothills surrounding the Mátra and the Hungarian mountains in general are largely developed on unconsolidated Neogene deposits. Now glacis on soft rocks could develop faster than pediments on hard rocks.

It was M. Pécsi (1963b) who first interpreted the pediments, foothill surfaces and half-planes in the forelands of the Hungarian mountains. Substantiating his ideas with palaeoclimatological and lithologic arguments he considered their development to be similar to those of pediments in hot semiarid regions, whereas he attributed the lower hillslopes encroaching upon them in many places to processes of the cold semiarid climates. It is most expedient terminologically to reserve the term pediment, as it is used by many authors, in keeping with its original meaning, for foothill planes developed under hot semiarid climates as a result of the removal by sporadic downpours of the products of comminution by insolation and of lateral erosion by intermittent streams. By analogy, the piedmont planes due to gelisolifluction, slopewashing by snowmelt and sporadic rainstorms after comminution by frost, and only subordinately to the intermittent fluviatile removal of waste, might be termed cryopediments (Pécsi, 1964a; and periglacial pediments) or cryoglacis if developed over soft rocks. The essential differences between these two types of foothill planes observed in this country are restricted to the processes that contributed to their evolution and do not extend to the forms proper.

Most of the higher, Upper Pliocene surface is a glacis developed over unconsolidated Neogene deposits, Upper Pannonian largely. This is a pediment or glacis dissected everywhere by subsequent uplifting. The Upper Pliocene pediments around our Mesozoic mountains are characterized in many places by intense structural dissection (Bükk, Mecsek Mountains, etc.), whereas the subsequent dissection of the Mátra pediments is of a decidedly erosional nature. It is presumably owing to the rigidity of the sunken volcanic base on the margin of the subsiding Great Plains basin that the Mátraalja was uplifted as a single unit rather than cut up by faults. This is proved by the fact that in the well-disclosed Pannonian deposits, lignite seams above all, faults even of 1 or 1·5 m throw are fairly scarce.

Most of the lower, Pleistocene foothill surface is a glacis of accumulation joining a narrow band of the eroded andesite root. The half-planes developed on the sides or rims of the Upper Pliocene glacis (2b and 2c) are cryoglacis slopes; the narrow levels joining their feet to the stream terraces are valley or mountain-border cryoglacis of erosion. The Pleistocene pediments and glacis are little dissected: indeed, locally (e.g. on the Tatármező) they are preserved as uniform planes.

The well-developed portions of the marginal zone of planation at about 400 m altitude on the western and eastern border of the Mátra display traces of lateral erosion (broad, erosional stream bed sections, scattered rags of well-worn gravel: e.g. Hangácstető, see Fig. 3). In their modelling, lateral erosion by streams carrying quartz pebbles, coming from the north, presumably played a decisive role. In the south, on the other hand, remnants of this level in the mouths of the larger valleys may be interpreted as pediment root ruins contemporaneous with the marginal ledges.

Evidence as to the mode and age of planation of the high surface is rather scanty, and even its original form is rather hard to reconstruct with any certainty. If, as has been supposed, it is connected with Upper Sarmatian and Lower Pannonian correlate deposits, the coarse gravelly and bouldery formations of these latter may be construed as indicating a process of pedimentation. Today the slope of this plane is fairly gentle, however. It should not, on the other hand, be forgotten that at the time of its full development this plane was much more extensive and that owing to its great age its remnants are strongly remodelled.

The small and intensely worn remnants of the summit-level do not permit any reconstruction of the original forms and the processes that wrought them. Their primary planation is connected merely as an exercise in logic with the oldest deposits indicative of areal destruction: those in the Lower Sarmatian (second phase of relief evolution). If this reconstruction is valid, they represent the profoundly remodelled ruins of a supposed ancient subtropical peneplain, preserved in places less accessible to erosion.

It should be emphasized that the Sarmatian or Pannonian age ascribed to the older surfaces of planation refers to the original form of their planation. Developed as planated surfaces in those times, they have been worn down and largely dissected and remodelled since. Furthermore, during the Pleistocene periglacials all steps were substantially remodelled and a number of new characteristic morphological traits were impressed upon them. Hence, age designations refer to the original, initial planated surfaces.

8. CONCLUDING REMARKS

Born in a constant battle of the opposed forces of endogenic and exogenic agencies, the stepped planes or planated surfaces dividing up our mountains bear witness to the young uplifting during a set of periodic climate changes of these mountains. This region is characterized since the Tortonian by stepwise structural displacements and periodic climatic fluctuations. The Hungarian Mountains underwent as a whole repeated, structural uplifting since the end of the Tortonian (with a concomitant subsidence of the forelands), with intercalated periods of rest. Climatic conditions were favourable all the time to the development of planated surfaces and pediment-like foothill steps, since from the Middle Tortonian to the beginning of the Pleistocene there was a hot climate of subtropical type with an alternation of arid and humid periods and some cooler episodes in between (at the ends of Sarmatian and Pannonian, respectively), whereas the Pleistocene was essentially a period of alternation of cold-arid and moderate warmish-humid climates.

The nature and intensity of destruction were consequently determined at any given time by the interplay of structural displacements and climatic changes. Consequently, the evolution and nature of the planated surfaces were also controlled by this same interplay. Altitude, number, position and extent of the planes were largely controlled by structural displacements; their forms, slope angles and traits by the climate acting through exogenic agencies.

PLANATED SURFACES AND PEDIMENTS OF THE BÜKK MOUNTAINS

by

Z. PINCZÉS

The Bükk is an element of the innermost range of the Northwestern Carpathians. The intensely folded Palaeozoic and Mesozoic rocks of which it consists exhibit South Alpine and Dinaric traits. The mountain rises abruptly over the low surface of the little-consolidated Tertiary deposits and volcanic tuffs surrounding it, a foreign element of some 30 km length along its long axis, with a summit-level at 800 to 900 m isolated on all sides from the neighbouring mountains.

1. GEOLOGY

The mountain consists according to a detailed analysis by K. Balogh (1964) of some Carboniferous and Permian and largely of Lower and Middle Triassic deposits. The Carboniferous includes grey clay shale with intercalated sandstones and limestones which outcrop in the northwestern part of the area, in a narrow zone along the Nagyvisnyó–Dédes–Mályinka line. The Upper Carboniferous deposits pass without interruption into the sandstones, sandy clay shales and quartz conglomerate and finally into the dark grey and black limestone of the Permian. The Lower and Middle Triassic are complete in the mountain, but there are some gaps in the Upper Triassic. The calcareous Lower Triassic sandstone and clay shale form a narrow zone parallel to the former from the Gerennavár to Lillafüred. Besides these formations one also finds, almost identical in areal extent, diabase tuffs and lavas (Anisian). The formations having the highest variety and greatest areal extent are those of the Ladinian which exhibit marked contrasts in facies. The clay shales, various limestones (cherty, flinty, Plateau-type, Répáshuta-type) and dolomites of this stage outcrop over the entire mountain. There is some regional differentiation, however. In the northern part of the mountain, limestone is predominant, whereas it is subordinate in the southern part. The diabases, porphyrites, quartz porphyries and their tuffs about Diósgyőr, Lillafüred and Bükkszentkereszt are placed in the Ladinian and Carnic. The Noric limestone of Nagyeged and Kiseged Hills are the last traces of marine Mesozoic.

The first folding of the above-described deposits took place in the Cimmerian phase of orogeny in the Jurassic (Balogh, 1964). However, the main phase of folding was the Austrian between the Lower and Upper Cretaceous. As a result of this latter, a diabase, gabbro and wehrlite magmatism took place about Szarvaskő. The Cretaceous dislocations resulted in the uplifting and destruction of the mountain, as proved by the partly Bükkian material of the Senonian conglomerate and sandstone complex about Nekézseny.

The dislocations entailed, among other things, the subsidence of the marginal portions of the Mesozoic mountain which were subsequently inundated by Tertiary seas. Recent geological observations (Balogh and others) find increasing evidence to prove that the Tertiary seas covered not only the border zones of the mountain but the main mass too. Eocene strata occur in the southern foothill region from Eger to Kisgyőr over a basal conglomerate and terrestrial red clayey products of destruction. The clayey, marly, gravelly and sandy strata of the Oligocene have a similar spread. The Miocene is represented on the southern border of the mountain by gravelly clay and sand, and near Egercsehi by sandy clay with lignite seams and subordinate rhyolite and rhyolite tuff. This latter covers a more extensive region at the southern foot of the mountain. The last marine deposits, the sandy, clayey and lignitic strata of the Pliocene do not attain any substantial thickness except in the southern foreland.

2. NOTIONS CONCERNING RELIEF EVOLUTION IN THE BÜKK

Geomorphologists working on the mountain have characterized it as an uplifted or stepped peneplain. One of the first workers, G. Strömpl (1914) distinguished two levels, the Bükk Plateau (700 to 800 m) and the karst flats surrounding it in the north, east and south (500 to 550 m). He interpreted planation after Cvijic and Grund by cyclic karst denudation, and attributed the sculpture of the lower level to marine abrasion. J. Kerekes (1936) mentioned two surfaces of planation from the environs of Eger—a higher one which he attributed to karst denudation and a lower one (320 to 360 m) sculptured by stream erosion. He placed this latter surface in the Pannonian (Pliocene).

S. Láng (1953) describes the Bükk as an uplifted stepped peneplain, due to the uplifting to various altitudes (600 to 959, 400 to 800, 500 to 720 and 200 to 360 m) of the fault-dissected elements of a "uniform Tertiary peneplain". He adduced as evidence for the existence of this peneplain, in addition to the equal heights of the summits, the rolled quartz gravels of the lower levels and angular quartzite debris on the plateau. He interpreted the absence of rolled quartz gravel from the plateau as indicating the intense uplifting and concomitant profound wear of the central mass of the Bükk.

S. Leél-Őssy (1952) contested Láng's views concerning the morphology of the High Bükk. In his opinion there never was any quartz gravel on the High Bükk the surface of which could not, consequently, be sculptured by stream erosion. Leél-Őssy proposed a mechanism of "rhythmic karst denudation" in its stead, thus reverting to Strömpl's ideas but expounding them in more detail, invoking a process of coalescence and flattening of dolines.

Z. Schréter (1954), a geologist surveying the Bükk, also mentioned one peneplain surface. He did not, however, deal any further with the processes modelling the peneplain or with the subsequent fate of the planated surface.

Z. Pinczés (1955) described from the southern part of the mountain two surfaces, an early Miocene peneplain at 500 to 600 m and a Pliocene one developed farther south on tuffs and Upper Pannonian deposits. He considered the quartz gravel on the planated surfaces as an argument in favour of his peneplanation hypothesis. In a subsequent paper (Pinczés, 1956) he emphasized the role of lateral erosion of streams emerging from the mountain besides slopewash in sculpturing the Pliocene surface (the rock plane at the mountain foot).

M. Pécsi (1963b), in connexion with the Tertiary relief evolution of the Hungarian mountains, called attention to the fact that the stepped surfaces of our mountains are not invariably the results of displacements along fault planes. It was Pécsi who introduced into Hungarian geomorphological literature the concepts of pediment and stepped pediment. In his paper he also gave a sketch of the Bükk Mountain surfaces. He considered the plateau to be the remnant of a Miocene peneplain with, underneath it, two levels (Upper Miocene and Pliocene) of planation and an Upper Pliocene pediment.

3. THE PROBLEM OF PLANATION IN THE MOUNTAIN

Researchers concerned with the Bükk have proffered rather diverse views as to its levels of Tertiary planation, their number, ages and conditions of evolution. Recent geological work on the mountain as well as our own geomorphological observations of the last two years have shed some new light upon these ideas.

It is beyond doubt that the surface of the Bükk is a stepped system of surfaces of planation. Its highest part is the *Great Plateau* with a mean altitude between 700 and 900 m. It is surrounded by a second step of 500 to 700 m altitude, the best-developed elements of which are the *Little Plateau*, and the Southwestern and Southeastern Bükk, which the author calls by the joint term *Middle Bükk*. In front of these, there is the *Lower Bükk*, at 210 to 350 m altitude from Andornak to Bogács and Miskolc in the southern foreland and at 200 to 450 m from Miskolc to Parasznya and Tardona to the Bán Valley in the northern and northeastern part of the mountain. The figures are but averages, of course. The devisions from them are due to young structural displacements and in particular to differences in the wear resistances of the various rocks (Fig. 1). Furthermore, the original surfaces of planation were dissected into interfluves and lowered in the process by the streams emerging from the mountain.

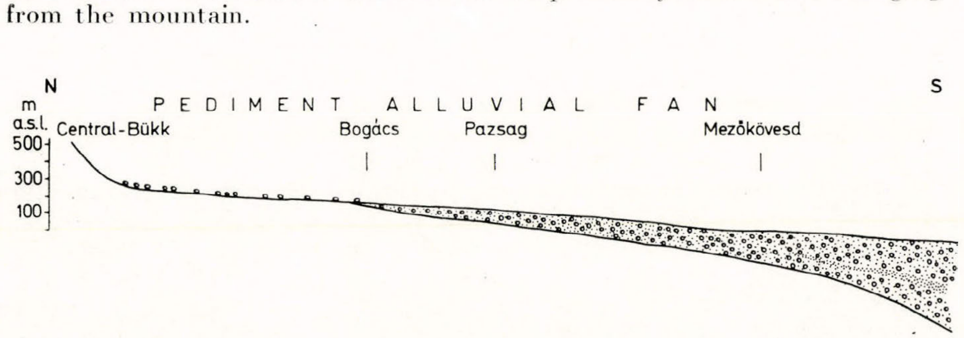


Fig. 1. A pedimental alluvial cone reaching down from the Bükk towards Mezőkövesd

The middle and upper surfaces of the mountain agree as to lithology in that both consist of Palaeozoic and Mesozoic rocks. These surfaces have consequently developed under presumably identical conditions, and simultaneously, too. Of the rocks outcropping on these surfaces, the Cretaceous volcanics of Szarvaskő are youngest and they are worn down flush with the Triassic. This surface of planation has consequently developed after the Cretaceous volcanism. The Late Cretaceous uplifting and concomitant wearing down of the mountain are indicated also by the correlate deposits (conglomerate, sandstone) outcropping at Nekézseny, north of the mountain. It is dated Senonian on fossil evidence (Balogh, 1964). Other products of subaerial weathering are known also from the southern Bükk (from the Eger–Bükkzsérc–Kisgyőr zone). It was first encountered on the surface in an outcropping at Bükkzsérc. At Sikkút, a drilling penetrated 257 m of silex and siliceous-shale rubble mixed with clay. This same formation was also drilled at Egerszalók (a conglomerate 3·5 m thick of quartz, dolerite and limestone pebbles underlying 67·8 m of varicoloured clay), at Mezőkeresztes (a greyish-red clay), at Diósgyőr etc. It is overlain by Upper Eocene marine deposit, whose base is, however, likewise a conglomerate or coarse sandstone (outcropping at Eger).

The spatial disposition of the correlate deposits indicates that the wearing down of the mountains had begun in the Upper Cretaceous and came to an end by the end of the Lutetian stage of the Eocene, since the deposits of the transgression that began in the Upper Eocene overlie the terrestrial deposits.

The planation of the Bükk is attributed by some to karstic denudation. This notion, plausible at a first glance, is unacceptable even for the *High Bükk*, because even there the lithology is not purely carbonatic (it includes also clay shales and volcanics). In the *Middle Bükk*, moreover, one encounters a variety of rocks forming something of a mosaic pattern. Clearly the wearing down to one and the same level of rocks liable and not liable to karstification cannot be due to karstic denudation. Taking into consideration the processes of planation that take place on today's earth one is led to the conclusion that the planation of the High and Middle Bükk is the result of weathering and denudation under a tropical climate. The climates of the Cretaceous and Eocene could well have served the purpose. G. Andreánszky (1954) proved on palaeophytological grounds a tropical climate for the Central European Eocene. The growth rings of the fossil tree trunks indicate annual periods of vegetative rest which in this case were the dry rather than the cool seasons. Hence, palaeophytology indicates a tropical climate with one rainy season, the classic regime of planation.

B. Bulla (1958, 1962) considers the remnants of planated surfaces in our mountains the vestiges of an ancient subtropical–tropical surface of planation. In his opinion, planation went on throughout the Miocene and even in the Pliocene; that is, he took into account no peneplains older than Miocene. This notion is to some extent self-contradictory. Bulla attributes planation to a process of wearing down taking place under a tropical climate, whereas he places the evolution of the Hungarian peneplains into the Miocene and Pliocene with non-tropical climates.

In connexion with the Lower and Middle Eocene planated surface of the Bükk, there arises the question as to what happened with the surfaces already developed in subsequent times, why did they not evolve any farther during the Miocene. The evidence on which to base the answer to this question is much more copious today than it was until recently. The Upper Eocene was a period of transgression in the Bükk region. This transgression did not come to an end until the uplifting late in the Oligocene. We have no information as to the extent to which the mountain was covered by the Eocene and Oligocene seas. The circumstance that only the basal terms of the Palaeogene deposits contain any Bükkian detritus, whereas the younger ones carry none, indicates that inundation became fairly extensive in those younger times. The Upper Eocene limestone found at an altitude of 500 m in the Csókás area of the Little Plateau also suggests that the transgression penetrated quite far into the mountain, rather than being restricted to its southern border. Hence, the geologists now active in this region agree with the idea, originally proposed by K. Telegdi Roth (1953), that the deposits of the Palaeogene sea presumably covered the entire mountain and were removed only by subsequent erosion.

There is also other evidence confirming the Bükk to have been covered with Palaeocene and even Neogene deposits. In the southern foreland of the Bükk, there are extensive Lower Miocene gravels over Mesozoic and Palaeogene rocks. Their pebbles are of a foreign origin, not containing any material deriving from the Bükk. Z. Pinczés (1956) holds this gravel to have come from the south, from a region where the crystalline cropped out on the surface (the ancient Tisia massif). A Helvetian gravel of quite substantial extent is shown on K. Balogh's map of the Little Plateau, too. Also, the deposits of the Helvetian transgression can be traced to altitudes up to 500 m in the northern part of the mountains. The gravels in question contain no material of Bükkian derivation, either. This proves again that in the Early Neogene the mountain was quite low and attracted waste (alluvial fans) from its surroundings.

Volcanism starting on the southern flank of the mountain in the Miocene produced tuffs, mainly of rhyolite, which travelled to the interior of the mountain and covered it with a tuff cloak. Subsequent denudation also destroyed this material but remnants of it are known from several localities. Two such remnants have been described from the mouth of the Hór Valley and from the southern flank of Nagyökrös Peak, respectively, by K. Balogh (1964). The present author has found several such remnants of various extent on some knolls north of Kács. In the karst dolines of the Bükk Plateau, a foraminiferal biotitic rhyolite tuffite (in the cut of the Csipkéskút road), a loose micaceous sand and sandy tuffite (in the cut of the Szilvásvárad–Miskolc road and at the bottom of the doline at the north end of Mélysár Ridge) were found by Á. Jámbor (1957) and K. Balogh (1964). All these corroborate the former existence of a tuff cover in the mountain, whereas the fragments of sea urchins, bivalves, fish teeth, etc., found together with the foraminifers in the rhyolite tuffite near Csipkéskút prove furthermore the inundation by the sea.

The repeated marine inundation of the Middle Bükk from the Eocene through the Oligocene to the Miocene and its covering by marine and/or volcanic deposits are highly probable on the basis of the evidence at hand. Proof for the High Bükk is much more scanty. Finds indicating a marine or tuffaceous cover are restricted to the end of the Miocene. Hence, it is possible that the Upper Eocene and Oligocene seas had not attained this region, or if they had, all deposits were worn down subsequently and the evolution of the relief could continue up to the Sarmatian in the Miocene. Should this assumption be proved, then we shall have to interpret the "Upper Bükk" as a buried and subsequently exhumed planated surface. This proof will require a great deal of further research, however. Similar conclusions were attained by M. Pécsi (1968) concerning the history of destruction of certain parts of the Transdanubian Mountains.

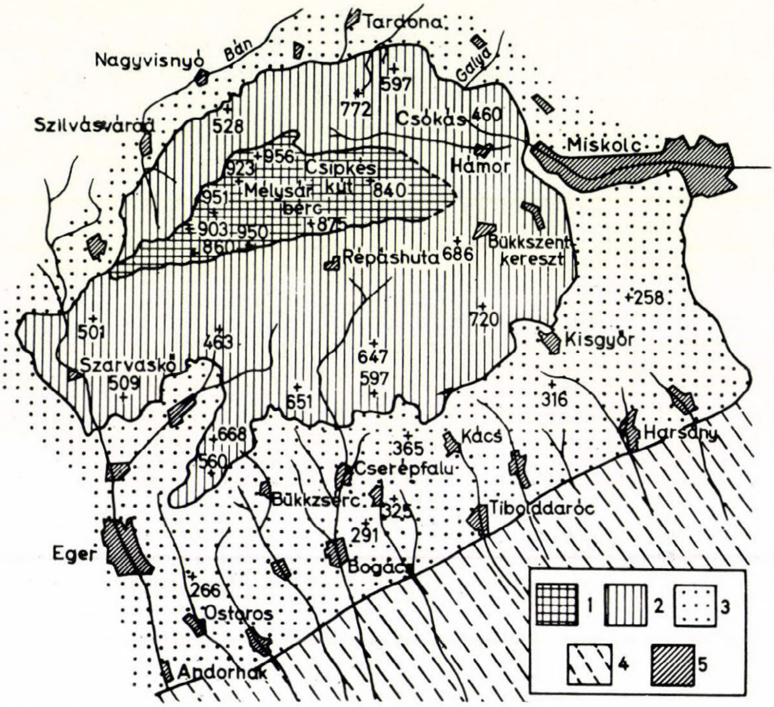


Fig. 2. Surfaces of destruction of the Bükk

(1) Lower and Middle Eocene surface of the High Bükk, (2) Idem, of the Middle Bükk, (3) Upper Pliocene foothill surfaces of the Lower Bükk, (4) Idem, of the Bükk Foreland (alluvial), (5) Communities

The situation outlined above undergoes substantial changes in the Tortonian and Sarmatian. The more elevated surrounding regions begin to subside and the central area, hitherto low-lying and often sea-covered (the Bükk of today) remains in a relatively high position. An inversion takes place and a new drainage system develops in a centrifugal pattern about the Bükk. The streams of this system begin to destroy the alluvial fans in the southern part of the Bükk from the Sarmatian onward and gradually redeposit them on the lower, third step of planation. The redeposited material contains, however, no Bükkian material at all. This means—as we shall see later on—that at the end of the Pliocene the main Palaeo-Mesozoic mass of the Bükk was still covered with unconsolidated young deposits which had to be worn down in order to expose the Lower and Middle Eocene fossil surface of planation. Hence, the High and Middle Bükk are exhumed truncated surfaces today.

The above-mentioned two surfaces of the Bükk conceal yet another problem: that of the evolution of the steep slope separating them. When did this slope form and was its origin structural or denudational? The question cannot be answered with full certainly today. Many hold this slope to be of astructural origin. The circumstance, however, that the high surface is almost fully surrounded by the middle one speaks in favour of a denudational origin (Fig. 2). Remarkably enough, the plateau gently slopes towards the east. As a result, the marginal slope is steeper and higher in the west (it is, indeed, a steep scarp of 200 to 300 m height along the Peskő–Tarkő line) and much more subdued in the east (50 to 100 m) between Lillafüred and Hollóstető.

4. THE PEDIMENT PROBLEM

Below the High and Middle Bükk discussed above there is a third step all around the mountain border. It is developed largely on rhyolite and rhyolite tuff in the southern and eastern parts of the area and on andesite pyroclastics about Miskolc. On the northern and western sides it is modelled partly in ancient rocks, but largely in loose Miocene deposits and to a smaller extent in volcanics. The deposits underlying this surface exhibit gentle centrifugal dips. In the southern foothills of the Bükk, this dip is about 10° SE. The surface of planation developed on these deposits truncates them (Fig. 3). Its evolution had begun in most places already in the Sarmatian (cf. the terrestrial Sarmatian deposits at Eger and Felsőtárkány). The advancing Pannonian sea presumably inundated such a truncating surface. It did not, however, penetrate farther than to the southern and eastern border of the Middle Bükk and did not rise up to or above the latter. After the withdrawal of the sea, relief evolution continued and the Pannonian strata, gently dipping towards the south–southeast, were eroded flush with the rhyolite tuff surface. This plane gradually retreated in the course of its evolution and even encroached upon the southern border of the Middle Bükk. In the environs of Eger, it is the Eocene, Oligocene, Miocene and Pannonian deposits that are truncated to one and the same level. At the mouth of the Hór Valley and west of Tapolcafürdő, this surface extends also to the Triassic deposits. Its evolution took place in the Upper Pliocene.

The earlier uniformity of this surface is betrayed not only by the almost equal altitudes of the interfluves, but even more markedly by the fact that the surface everywhere bears crystalline pebbles, which cover it veneer-like and uniformly. Now this, as the present author proved in 1955, indicates that this surface was modelled by lateral erosion by streams emerging from the mountain. The surface proper is partly a "pediment" developed on hard rocks and partly a "glacis" modelled in softer ones. The streams emerging from the mountain attacked the ancient Miocene alluvial fans on the mountain border and spread this gravel all over the piedmont surface. A gravel found north of Ostoros over Pannonian deposits was analyzed at my request by L. Kulcsár who found the following distribution: siliceous shale 52·7 per cent; varieties of SiO_2 rocks (metamorphic quartzite, jasper, lydite) 32·3 per cent, quartz 7·2 per cent, silicified tuff 6·6 per cent, silicified sandstone 1·2 per cent. It is remarkable that there is no Bükkian material either here or in any other place. On the other hand, in the uppermost terraces of the streams subsequently incised into the pediment and in the alluvial fan south of the villages Andornak, Novaj, Bogács, Tibolddaróc, Harsány and Bükkaranyos, the Bükkian material is ubiquitous (indeed, locally dominant) as are old crystalline pebbles.

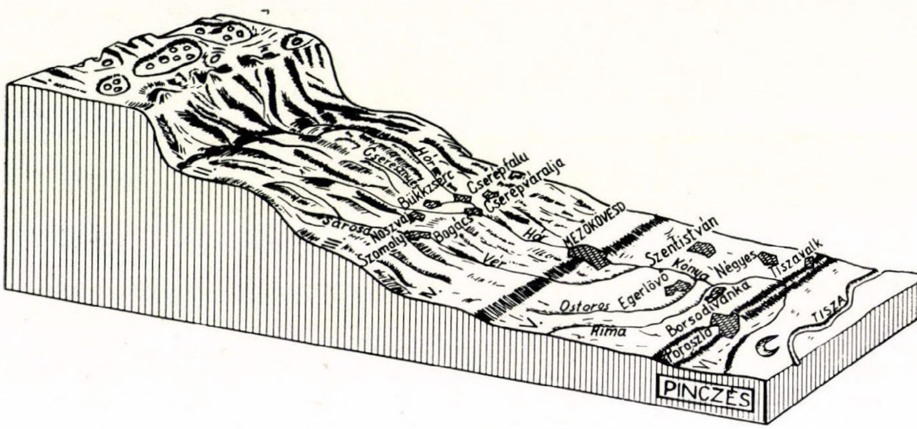


Fig. 3. Step surfaces of the Bükk and its foreland

(I) High Bükk (Lower and Middle Eocene surface), (II) Middle Bükk (ditto), (III) Lower Bükk (Upper Pliocene foothill surface), (IV) Foreland of the Bükk (Early and Middle Pleistocene alluvial fan), (V) Borsod Plain (Late Pleistocene alluvial fan), (VI) Floodplain of the Tisza River on the Borsod Plain (Holocene)

Now this shows that during the evolution of the pediment, in the Upper Pliocene, the Bükk was still covered with the loose deposits of earlier times from which it was freed only at the very end of the Pliocene.

The foothill surface consisting of pediment and glacis elements surrounds the entire main mass of the mountains. It is particularly well developed in the south and southwest where it was preserved so well because it had been modelled in a relatively hard rock (a volcanic tuff). In this region, this foothill reaches up to the Mátra and even reaches far north between the two mountains. It is sharply distinct from the mass of the Middle Bükk which rises 200 to 300 m above it. Along the Eger and Tárkány creeks it penetrates deep into the mountain, forming what is called the Tárkány Embayment. On the other hand, it nowhere penetrates into the valleys incised into the mass of the Middle Bükk. These valleys are invariably V-shaped, with local remnants of Pleistocene terraces. This shows that at the time of pedimentation the mass of the mountain was being uplifted—more rapidly in its innermost portions—which resulted in the continual incision of the valleys.

After the modelling of the foothill surface, its uniform surface was dissected by young structural displacements. This is particularly conspicuous in the vicinity of the village of Cserépfalu (asymmetric fault steps). The main mass of the Bükk continued to rise in the meanwhile. K. Balogh (1964) estimates an uplifting of 300 to 400 m since the end of the Pannonian. This has given rise to deep valleys which dissect not only the earlier planated surfaces but the pediment, too. This is why extensive surfaces of planation are restricted today to the limestone areas, owing to the peculiar wearing properties of limestone.

SURFACES OF PLANATION IN THE MECSEK MOUNTAINS

by

GY. LOVÁSZ

The relatively small mountainous area of northeast–southwest strike in the south of Hungary includes among its most typical morphological features some flights of stepped surfaces of planation. The Mecsek is one of the mountains exhibiting the most conspicuous surfaces of planation in this country. This is partly due to the structural and partly to the lithologic conditions prevailing in it.

The surfaces of planation of the Mecsek have been long known, especially in the vicinity of the town of Pécs, situated on its southern border. The first descriptions going into any detail are those in the publications of P. Z. Szabó (1931) and E. Vadász (1935), who described first and foremost the surfaces of planation on the southern mountain border. On the basis of the spatial disposition and age of the geological formations and of the forms developed on them, both authors attributed the stepped planes encountered in the mountain to abrasion; to be more exact, the older, higher marginal plane was dated as Mediterranean, the younger, lower step as Pannonian. An essentially similar position was also taken by Gy. Prinz (1936). It should be noted that the statements of all three authors refer largely to the western part of the mountain, although they did not, to be sure, carry out any special morphological analysis either in the western, or in the eastern Mecsek.

Geomorphological investigations carried out in the last three years included among their main tasks the establishing of the number of planated surfaces in the mountain, the analysis of their origin, and finally the drawing of conclusions as to relief evolution in the Mecsek in general on the basis of their spatial disposition.

For the establishing of the number of planated surfaces, the selection and analysis of so-called representative profiles seemed the most expedient method, because surfaces of equal age are now situated at various altitudes in different parts of the mountain. Leaving out of account the disturbances caused by structural displacements subsequent to planation, the interpretation of the planated surfaces on the assumption that elements at various altitudes are of different age leads to erroneous conclusions.

This method has led to the demonstration in the Mecsek of two marginal surfaces of planation, dominated by a so-called summit region or summit-level. Furthermore, there is below them a foothill half-plane (a glacis) (Fig. 1).

The foothill planes are most typically developed on the southern border of the mountain, partly for lithologic and partly for structural reasons. In the northern and western foreland of the mountain there is a hilly area sculptured in young, Pannonian deposits, the morphological transition towards which is rather vague owing to intense dissection by a dense network of valleys. The hills in the southern foreland also consist of loose Pannonian deposits which, however, underwent a less intense uplifting in the Pleistocene and, being less faulted, have a less dense drainage. This is why the foreland has the nature of a foothill half-plane here.

The spatial disposition of the above-mentioned surfaces of planation has been decisively influenced by the great structural element of the mountain. The Mecsek consists of three structuro-morphological regions, eastern, middle and

Fig. 1. Areal extent of the various surfaces of planation in the Mecsek Mountains

(1) Tropical-subtropical planated surface, (2) Helvetian level of abrasion, (3) Lower Pannonian level of abrasion, (4a) Glacis of erosion (late Pliocene – early Pleistocene), (4b) Glacis of accumulation, (5) Structural line, (6) Directions of selected profiles (See also Figs 2, 3, 4 and 5)

western. It is in the eastern and western units that one finds the highest peaks. The middle region is slightly sunken graben fashion along faults of northwest–southeast strike and is less dissected morphologically (see Fig. 1).

(1) The "summit level" actually means no more than surfaces of small extent in the respective central regions of the Eastern and Western Mecsek. So far no correlate deposits at all have been discovered on them, so that they cannot be dated by such means. The plane below the summit-level is, however —in places more or less protected from general denudation—modelled in Miocene deposits. Hence, the summit-level is part of an area which once rose above the Miocene seas. Geological research has revealed the mountain to have lain dry from the Jurassic to the Helvetian of the Middle Miocene (Vadász, 1935). The actually rather restricted summit-level underwent, then, a long

process of sculpture by various processes of denudation under largely tropical climates, presumably including tropical planation. This may be inferred from, among other things, the presence of Cretaceous bauxite in the Villány hills 30 km south of the Mecsek. Also, the karstification to some extent of the limestone areas of the Mecsek summit-level is presumably a result of largely trop-

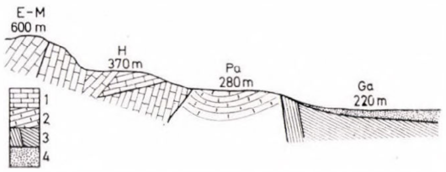


Fig. 2. Surfaces of planation of the Western Mecsek in the environs of the town of Pécs (Profile C–C of Fig. 1)

(1) Triassic limestone, (2) Sarmatian limestone, (3) Upper Pannonian sand, (4) Pleistocene loess; E–M Eocene–Miocene remnant of planation, H – Helvetian level of abrasion, Pa – Lower Pannonian level of abrasion, Ga Late Pliocene – early Pleistocene glacis of accumulation

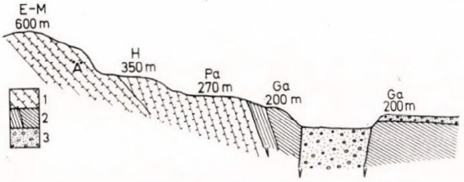


Fig. 3. Levels of planation of the Western Mecsek west of Pécs (Profile B–B of Fig. 1)

(1) Permian sandstone, (2) Upper Pannonian sand, (3) Pleistocene sand, gravel, loess; "A" – Break due to abrasion in the slope profile
(For the meaning of the symbols referring to surfaces of planation cf. Fig. 2)

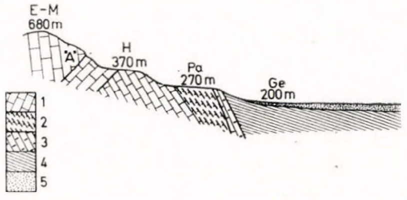


Fig. 4. Levels of planation of the Eastern Mecsek near the village of Pécsvárad (Profile D–D of Fig. 1)

(1) Jurassic limestone, (2) Helvetian terrestrial and marine deposits, (3) Sarmatian limestone, (4) Upper Pannonian sand, (5) Pleistocene loess, Ge Late Pliocene – early Pleistocene glacis of erosion
(For the rest of the symbols referring to surfaces of planation cf. Fig. 2)

ical and otherwise subtropical denudation. However, owing to the profound subsequent wearing down of the surface there are no traces of this today. Thus confronting geological history with the present state of the relief one may assert the summit-level of today to be a deeply worn down remnant of a surface of planation sculptured by tropical and subtropical processes of denudation.

(2) The summit-level region of rather small extent is surrounded belt-like by the planated surface of the upper marginal step. This is the most conspicuous surface of planation in the Mecsek. It is particularly well developed in the environs of Pécs and Pécsvárad, both at the southern foot of the mountain. It is typical and highly conspicuous in both places, and of considerable areal extent, thanks to being developed and preserved on Triassic limestones (Fig. 2). West of Pécs it has been modelled in Permian red sandstone (Fig. 3), and in the eastern part of the mountain largely in Lower Jurassic marine limestones and but subordinately in Cretaceous trachydolerites (Fig. 4). The development of the form on this last type of rock is rather vague, however, being restricted to a few narrow interfluvial ridges. The planated surface forming the upper marginal step is encountered in two variants. On the one hand, it surrounds belt-fashion, as we have already said, the two centres of the summit-levels; on the other, it broadens and forms a soft saddle in the middle (graben) zone intercalated between the Eastern and Western Mecsek (see Fig. 1). Observations at several points of the mountain have revealed this surface to truncate the Triassic and Jurassic limestones (see Figs 2, 3, 4). In most places, it has no correlate deposits, either. This is especially true of its first variant, that surrounding the two remnants of summit-level. In the saddle of the Middle Mecsek, on the other hand, it is overlain by nearshore Helvetian deposits. These have been shown by geology to be terrestrial and limnic and locally of quite considerable thickness. Lithologically, the coarse gravelly and sandy deposits are rather varied. Besides quartz gravel, abundant boulders of limestone and Permian sandstone prove this area to have been a basin of accumulation for the immediate and more distant neighbourhood. The lithologic composition of the gravels is related to the wearing down of nearby surfaces of granite, limestone (Triassic and Jurassic) and sandstone (Permian). They were deposited in the littoral zone, flush with the level of Helvetian abrasion. This latter is only locally covered with Helvetian strata. The marginal half-plane is separated from the summit-level by a broken slope typically of abrasion (points marked "A" in Figs 3, 4). The steep slope has been preserved by the limestone and the very hard sandstone. Abrasional planation in the Middle Miocene is proved particularly in the Western Mecsek by holes of rockboring gasteropods. The steep slope leading from the upper marginal surface to the summit-level is, then, essentially due to abrasion. There was also substantial subaerial and limnic accumulation on the seashore, in basins sheltered from the open sea, some of them filled with desalinated water. More often, however, the upper marginal surface lacks correlate deposits and is a surface of planation sculptured exclusively in hard rock (limestone, sandstone).

(3) The extent of the lower surface of planation (at 280 to 330 m above sea level) differs a great deal from that of the Helvetian surface of abrasion. This lower surface is uninterrupted around the entire mountain mass; that is, at the time of its evolution the morphological subdivision of the Mecsek into an eastern and a western unit had ceased and the mountain had become a coherent block.

Although the presence of the lower surface can be demonstrated all around the mountain, its extent is highly varied.

On the northern border of the Eastern Mecsek, where the surface is deeply dissected by stream valleys, it forms interfluvial ridges. A further morphological feature of the lower surface is that it is separated by normal slopes from the Helvetian surface above it. The broken slopes typical of the upper surface are absent.

As far as could be established thus far, the lower surface is invariably modelled in hard rock, e.g. in Sarmatian and Jurassic limestone in the environs of Pécs (see Fig. 2). The slope limiting it upward is quite often in Triassic limestone. Immediately west of the town it is sculptured out of Middle Triassic marl, and thin- and thick-laminated limestone. On the southern part of the surface, Permian sandstones are also encountered. (Elsewhere the base of this form is the Permian sequence, or again Jurassic or Triassic limestones—cf. Figs 3 and 5.)

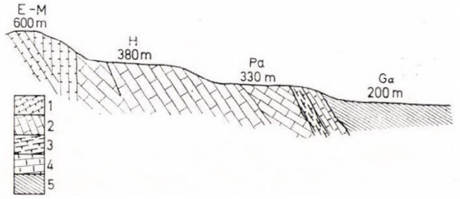


Fig. 5. Levels of planation on the western border of the Western Mecsek. (Profile A–A of Fig. 1)

(1) Permian sandstone, (2) Triassic limestone, (3) Helvetian terrestrial and marine deposits, (4) Sarmatian limestone, (5) Upper Pannonian sands
(For the symbols referring to surfaces of planation cf. Fig. 2)

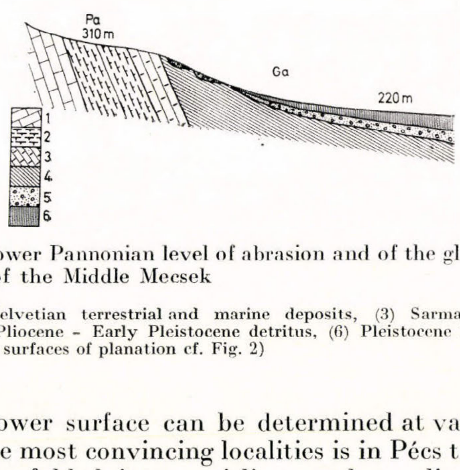


Fig. 6. Profile of the Lower Pannonian level of abrasion and of the glacis of accumulation in the southern foreland of the Middle Mecsek

(1) Jurassic limestone, (2) Helvetian terrestrial and marine deposits, (3) Sarmatian limestone, (4) Upper Pannonian sands, (5) Late Pliocene - Early Pleistocene detritus, (6) Pleistocene loess
(For the symbols concerning surfaces of planation cf. Fig. 2)

The age of the lower surface can be determined at various points of the mountain. One of the most convincing localities is in Pécs town proper where a Sarmatian limestone folded into anticlines and synclines is seen to have undergone planation (see Fig. 2). The Sarmatian limestone was folded in the late Sarmatian or in the Lower Pannonian, and subsequently planated by abrasion. Hence, on the basis of the outcrop in Pécs, the lower surface was modelled in the Lower Pannonian.

In the western part of the mountain, this surface is a karsted plateau of 300 to 330 m altitude. Even here it passes into the older surface above it by the intermediary of a normal slope. It bears no sedimentary cover at all: the karsted Triassic limestone is overlain only by Pleistocene loess. However, at the foot of this step there are numerous outcroppings of Mediterranean, Helvetian conglomerate and Sarmatian limestone. These either participate in constituting the base of the planated surface or lean against its foot (see Fig. 5). Their spatial disposition proves also in this area a planation and modelling at the end of the Sarmatian or in the first half of the Pannonian.

As regards the age of planation, a similar conclusion can be drawn also from an observation of the Middle Mecsek, where on a planated margin of Jurassic limestones there are first terrestrial and limnic deposits of the Helvetian and then Sarmatian limestones as deposits leaning against or partly underlying the surface thus developed (Fig. 6).

On the southern border of the Eastern Mecsek, the geology is more varied, but the conclusion emerging from its analysis is the same as above. Here the plane of the lower surface of planation is sculptured in truncated Jurassic limestone and Helvetian terrestrial deposits and there is a Sarmatian limestone, likewise denuded, leaning against the slope (see Fig. 4).

It can consequently be proved that the surface in question came to exist in the Lower Pannonian because it truncates the Mediterranean and Sarmatian deposits at the same level. Geology has not revealed any Lower Pannonian strata leaning against the mountain anywhere in the region. This obvious hiatus clearly indicates a Lower Pannonian episode of destruction.

This author considers the lower surface of planation to have been modelled by abrasion, because it is present almost everywhere on the mountain border, independently of the larger valley mouths. It cannot, consequently, be attributed to lateral erosion over hard rocks by the Lower Pannonian streams emerging from the larger valley mouths. Its abrasional origin is confirmed also by the history of geological evolution: the mountain was slightly uplifted after the Helvetian and Tortonian stages; the subsequent period of rest, covering the Sarmatian and Early Pannonian, entailed abrasion at a new, lower level. This period of rest went on until the intra-Pannonian episode of structural displacements.

The large-scale intra-Pannonian structural movements initiated another period of uplifting (Vadász, 1935) which also raised the Early Pannonian surface of abrasion. The present appearance of the latter has, however, been influenced also by the late Pannonian (Rhodanian) phase of orogeny, as proved by the intensely tilted Upper Pannonian strata of many large sandpits and other exposures.

(4) It was after the above-mentioned movements, at the end of the Pannonian or at the beginning of the Pleistocene, that there developed a most conspicuous surface half-plane (glacis) which left its mark upon the southern foreland of the Mecsek. This form could not develop and persist elsewhere, firstly because the Pannonian hills in the northern foreland were uplifted to higher positions at the end of the Pleistocene and secondly because that foreland is more densely faulted. The drainage network is much denser in the northern than in the southern foreland. This is why in the northern

foreland there remained from this foothill surface nothing except some narrow interfluvial ridges. In part of the southern foreland of the Mecsek, the foothill is relatively little faulted, and on the virtually undissected Early Pleistocene plateaux of this area the origins of these forms could be suitably studied. The southern foreland of the Mecsek is, besides the above-adduced reasons, a highly educative region of studies concerning foothill surface developed on soft rocks—the glacis—also because the peculiar development of its valley pattern permits certain detailed genetical observations to be made.

This form is not of a general spread in the southern foreland of the mountain, either. In the eastern part of that foreland, dissection is too intense to permit a detailed study. In front of the Western Mecsek, there is, on the other hand, a quite young Pleistocene structural basin (the Pécs Basin), which destroyed part of the surface developed in this region. All in all, the most suitable area for glacis studies is the southern foreland in the broader sense of the Middle Mecsek.

Of the three types of glacis distinguished by Birot and Dresch (cf. Pécsi–Szilárd, 1968), two can be recognized beyond any doubt in this area.

A classic example of the glacis of erosion is encountered south of the village of Pécsvárad. It is proved by numerous exposures that the foothill half-plane is essentially a surface truncating some Upper Pannonian sandy strata slightly tilted toward the south. It is not overlain by any accumulation, alluvial or otherwise, of sediments. Next to the mountain it is overlain by just a few dozen centimetres of loess (see Fig. 4).

The glacis of accumulation is typically developed to the east of the town of Pécs. In this area there are two fault-controlled valley mouths which in the late Pannonian and the Pleistocene dumped onto the foreland considerable amounts of waste coming from the mountain. The composition of this waste suggests the wearing down, first and foremost, of the Helvetian conglomerate. After the Pannonian, these processes of waste transportation and deposition gave rise to a half-plane overlain in the vicinity of the two valley mouths by a gravel layer of varied but slight thickness. The latter lies between the south-tilted sandy Pannonian and the loess which directly underlies the ground surface.

Further evidence seems to indicate that the processes of accumulation were dominant not only over the extensive glacis half-plane but earlier also over the steeper front of the form (see Fig. 6), because in this one, in the big gravel and sandpits cut in the steeper slope, in the steeply south-tilted and truncated sandy Pannonian there are numerous stream beds about 1 m deep and 4 to 6 m wide, filled with the detritus of Helvetian terrestrial and marine deposits and held together by a calcareous cement. These buried stream beds belonged to watercourses independent of the neighbouring big valleys which spread the detritus of the Helvetian deposits of the higher surfaces of planation onto the plane surface. In this same area, another type of stream bed, this one filled with loess, can be demonstrated. This clearly shows that at a later stage, when the higher surfaces were already loess-covered, this process continued with only a change in the material transported.

The glacis sculptured in Upper Pannonian sandy deposits can be detected also in the southern foreland of the Western Mecsek, in the southern continuation of a valley developed west of Pécs. The continuity from the mountain foot outwards of this plane is interrupted by the above-mentioned Pleistocene, so-called Pécs Basin (Fig. 7), so that its continuation can be traced only

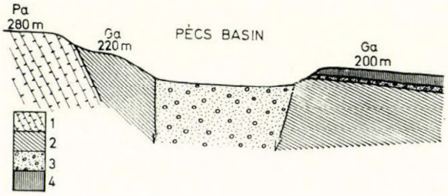


Fig. 7. A glacis interrupted by a structurally controlled basin subsidence in the western outskirts of Pécs

(1) Permian sandstone, (2) Upper Pannonian sands, (3) Late Pliocene – Early Pleistocene sand and gravel, (4) Pleistocene loess
(For the symbols referring to surfaces of planation cf. Fig. 2)

south of this basin. The waste deposited over a truncating surface, typical of a glacis of accumulation, has been disclosed in a borehole, some 7 km south of the mountain foot. This is, consequently, a structurally remodelled one-time glacis of accumulation.

The areal extent of the two types of glacis discussed above exhibits a certain regularity. The so-called glacis of erosion develops in front of the slope of the Lower Pannonian surface of abrasion, wherever there is no significant valley mouth on the mountain front. In these zones, the half-plane was obviously modelled by processes of erosion above all.

The glacis of accumulation occurs on the other hand in front of the larger valleys emerging from the mountain, where the half-plane was modelled not only by the lateral erosion of the streams but also by their subsequent accumulating activity.

The summit-level of the Mecsek Mountains developed for a long time during the Tertiary and was consequently modelled by a variety of processes. It is a largely tropical and to a lesser extent subtropical peneplain remnant.

The next surface, the so-called "higher surface of planation" of the mountain was largely sculptured by Helvetian abrasion.

The "lower surface of planation" of the Mecsek was likewise modelled first and foremost by abrasion, but this episode of Lower Pannonian abrasion was much shorter than the other.

In the increasingly arid and cool period of the Post-Pannonian and Early Pleistocene, an extensive half-plane developed in the southern foreland of the mountain. This piedmont surface of the glacis type invariably truncates unconsolidated Upper Pannonian coarse sands. The glacis of erosion is restricted to the fronts of the Lower Pannonian surface of abrasion, and the glacis of accumulation to the mouths of the bigger valleys emerging from the mountains.

PLANATION IN ARID SUBTROPIC AND TROPIC REGIONS

by

H. MENSCHING

1. INTRODUCTION

The subject discussed here includes both the morphological complex of planation and its regional restriction to the arid subtropics and tropics. Both these topics stand in need of explanation.

Planation is an essential morphological complex of relief evolution in the subtropics and tropics. It is to be considered on the one hand morphodynamically, that is to say, in the currently observable processes of its system of degradation. On the other hand it must be studied morphogenetically, or in its implications as to relief evolution in the (recent) geological past. In doing so, one has first to take into consideration the climato-morphological limitations of current relief-modelling processes (their regional differentiation) and secondly, to raise the question of the morphological potency of climatic fluctuations. The problem to be of primary interest is whether in the arid zone they entailed merely variations in the intensity of relief evolution or whether they affected the system of degradation in its fundamental principle. All in all, it is the evolution of planation rather than the entire scope of relief evolution that is discussed in this paper.

The arid zone includes in this regional sense both the arid subtropics and the arid tropics. Even this is sufficient to intimate that the climato-morphological system to be treated here exhibits certain peculiar features due first of all to aridity. It cannot therefore be delimited by thermal criteria (isothermals) or hygric criteria (isohyetal) alone. Aridity as a phenomenon has a profound and decisive influence upon the mode of degradation and on the system of fluvial transport. The mode of weathering is only one component of this complex, although an important one.

The present report is based in the first place on research in the Saharan area (between a semiarid Mediterranean and a fully arid Saharan climate). The author's own observations concerning the arid region of the United States (Colorado, Arizona, New Mexico) and the northern region of Tanganyika are also be referred to. The ideas to be proposed concerning a "system of planation in the arid zone" and the research results submitted for discussion are supplemented by photographic material.

Finally, the question of the differences between planation in the arid subtropics and tropics and in the semi-humid (humid) tropics with alternating dry and wet seasons (cf., reports by J. Büdel and H. Louis) is raised. Are these differences matters of degree or of principle?

The distribution of precipitation over the seasons is of a considerable importance. Does this factor affect relief evolution in the arid zone (outside the mountainous regions), and does precipitation occur in the clear, seasonal form of summer or winter rains, or not? This question must be answered by observations made in the arid regions of the USA as well as in the Saharan region.

Furthermore, arid zones with cold winters should be included in the present discussion. Recent research has provided valuable evidence of a direct relationship of planation with these two types of climate (Richter, Haase and Barthel).

Besides these climatically (or climatogenetically) active factors of morphodynamism and morphogenesis it is necessary to put a clear emphasis on lithologic control. Relief developed over sedimentary rocks is to be distinguished from relief over crystalline rock having different structural and epeirogenic characteristics, still there are important higher-order morphodynamic processes which act similarly in both lithologic domains, producing in both of them extensive planated reliefs in the piedmont zones of hilly and mountainous reliefs. It is necessary to have this lithologic difference more clearly expressed in the terminology. Discussions (primarily with French researchers) have shown the following terminology to be sensible and useful:

"Piedmonts" and "piedmont planes" are purely descriptive terms for inclined planes at the foot of hills and mountains, between regions of high and low relief.

"Pediments" are piedmont planes with a locally outcropping rock base, developed under arid climates, with a conspicuous break in grade ("knick") at the foot of the mountains; they are particularly marked in crystalline regions.

"Glacis" are piedmont planes, often terraces ("glacis terraces") at the feet of high relief elements (benches, hills, mountains) with a tendency to be modelled in alternating hard and soft rock patterns.

All these piedmont planes whose variants occur also in the tropics with alternating dry and wet seasons ("slopewash planes", "Spülflächen") are index forms of a morphological evolution which leads to planation. In their role as elements assuring the transition between the highs and lows of the relief, in the subtropics and tropics, these piedmont planes are important elements of the system of planation as a whole. They represent elements of the planated relief rather than of the valley relief: they are by no means valley slopes!

The drainage network exerts in its roles of providing local and regional baselevels of erosion, and as transporting agency of the waste to be removed, a decisive influence upon the evolution of the planated relief. Its exo- or endorhaeic nature and its climatic control have a direct influence on morphogenesis. The hydrologic-morphologic centres of control of the more elevated central and peripheral mountains of the arid zone also play a substantial role. If their vertical climato-morphologic zoning has been considerably affected by the climatic fluctuations of the Pliocene and Quaternary, then these fluctuations have also affected their forelands in the broader sense. In this respect it is necessary to consider in a general way the load-capacity ratio of the drainage network in our interpretation of the efficiency of erosion. Repeated investigations into the effectiveness of the (cooler) pluvials in the mountains of the arid zone have furnished manifold evidence as to the alternation of phases of erosion and accumulation in the piedmont regions. This alternation is particularly marked in the region of climatic transition toward the more humid temperature zone.

The vegetation of the arid zone—reduced to zero by high aridity, or concentrated along the lows of the relief—also affects decisively the removal of the products of weathering and hence also the load-to-capacity ratio. Higher humidity in the tropics with alternating dry and wet seasons results in a denser vegetation: still, the removal of waste is not hampered, because the efficiency of slopewashing is enhanced (1) by more frequent precipitation and (2) by a more thorough chemical preparation of the material (with more finer-grained products) which are easy to remove.

The relationship of planation to plane preservation requires exact definition. Examples are discussed in detail later on. In the arid subtropics (and tropics) the tendency to a preservation of planated surfaces is very strong. The "beachheads" of the present relief ("highs" such as mountains, step faults, high plateaux, volcanic complexes and "lows" such as depressions, grabens and non-uplifted plains of earlier origin), brought into existence by the last structural displacements of the late Tertiary, triggered by their oro- or epeirogeny the evolution of broad piedmont plains in the forelands of the high relief: we call them initial plains ("Initialflächen"). It was only after the evolution of the drainage network (endorhaeic or exorhaeic) that a climatically controlled degradation (or aggradation in the depressions) of these initial surfaces took place. Phenomena of advance in depth ("Tieferschaltung", v. Wissmann) resulted in some low-level surfaces. In a regional differentiation, increasing aridity makes the tendency of preservation of elevated planes more and more emphatic. This tendency of plane preservation (Mensching, 1958a) (cf. mesas, hamadas, elevated piedmont planes in all arid zones of the Earth !) is an essential trait of all arid and semiarid climates. This tendency is in conformity with the morphodynamic efficiency of processes of planation which will possibly build lower-level surfaces without, for that matter, entirely destroying the more elevated ones. Higher humidity in the tropics with alternating wet and dry seasons seems to attenuate the tendency of preservation, but not that of planation. I have had the opportunity to observe this in Northern Tanganyika. It is in my opinion this relationship between planation and preservation that explains the overriding importance of planes, and plains in general, for the relief of the arid zone.

This morphological evolution of plane reliefs in the arid zone is in itself an indication that the climatic fluctuations that took place since the late Tertiary could possibly effect—quite substantially in certain cases—the degree of aridity without changing the principle of the climato-morphologic system as long as the climate stayed in the arid–semiarid bracket. Exceptions may possibly be found in the borderzones (the Sahel in the southern Sahara). This, however, still awaits adequate research. Observations in the arid zone of Africa and the USA have, then, revealed the following.

2. PLANATION OVER SEDIMENTARY ROCKS

A point to be considered is the spatial position of the deposits which, usually spanning an interval from the Cretaceous to the Quaternary, either form extensive basin fillings in the forelands of mountains or tableland-like, horizontal or gently dipping succession of strata. Both are extremely widespread in the arid zone. The actual relief is characterized by the occurrence side by side of extensive planes and steep scarps. In front of the scarps there are numerous flat-topped inselbergs (gara), some of them quite far from the scarp. We usually have under such geological conditions a "meseta relief" in the semiarid zone, a "hammada relief" in the arid desert region.

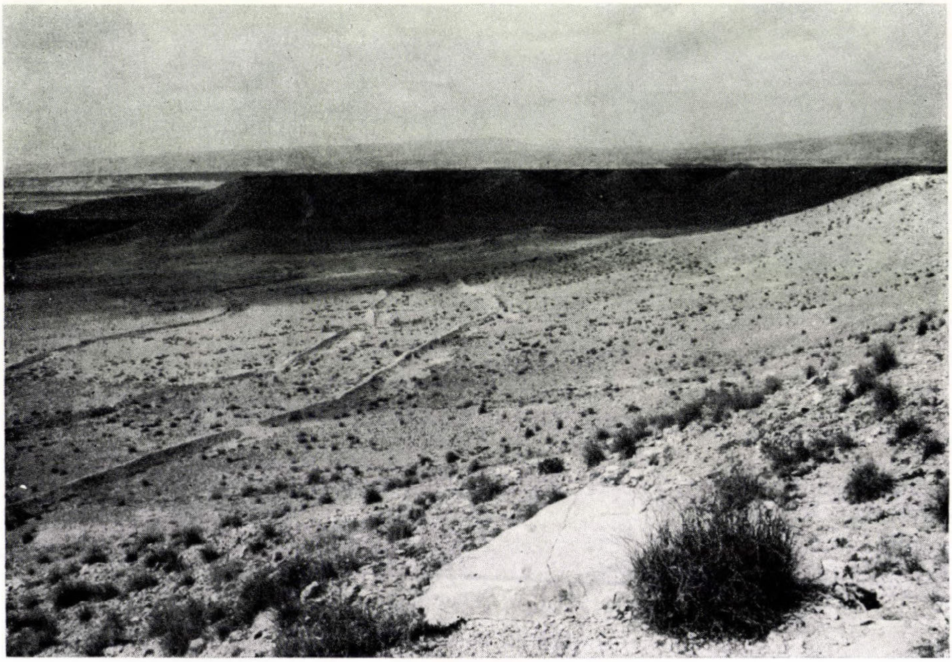


Fig. 1. South flank of Djebel Mrhila in Central Tunesia. A main glacis level, covered with a calcareous crust, reaches far into the foreland. Precipitation in the present-day halfa grass zone amounts to about 300 mm per year. Altitude of the foreland cca 700 m, that of the main crest about 1,300 m

The syn- or post-tectonic initial relief is dominated by extensive initial surfaces—either as pediments in front of the mountains over alternating hard and soft formations from the Miocene to the Quaternary or on relatively elevated Cretaceous or early Tertiary rocks, frequently matched to the horizontal bedding of these latter (accordant planes). The first type includes among others the Ebro, Moulouya and Gila Basins; examples of the second are the North Saharan hammadas, the Tademait Plateau and the Colorado Plateau. Some of the northern hammada surfaces originated as piedmonts of the Atlas as revealed by their gravel cover (microkarsted today).

In the environs of the hydrologic centres of the mountains, initial surfaces are more intensely decayed on their borders; in front of them there are lower-level planes and numerous inselbergs. The relative arrangement of the bench scarps (kreb) and the big wadi systems is a clear indication of their interdependence. The central hammadas exhibit a similar situation. The baselevels of their degradation are often situated in broad depressions such as the Tidikelt basin south of the Tademait Plateau. Stream systems of sufficient discharge may result in the dissection of such plateaux, as is the case with the Colorado Plateau.

Owing to an enhanced aridity and a reduced morphologic efficiency of the drainage, these initial surfaces are less dissected if at all (e.g. the Tademait Plateau) or have been lowered parallel to themselves in parts of the region. By and by, however, they have been remodelled under preservation of the initial plain: hence, they are of a polygenetic nature. Nearer to the more humid border of the Northern Sahara (this effect is also emphasized by high mountains bordering on the arid zone in the US) one encounters terraced glacis with up to 5 levels of glacis terraces. Heavy loads borne during the pluvials by the rivers emerging from the mountains formed in the forelands extensive planes with gravel covers, whereas rivers with enough drainage areas incised themselves during the interpluvials when load was less heavy. Still, the more elevated and older quaternary glacis surfaces are preserved as planes, partially remodelled between these main elements of the drainage pattern. This tendency of plane preservation is emphasized by the formation of cemented and calcareous cappings on the surface. The question whether these planes are now being further developed or dissected cannot be answered except with reference to the size of the respective rivers and their respective drainage areas. Erosion in depth (linear erosion) and planation or the preservation of planes can be active side by side within one and the same region. This is another typical feature of morphodynamism particularly under semiarid climates.

As regards the existence side by side of planes and scarps it is important to consider first of all the processes of degradation acting on the scarps proper. These are uniform in principle although different in intensity in their action upon the scarps of sedimentary rocks, i.e. on bedding-plane benches from the semiarid to the fully arid climatic zones.

Degradation of the scarps takes place by groove erosion. The grooves retreat but seldom as valley grooves into the plane: the more arid the climate, the weaker their potential of retreating erosion. Still, sharply concentrated flow off and the large number of grooves particularly in soft sedimentary rocks keep the scarp continually steep (or steepen it at the beginning of the process). Undercutting plays an important role here. At the same time, the grooves and groove valleys attract an enormous quantity of fine waste, so that the reduction of grade at the foot of the scarp at once makes erosion areal, with deposition of the waste removed from the scarp. Coarse detritus of boulder size and bigger will at best reach the foot of the scarp, never the piedmont plane proper. The morphodynamic processes act in such a way as to develop a series of glacis planes and glacis terraces on the piedmont. This system of glacis is obviously dependent on the drainage areas that develop: larger systems of degradation have their base-point of erosion in depth (Wissmann, 1951) farther away from the scarp than smaller ones which have it directly at the scarp foot. If the forms do not depend on shifts of the load-to-capacity ratio in pluvials owing to a lowering of the vertical climato-morphologic zones, it is hard to assign the glacis terrace systems of fully arid regions to pluvials or interpluvials. Depending on the altitude of the baselevel of erosion in the foreland, the number of glacis terraces also varies strongly as a function of the drainage area related to it at the time of its evolution. The richer the precipitation in the drainage area, the greater the capacity for erosion, but load also increases provided

Fig. 2. Decay of extraordinary intensity of a glacis region on the south flank of the Aurès in East Algeria. Dissection is far advanced in the proximity of the deeply incised main valley (the Oued Abiod), in very soft Eocene deposits highly prone to erosion

the waste is not held back by a dense vegetation. This will not, however, be the case unless the climate grows humid. Otherwise, however, the morphological system of the arid zone will undergo just a change of intensity, not one of principle.

It is important to note that the processes of degradation on the scarp border represent the only morphologically active mechanism in an arid climate. It is not the processes of planation that proceed against the scarps: it is the active erosion on the scarps that constitutes the source of energy between planation and scarp evolution. The decisive factor is and remains the evolution of the occasionally watered wadi network under the given climatic conditions. The integrated effect of the grooves of erosion will preserve and intensify the relief (of the benches in our case). There develops in the process a system of piedmont planes in front of every bench, with various slope angles depending on distance from the baselevel of erosion.

The morphodynamic system outlined here extends (in areas of relatively young sedimentary rocks) with gradual transitions from semiarid Spain (Meseta, Ebro) to the central Sahara (e.g. the Tademait with less than 50 mm of precipitation). The piedmont planes pass in these regions with gradually diminishing slope angles into plains of sedimentation (e.g. the sebkhas). In the case of an exorhaeic drainage there develops a system of glacis terraces which reflects the climatic fluctuations of the pluvials. Morphogenetically, the overall aspect of this relief is dominated by the tendency toward preservation of the higher planes, including the initial surfaces; conditions are quite similar in the arid zones of the US. The numerous inselbergs in front of the scarps fit quite naturally into this system of degradation. One of the integrating factors of this relief evolution under a semiarid climate is the dominance of physical-mechanical weathering. The strong contrast between coarse detritus and fine products is so typical of this type of waste removal that its local and regional extent is indicative of the morphogenetic processes: coarse detritus, concentrated on the steep relief, is encountered on the plane relief of the fully arid climatic region (e.g. on some hammadas) only where no removal is possible. Over all piedmont planes of the fully arid region, fine waste is predominant. In the semiarid region and at the feet of taller mountains there occurs also coarser detritus (piedmont detritus of typical shape) on the glacis terraces. The gradual change of the relationship between weathering and transport under the given hydrologically possible conditions of waste removal manifests itself in this regional differentiation, as well as in other ways.

An initial surface like the Tademait Plateau, which owing to its extremely gentle slope (0·1° over 160 km) and extremely arid climate possesses no means of fluvial waste removal except in the drainage area of the Oued Mya, is covered with finest waste thoroughly mixed with coarser detritus, and this without any sorting: a sure sign of arid conditions of weathering. It consequently seems impossible to me to interpret it as a fossil "tropical peneplain". The actual relief of planes and scarps of the arid zone cannot be interpreted morphogenetically in any other way than as a relief formed under an arid and semiarid climate.

3. PLANATION IN REGIONS OF CRYSTALLINE ROCKS

Excellent examples of this process are encountered in the extremely dry central Saharan region between the Tassili and the volcanically dominated Hoggar Massif. First of all, there is a "peritassilic socle plane" sculptured in granite, on which sits the volcanic Hoggar Massif. The late Tertiary and early Quaternary basalt sheets of the latter have covered and preserved the socle plane. Our aim is to analyze this extensive socle from plane in a morphogenetical viewpoint.

This plane, cut in pre-Cambrian igneous rocks (locally also schists) had been stripped of its cover of Palaeozoic sandstone of the Tassili Group relatively early (before the Cretaceous?), but the initial surface decisive for the relief of today was initiated only at the time of origin of the young Hoggar Massif volcanics. It accordingly declines from the centre of uplifting in the massif some 500 m towards the inner Tassili benches which are some 150 to 200 km distant. The morphogenetic evolution of this initial surface was obviously controlled by the postepeirogenetically developed drainage network of the centrifugal wadi system radiating from the Hoggar.

This initial surface, developed up to the Tertiary–Quaternary limit—none other than the peritassilic socle plane—is dominated by numerous insular massifs (e.g. Tefedest, the Tesnou at In Ekker), and innumerable inselbergs, the positions of which are undoubtedly controlled by the laccolithic structure and corresponding arching of the granite massifs. There is no justification for trying to reconstruct from their summit-levels some higher morphological plane (a procedure which is attempted time and time again). Sloping less than 1°, the actual socle plane is composed of a multitude of slopewash pediments, the control centres of whose denudation are the insular massifs and inselbergs about which they have developed. These pediments have slopes of 2 to 4°. The bases of areal degradation are the relevant elements of the wadi system, whose first origins date quite far back as the wadis cut the Tassili benches in the centrifugal direction.

The actual socle plane, situated between 900 and 1,400 m, does not represent the original initial surface, because the areal degradation of the pediments effected a gradual lowering of this surface with a concomitant etching out of the inselbergs. This process emphasizes the contrast—particularly marked in crystalline regions—between the steep, most often convex rocky slopes of many inselbergs and the extensive, gently sloping piedmonts of arid regions. Slope weathering is known to be extremely slow here (rock engravings !); still, it is not entirely absent: the development of crusts on smooth surfaces hinders physical weathering, but in crevices and taffoni hallows weathering by exfoliation and desquamation is by no means absent. This entails a clear-cut differentiation at the front of weathering. The slow average rate of weathering —by crumbling in granite—is due, besides scarce precipitation, rapid flow off and the immediate drying of smooth surfaces exposed to the sun, also to the very dry air. Retreating weathering of inselberg slopes is consequently—possibly in contrast to the humid tropics—extremely slow.

Degradation on the pediments is characterized by shallow runnels (not "slopewash hollows"), united but seldom into more important and consequently deeper systems of drainage. They reflect the high load-to-capacity ratio of the fluvial processes which become more and more sporadic as one proceeds from the semiarid towards the fully arid zone. The marked contrast between block weathering and crumbling plays a decisive role: load capacity is sufficient to remove grit but not boulders and blocks, and this contrast in the size of waste affects even the evolution of the break ("knick") at the feet of inselbergs (see e.g. Meyer, 1967). It further entails the sharp contrast between the grades of the slope and the piedmont plane in granite, not reproduced in this form in any other rock.

Pediments of the fully arid zone bear numerous shieldlike protuberances ("humps", "Grundhöcker"; Büdel). Pediments are in effect grit-covered rock piedmonts. There is no crystalline rock chemically weathered, e.g. as a result of a wet-tropical episode, at least not on the slopewash pediments of the peritassilic socle plane. A basalt-covered (Pliocene?) pediment over gneiss on the crystalline socle north of Tamanrasset exhibits a weathering with physical comminution dominant over chemical weathering. The analysis of a basalt-covered gneiss in the Atacora Massif (on the Akar-Akar) provided no indication of intense chemical weathering either, although such weathering was suggested by Kubiena for the more elevated basalt planes of volcanic sheets, on the basis of remnants of fossil red loam. A Tertiary age is to be presumed for these. Morphologic facts reveal a relief evolution under more or less arid conditions after the formation of the volcanic Hogger Massif, presumably with rather savannah-like (pluvial) climatic episodes of enriched rainfall but the continuation of arid seasons. The decisive factor seems to be in this case also that the actual relief was not sculptured by a fundamentally different set of morphodynamic processes, although gradual climatic fluctuations resulted in changes in the mode of weathering. Within the region of the crystalline socle, this relief is composed of slopewash pediments, which are in continual evolution even now although their origins date back to the late Tertiary. They cannot consequently be regarded as exclusive forms either, although the time factor of their general evolution should by all means be taken into consideration. On the other hand, the existence of fossil peneplain and pediment remains—basalt-covered in the Atacora Massif and uplifted together with it—is highly probable.

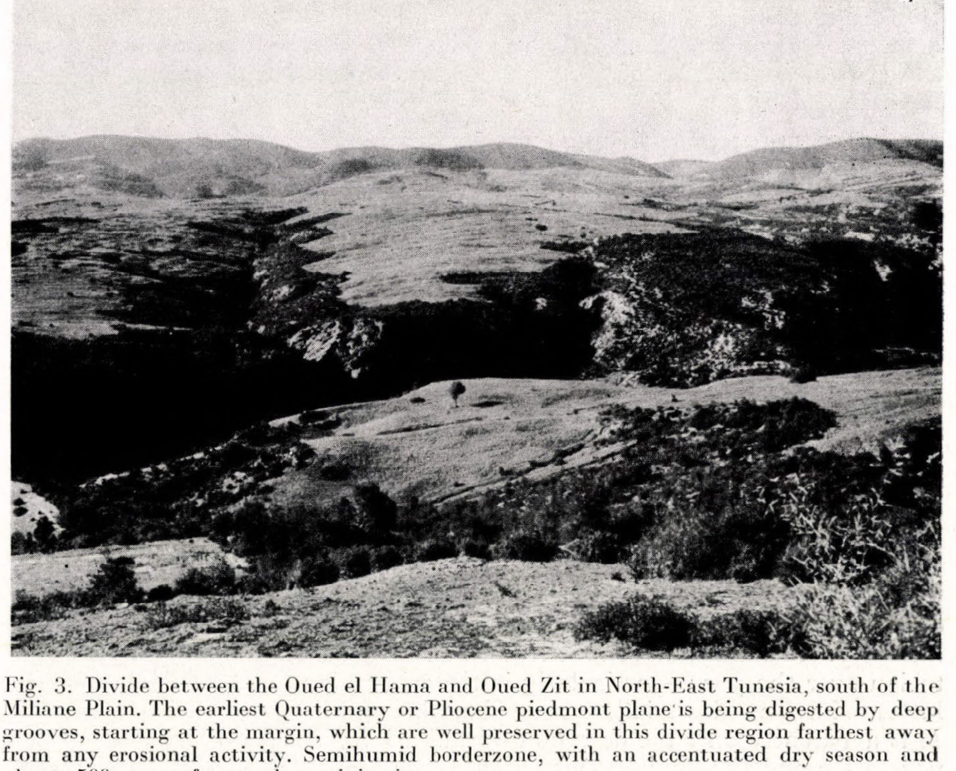


Fig. 3. Divide between the Oued el Hama and Oued Zit in North-East Tunesia, south of the Miliane Plain. The earliest Quaternary or Pliocene piedmont plane is being digested by deep grooves, starting at the margin, which are well preserved in this divide region farthest away from any erosional activity. Semihumid borderzone, with an accentuated dry season and about 500 mm of annual precipitation

4. THE INFLUENCE OF PLUVIALS ON PLANATION

It is impossible to give here a detailed account of pluvials in the arid region. The glacis terraces of the northern border of the Saharan climatic region are assigned to various pluvials. A main pluvial and a quite recent (probably Neolithic) humid episode have been recognized in the central Sahara. The main pluvial gave rise to mighty accumulations in the valley systems (20 m above the actual valley bottom). This accumulation is connected everywhere directly with sheets of scree, dissected today, which provide insight into the origin of this terrace material. Such "parabolic slopes" (Büdel, 1955) are true slopes glacis, forms of transition towards the mighty glacis terrace. Along systems of big wadis, this terrace penetrates into the region of piedmonts (and the zone of "sandwash plains" where the wadis emerge from the Hoggar). It occurs also along the wadis of the tassili cliffs. Its morphogenesis is exactly the same as that of the glacis terraces of the semiarid region (southern border of the Atlas). It follows that even the great Saharan pluvial and the concomitant episode of intense degradation (with a more humid vegetation) deviated but slightly from the fundamental principle of modelling in the arid zone. The question whether the great pluvial was "Mediterranean" or "tropical" cannot be answered off hand by its morphological efficiency. Its connexion with the fluctuations of vertical climatic zoning in the Central Saharan Mountains is obvious. Rognon imagines a temperature depression sufficient to have brought about a morphologically active "periglacial-nival" zone which provided increased amounts of waste. Lack of space prevents the discussion of these problems.

5. REGIONAL DIFFERENTIATION OF PIEDMONT PLANES OF THE ARID ZONE

Over and above their obvious lithologic control, the glacis and pediments of the arid zone are climatically and hydrologically controlled first and foremost. The semiarid borders of the arid zone exhibit in the marginal zones of the mountains an intense modelling, emphasized by climatic fluctuations, of glacis terraces over young sedimentary rocks. In fully arid regions, this subdivision into terraces is repressed by the tendency to preserve the initial plains. Terraces are as a rule more enhanced when in connexion with large valley systems than with small ones. Pediment surfaces, less thoroughly dissected in crystalline regions than in sedimentary ones, are overwhelmingly polygenetic in fully arid regions. From the first origins of a pediment, there is usually a continuous evolution to a currently remodelled slopewash pediment. This is why it is difficult to distinguish fossil from recent piedmont planes. An enhanced aridity presumably results in a set of circumstances in which only the most extreme pluvials have any morphological effect. However, even these do not affect the principle of the system of relief evolution, only its intensity. A comparison of arid regions and the distribution of their precipitation over the year—particularly in the arid regions of the US—reveals the latter to have no direct influence on planation and the preservation of planes. It is apparently only the degree of overall aridity and its direct influence on vegetation and the fluvial processes of degradation that play a decisive role.

6. DOES THE TOTALITY OF PIEDMONT PLANES OF THE ARID ZONE CONSTITUTE A PENEPLAIN RELIEF?

This problem is open to further discussion. It would be necessary beforehand to take a terminological decision, concerning first of all the content of the term "peneplain". The concept of piedmont plane, which would be suitable for the purpose, had unfortunately been given a well-defined genetic connotation and interpretation by W. Penck (1924). The use of the term pediplain as employed by American and French authors (Dresch, Cotton and others) should also be discussed. This might permit the expression in the terminology of the progression from pediment to pediplain. In any case, the various forms of piedmont planes (glacis, pediment) and the morphodynamic process leading up to them should be given proper consideration, which is not made possible by the simple use of the general term "peneplain". A sharper distinction between surfaces of degradation and aggradation seems likewise to be necessary.

7. THE ROLE OF PIEDMONT PLANES IN THE SYSTEM OF PLANATION OF THE ARID SUBTROPICS AND TROPICS AS OPPOSED TO THE HUMID TROPICS (CONCLUDING REMARKS)

Glacis and pediments are "plains of transition" between high- and low-relief regions in the arid climatic zone. The tendency of preservation of older (and usually higher) levels of planation results in the extension of plane systems over the entire arid region, particularly conspicuous in the regions of younger sedimentary rocks. A polygenetic—temporally persistent—evolution of piedmont planes (resulting in a decrease of slope angles provided the baselevel of erosion stays at the same altitude) results in piedmont planes covering a substantial portion of the entire relief. Not all planes are, however, piedmont planes or direct continuations of such. The initial plains of plateaux (mesetas, hammadas) are mostly accordant planes controlled by the almost horizontal bedding of the sedimentary sequence. They are under a regime of plane preservation more emphatic than planation. Piedmont planes, pediments in particular, undergo on the other hand rather an active planation, which may, it is true, be very slow under an arid climate. The time factor, i.e. the time intervals with parallel-oriented processes of planation, must be placed in proper perspective. Piedmont planes (glacis, pediments) are by no means only "marginal phenomena" at the feet of the high relief: on the contrary, in the morphodynamic sense they dominate the plane relief of the entire arid zone.

According to numerous observations and descriptions (Kayser mentions for instance such piedmont rock surfaces from the semiarid tropics of South Africa), this system of planation reaches deep into the arid and semiarid regions of the tropics. The ratio of piedmont planes to the entire planated relief (peneplains !) seems to decrease towards the humid tropics, which suggests the possibility of a climato-morphologic boundary between the regions. Further research may bring important results in this respect. However, it seems certain that even in the humid tropics with alternating wet and dry seasons the contribution of piedmont planes of the type of "wash plains" (Cotton, 1962) with shallow dells ("Spülmuldenfluren"—Louis, 1958) to the entire planated relief is not insubstantial. Such forms belong to the system of planation rather than to that of valley sculpture. By no means, however, do they exclude the sculpture of true valleys !

Finally there arises the question whether relief products of a humid tropical climate with alternating wet and dry seasons can be demonstrated in the arid zone. This is a point that had been repeatedly raised, in connexion with inselberg landscapes as well as with planated reliefs in general.

There have been found remnants of soil which prove beyond doubt a much more humid tropical climate. This holds in particular for the early and late Tertiary, but the aridity of these climates is not to be belittled. Chemical weathering, emphasized by more humid conditions, may have had a greater importance during an older, Tertiary relief evolution; still, the actual set of forms can to a considerable extent be derived from a morphodynamic system of planation under arid and semiarid conditions plus the climatic fluctuations of the Quaternary. This is especially true of extensive surfaces, subject to active planation even under arid and semiarid conditions. During the first etching of the inselberg forms and of large benches in the sedimentary rocks, such a weathering in depth could certainly promote and accelerate the subsequent lowering of the relief.

In summary, the actual relief of planes and steps in the arid regions, the actual glacis terraces and slopewash pediments, reaching up to the late Tertiary (Pliocene) levels of planation, which together constitute the planated relief, have developed under gradually fluctuating arid to semiarid climatic conditions and represent a set of forms typical for the arid subtropic and tropic climatic region. They have replaced a possible relief generation of a previous more humid tropical climate in such a way that this latter nowhere determines the "fundamental character of the relief forms" ! Planes and plains, including also the piedmont planes (pediments), constitute in themselves no proof of a humid tropical palaeoclimate with alternating dry and wet seasons. The arid subtropic and tropic climates consequently define an independent climato-morphologic zone.

ORIGIN OF PEDIMENTS IN THE WESTERN UNITED STATES

by

J. H. MACKIN[1]

ABSTRACT

Corrasion (lateral planation) pediments and weathering–washing (sheet wash) pediments are end members in an isomorphous series; thus the definition of a pediment must be descriptive, not genetic. A pediment is an erosion surface, planar or with low local relief but with high overall slope, that forms in arid or semi-arid regions.

Formation of pediments primarily by lateral planation by streams was championed in the United States by Douglas Johnson. Gravel is left behind as the stream migrates laterally. The thickness of the gravel cap on the cut bedrock surface tends to approach the maximum depth of the flood scour channel. Lateral cutting by arid-region streams is rapid compared to that in humid regions because of the lack of bank stabilization by vegetation.

Pediments formed dominantly by sheet wash occur on rocks that weather to grus that is easily removable during the cloudburst rainfall so characteristic of arid regions. This leaves a stripped rock surface of minor relief but whose overall appearance is that of a smooth erosion surface.

The sharp angle maintained between pediment and mountain front is the result of: lateral stream planation that truncates spurs of the mountain front, washing of the scarp, sapping of a resistant layer at the top, formation of a residual armor of boulders, and/or the tor effect.

Both pediments and piedmont fans are characteristically convex-upward in profile because both are slopes of transportation.

Only pediments formed relative to stable or slowly lowering baselevel are discussed in this paper. Pediment problems not discussed include: rising local baselevel; effects of retreat of mountain front in uniform rocks; high-level Pliocene pediments of the Rocky Mountains.

1. INTRODUCTION

I have been a stay-at-home, and my understanding of pediments is distinctly provincial. I hasten to emphasize that if my views differ sharply from those held by some of you, it is simply that I am not adequately aware of concepts and evidence foreign to the western United States and Mexico. Certainly much of the controversy in the United States regarding pediments has arisen from the fact that people working in different places have seen different things. If a man is familiar with pediments of only one origin, and thinks that all pediments are the same in origin, he is likely to disagree with those who have worked with pediments elsewhere. Many of our problems are of this nature; the disagreements between different schools of thought in the United States, over the years, would have been greatly reduced had the men exchanged visits in the field. That is the reason I am here—to hear views foreign to my thinking, and to see your mountains.

[1] This version of Professor Mackin's paper, who died on August 12, 1968, is a nearly verbatim text of his oral presentation. The illustrations are those projected during the symposium. The abstract was prepared by Dr. William R. Muehlberger.

The first problem is a matter of definition; what *is* a pediment? Some pediments in our west are cut by lateral stream planation—the evidence is conclusive. But it is equally certain that others are formed by weathering and washing; the streams act primarily as agents of transportation, and lateral planation is negligible. These corrasion pediments and the weathering–washing pediments are end members in an isomorphous series; the relative importance of the two processes can vary from almost zero to almost 100 per cent, depending on conditions. Hence, because pediments are polygenetic, they cannot be defined in terms of mechanism of origin; the definition must be descriptive.

The pediment above all is an erosion surface, whether cut in hard rock or unconsolidated sediments of any origin. It is planar or has low local relief, but is characterized by a high overall slope of the order of a few tens or hundreds of meters per kilometer. The slope is a slope of transportation; it tends to decrease uniformly from a "mountain mass" which is commonly but not necessarily present, to a local baselevel that may be stable or slowly rising or lowering. It can of course be dissected, or buried, or greatly modified by processes other than those that formed it, but these changes merely call for qualifying adjectives; they do not enter into the definition.

It seems to me regrettable to call any erosional lowland at the base of a mountain mass or scarp a pediment. This makes pediment synonymous with

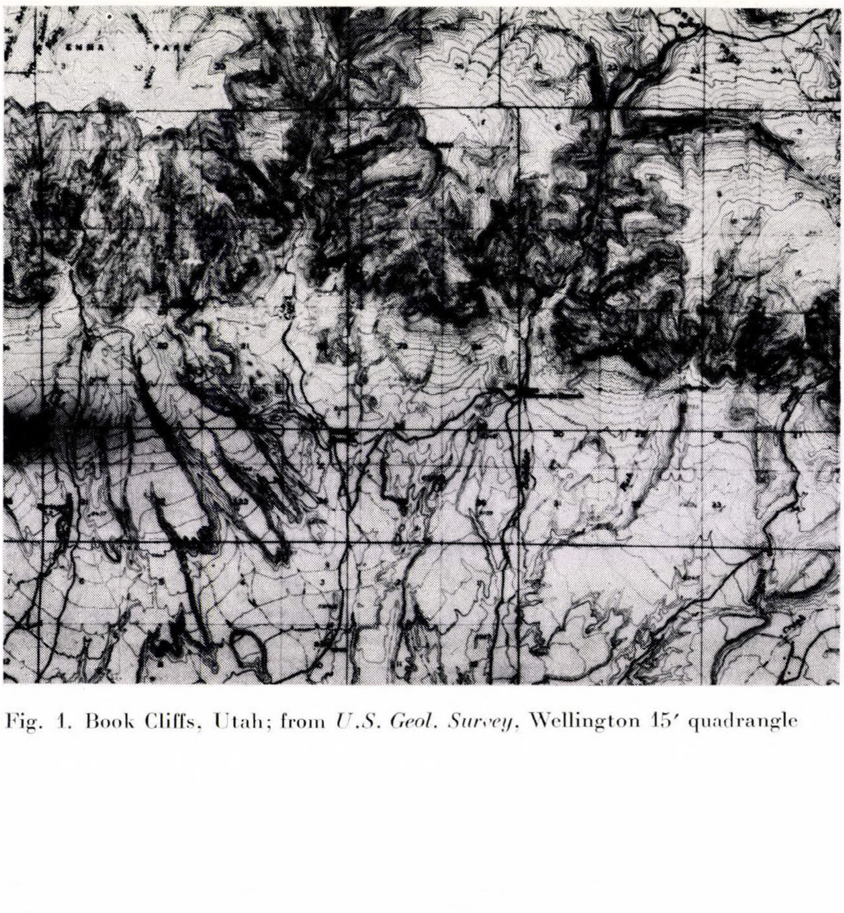


Fig. 1. Book Cliffs, Utah; from *U.S. Geol. Survey*, Wellington 15′ quadrangle

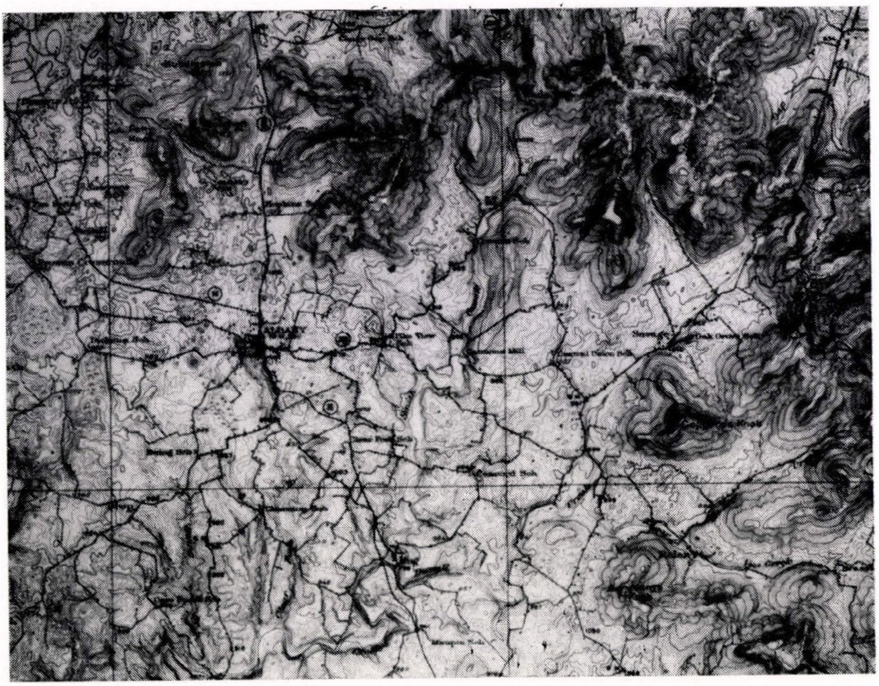


Fig. 2. Cumberland Escarpment, Kentucky; from *U.S. Geol. Survey*, Byrdstown 15′ quadrangle

Fig. 3. Pediment at 3,000 meters, east flank of Big Horn Range, Wyoming

piedmont, and we have no need for synonyms. The pediment is a landform of arid and semi-arid regions, and the definition can be genetic to this extent, that the dominant formative processes are corrasion, weathering, and washing. *Creep*, which is chiefly responsible for the modelling of slopes in plant-held soils of humid regions, is negligible, as are all other slow mass movements, such as cryogenic erosional processes of high latitudes and altitudes. I think that there is much merit in Blackwelder's (1931, p. 138) statement that the pediment is "the desert-inhabiting species of the genus peneplain"; the varieties intergrade, and the intergradations are instructive, but this does not mean that the end members, pediments and peneplains, or pediments and altiplanation surfaces, are the same.

Some erosion surfaces are illustrated in Figs 1–3. The planar surfaces at the base of the Book Cliffs in Utah (Fig. 1) are pediments, cut in shale and veneered by gravel which acts as a resistant cap rock. The lowland at the base of the Cumberland escarpment in Kentucky (Fig. 2) is characterized by concavo-convex hills. The overall slope is low; the surface is not a pediment and will never evolve into one, however much the hills may be reduced. In Fig. 3, the erosion surface *is* a pediment on the east flank of the Big Horn Range at about 3,000 meters. It is probably late Pliocene, and has been modified by cryogenic processes, but not so much as to obscure its origin.

2. PEDIMENTS FORMED BY LATERAL PLANATION

The concept that pediments are formed primarily by lateral corrasion by streams is commonly associated in the United States with the name of Douglas Johnson (1931, 1932a, 1932b), but Fig. 4, from G. K. Gilbert's (1877) "Henry Mountains" monograph, predates Johnson's papers by half a century. The Henry Mountains, Utah, are intrusions of diorite porphyry, surrounded by slopes cut on relatively weak sedimentary rocks. The term pediment had not come into use at the time of Gilbert's study, but his drawing, its title ("A slope of planation") and its context, indicate that it *is* one, and that it was formed chiefly by lateral stream planation. Any doubts would be resolved by Fig. 5, also from Gilbert's Henry Mountains monograph; the cap rock is a veneer of gravel, a few meters to many meters thick, resting on a surface which truncates the rock structure. The gravel is not evidence of aggradation; a stream cannot shift laterally without leaving behind a sheet of alluvium the thickness of which tends to approach the maximum depth of the flood scour channel. Were this not the case the channel would have become infinitely wide and would cease to be a channel. The rock surface is not a peneplain, stripped of its regolith, warped to the form of a stream profile, and overspread by gravel. The slope is original, and the gravel sheet is an integral part of the planation surface.

Figure 6 is a view of the planation process on the west side of the Three Peaks intrusion in southwestern Utah; the picture was taken about an hour before a flash flood, resulting from a minor cloudburst, cut back this bank in Cretaceous sandstone and shale as much as a meter in some places. The upper surface is an extensive pediment, mantled by 2 to 3 meters of alluvium; the square white planetable is at the contact of gravel and bedrock.

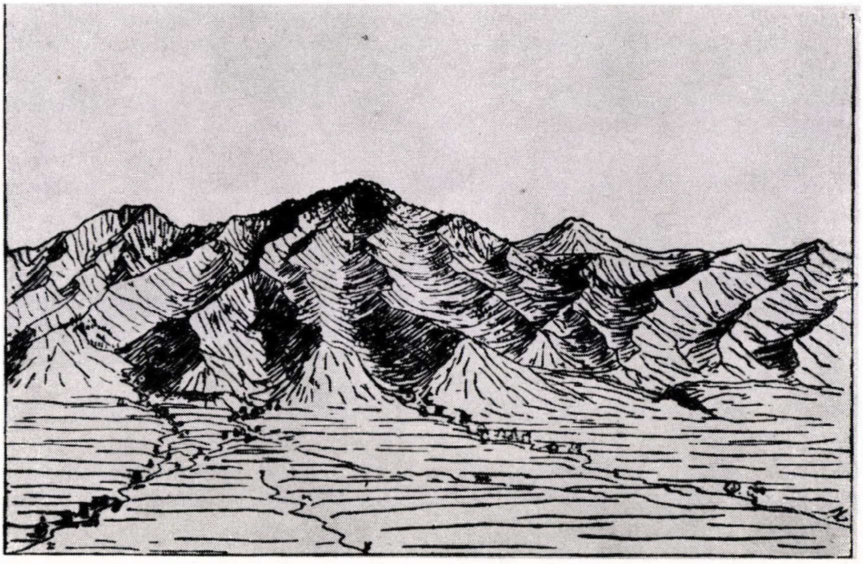


Fig. 4. Lateral stream planation on a pediment, Henry Mountains, Utah; from Gilbert, 1877, Fig. 62

Fig. 5. Gravel caprock on a pediment, Henry Mountains, Utah; from Gilbert, 1877, Fig. 63

The area shown in Fig. 7 is in the Colorado Piedmont northwest of Denver. The Front Range is to the west; the pediment surface (recently described by Scott, 1963, pp. 14–15) is almost perfectly planar. It is cut on weak sedimentary rocks, mostly Cretaceous, which dip to the right. The surface is composite; the "Rocky Flats" surface, to the north, is about 10 meters higher than the similar surface in the south central part. Both are deeply dissected; they are preserved because the capping gravel is far more resistant to erosion than the bedrock.

The point I would like to stress is that lateral corrasion planes may range from the more or less continuous surfaces that surround mountain ranges to what are simply stream-cut valley floors, or terraces that are remnants of such valley floors.

At precisely what width, or width/length ratio, or width of planation surface/width of channel ratio we should draw the distinction between pediment and stream-planed valley floor, or a dissected pediment and a stream-cut terrace, is inconsequential. There is a broad transition zone in which individual geomorphologists may differ, but so long as the origin of the surfaces is understood, argument as to the terminology is merely a play on words. However, the fact that there *is* a complete transition (the examples used could be multiplied many times) raises a question of theoretical interest: why is it that, in humid climates where streams are everywhere and average discharge per unit of area is large, lateral corrasion planes are commonly narrow and the interfluves are overwhelmingly dominant, while in the semiarid to arid climates, in areas of comparable overall relief, lateral planation surfaces may be so broad as to coalesce? The contrast between the surface of the base of the Cumberland scarp in Kentucky, and the surface of the base of the Book Cliffs in Utah, noted earlier, is a case in point; the relationship is systematic and is one of the key elements of the pediment problem.

It is difficult to cast the problem in quantitative terms. The relatively narrow valley floor or terrace of an eastern river is not directly comparable to its counterpart along a western river of comparable average discharge, because average discharge has little meaning in this connection; the relative resistance of rock to corrasion can be evaluated only loosely, and the duration of time represented by the valley floor or terrace, which is essential in determining the rate of lateral corrasion, can only be guessed. Moreover, other factors are involved for which numerical values can be assumed if we are so minded but cannot be estimated closely. Like most geographic problems, this one must be thought through in qualitative terms before it is profitable to plug in sets of numbers as order of magnitude tests.

One important element is a copious supply of large, tough clasts to the river. The nature of the bedrock is a significant background factor—dense basalt, for example, as compared with friable siltstone. More directly pertinent for present purposes is the degree of weathering prior to the delivery of the rock to the river; for example, fresh clasts avalanched or washed from arid slopes versus clasts reduced to granules or with resistance to attrition greatly reduced by chemical weathering during their slow streamward movement, chiefly by creep, through the thick, plant-held regolith of the humid hill slope. A continuing supply of large, tough clasts requires high bed velocities for transportation, and *the* *power of a stream to corrade its bed and banks varies directly with its power to transport bed load.*

It has long been known—it is implicit in two of Gilbert's classic papers (1914, 1917) and was brought out clearly by Rubey (1938) — that high gradient, low discharge streams are far more effective agents of bed load transportation and corrasion than low gradient, high discharge streams.

Fig. 6. Stream-cut bank in pediment, west side of the Three Peaks intrusion, Utah

The fact that the average velocity of many streams tends to *increase* in a downvalley direction (Leopold–Maddock, 1953), as the calibre of the bed load *decreases*, is seemingly anomalous. Actually it is a reminder that while average velocity is a depth-slope function, modified by a roughness factor, bed load transporting power (and hence corrasive power) varies, *not* with average velocity but with bed velocity; this relation provides a rational explanation for the well documented empirical generalization stated above, i.e., that the high gradient, low average discharge streams of arid regions are far more effective agents of transportation and corrasion than the low gradient, high average discharge streams of humid regions. Especially if we recall that the high gradient streams of the arid regions are characterized by peak flows which may represent most of the discharge of one or many years, it is not surprising that corrasive power seems to vary directly with slope, and, within certain limits, inversely with average discharge or depth.

This general principle, which applies primarily to differences in development of planation surfaces in different climates, is confirmed by the fact that, when there is through-flowing drainage and no marked difference in rock resistance, stream-cut surfaces tend to be wider near the mountain front than farther out on the piedmont; that is, the breadth of the surfaces decreases with the stream gradients, which in turn reflect a decrease in calibre of load, chiefly by attri-

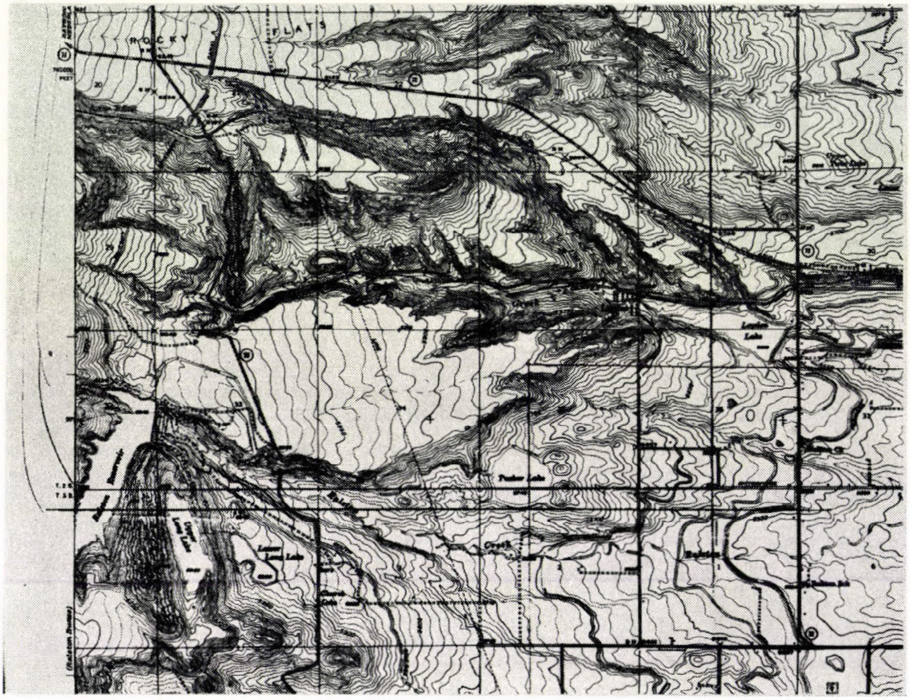


Fig. 7. Pediment northwest of Denver, Colorado; from *U.S. Geol. Survey*, Golden 7 1/2′ quadrangle

tion. Two places already noted serve as examples; the planation surfaces of the Book Cliffs region (see Fig. 1) decrease markedly in width in the first 10 kilometers out from the base of the cliffs, and the Rocky Flats pediments (see Fig. 7), which are virtually continuous for several kilometers along the Boulder-Golden mountain front, are replaced eastward by hills with concavo-convex slopes and soil, weathered in place, that are the antithesis of the planar, gravel-veneered pediments.

Another and entirely different factor is significant in many places. The banks of channels of perennial streams of humid regions are commonly covered by vegetation, ranging from grass and shrubs to trees; the banks of the channels of ephemeral streams of arid regions are commonly barren. The river engineer is well aware of the protective value of bank vegetation; use of a mat of living willows is a standard and effective procedure in controlling bank erosion. Not only is the vegetative blanket erosion resistant, both above and below the normal surface; after an episode of scouring that damages or destroys the network of roots and branches, it is self-renewing. The barren banks of arid regions, on the other hand, are more readily cut and they stay cut, to be eroded back still farther in the next attack.

Fig. 8. Three Peaks intrusion, Utah, viewed from the south

Fig. 9. Pediment surface, interior of the Three Peaks intrusion

Fig. 10. Pediment surface, interior of the Three Peaks intrusion

It is surely true, as we are accustomed to think, that straight and angular slopes that tend to maintain their steepness as they retreat, rapid runoff and corresponding extremes in stream discharge, steep slopes of transportation, and all of the landforms and processes that we associate with aridity, are *indeed* characteristic of that climate. But the relations outlined here indicate that *climate* is an *indirect* cause; nearly all arid-humid geomorphic contrasts are in fact due to the absence or presence of a vegetative cover, and this, in turn, is significant chiefly because it makes the difference between washing and creep. There are no extensive lateral planes at the base of the Blue Ridge escarpment or other mountain fronts of our humid east, but I think that there would be, with change in rainfall, if the mountains were stripped of their covers of vegetation and the residual soil held in place by the vegetation.

3. PEDIMENTS FORMED CHIEFLY OR WHOLLY BY WEATHERING AND WASHING

In Fig. 8, the essential features are sufficiently clear in profile along the skyline. The peaks are quartz monzonite porphyry, resistant to erosion because they escaped deuteric alteration along the western border of the Three

Fig. 11. Pediment, east side of Three Peaks intrusion

Peaks intrusion in southwestern Utah. Pediments slope both west (to the left) and east, from the axis of the intrusion. In the discussion of Fig. 6 we considered part of the western pediment, cut in Cretaceous sandstone, veneered by gravel, and clearly formed primarily by lateral planation.

We will shortly examine details of the morphology of the sharply contrasted type of pediment on the east; this distant view in Fig. 8 is useful to emphasize its uniform slope, slightly concave upward, all the more remarkable because the west half of the slope, west of the small knob on the horizon, is cut in porphyry, while the east half is cut in Tertiary alluvium, derived from the east and displaced downward against the porphyry by a major Basin-Range fault. There is no topographic break at the surface trace of the fault.

The rock in Fig. 9, in the interior of the intrusion within the crescentic ridge, is altered porphyry which weathers rapidly to crystals and small aggregates of crystals. I had the good fortune to be out in the brief cloudburst which filled the weathering pits with water, and to observe the process by which the surface is formed, namely, the flushing away, by sheet wash, of gruss loosened by weathering since the last storm.

Figure 10 is another view of the same pediment. This surface, sparsely covered by grass and gruss, is about 75 per cent bare rock; it represents a climax of the reduction of local relief by sheet washing, on a surface with an overall slope of 2 to 3 degrees. Exactly as in the case of the lateral planation type of pediment the slope is a graded slope of transportation, but corrasion is negligible in modelling the surface, as is evident (Fig. 11) in a minor stream channel characteristic of the east Three Peaks pediment. Note, for future reference, that the alluvium is chiefly gruss and that there are no cut banks. Most local sheet floods move the gruss only short distances, of the order of a few hundred meters. Only the 2- or 5-year flood flows down the entire slope to its base. This flow, while rare, controls and gives unity to the entire slope.

In that it is produced chiefly by interstream erosion processes, is not normally mantled by alluvium, and is rarely planar in detail, the weathering–washing pediment is analogous to the stream-cut valley floor. There are of course intergradations, but there are basic differences: (1) the overall slope of the weathering–washing pediment is steep because the controlling stream gradients are steep for reasons already stated, while the overall slope of a peneplain is low because the stream gradients are low; and (2) relief features tend to be angular forms produced by washing in contrast with concavo-convex forms produced by creep.

The question is the reason for the difference in the relative importance of planation versus weathering and washing on different pediment surfaces. The question is brought into sharp focus, and the range of hypotheses is reduced, by the contrasted relations on the opposite sides of Three Peaks. In any unit area on the pediments that slope eastward and westward from that range, climate, rates of weathering, incidence of local cloudbursts, and most other factors are substantially the same. But it happens, for reasons of no concern here, that nearly all—perhaps 90 per cent—of the drainage of the axial peaks flows *west*.

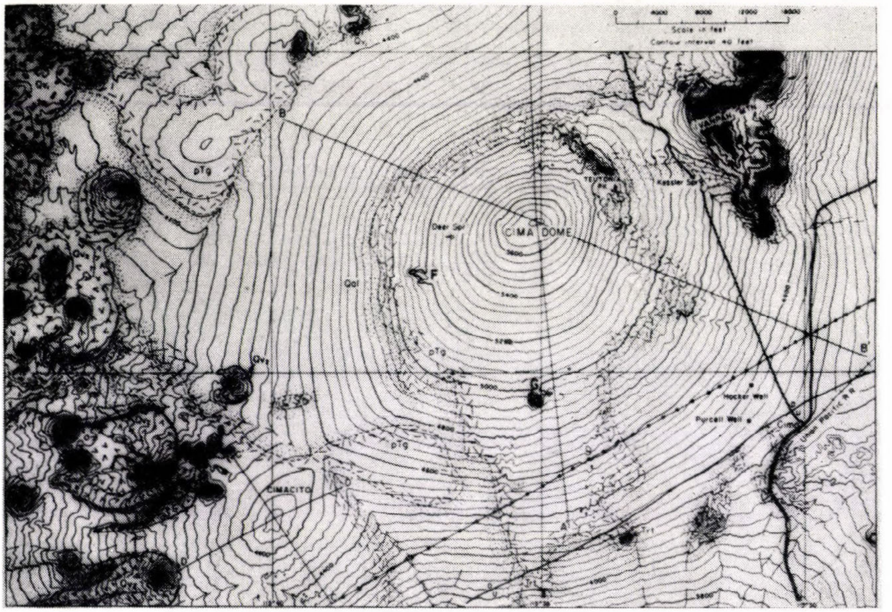


Fig. 12. Cima Dome, California; from Sharp, 1957, Fig. 2

Here, then, is another factor to be added to coarseness of clasts and other elements favoring planation on pediments; the corrasive power of the streams, and the magnitude and duration of through-flowing floods, is a function of the areal extent and relief of the "mountain mass" from which they issue. At one extreme, weathering and washing relative to planation by powerful streams are negligible, as on the west pediment of Three Peaks; at the other, in the absence of such streams, the effects of weathering and washing dominate, as on the east side of Three Peaks, where the mountain headwaters area is limited in extent and low in relief. The climax is illustrated (Fig. 12) by Cima Dome in the Mohave Desert (Sharp, 1957) where pediments coalesce to form an almost perfect cone with no "mountain mass"; the Cima pediments are the weathering–washing type.

This concept, that, other things being equal, the mechanism of origin of a pediment is determined by the corrasive power (or absence thereof) of the streams traversing it, implies that the dominant erosional process on a given pediment tends to change with changes in the extent and relief of the nuclear mountain mass, climate, and any other condition that affects corrasive power. It follows that, while the present is generally a clue to the past, processes now in operation on a surface are not necessarily the same in degree or even in kind as those by which it was formed. I am well aware, as has been stressed both in Europe and America, that landforms in many places are "fossil", but this consideration does not vitiate comparison of the east and west Three Peaks Pediments, neither of which is fossil.

4. THE MOUNTAIN FRONT

So far we have been concerned wholly with the pediment surface. Now we deal with another aspect of the problem—the tendency of the mountain front to remain steep, so that it meets the pediment at an angle or a concave upward slope of small radius.

It is first of all essential to separate those mountain fronts which are due simply to differential erosion of weak and resistant rock, as shown diagrammatically in A and B, Fig. 13. Ts in all of the diagrams is a master stream, stable or slowly degrading, to which all of the pediments are graded; it indicates

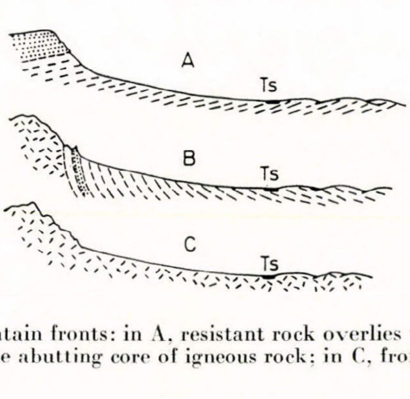


Fig. 13. Retreating mountain fronts: in A, resistant rock overlies weak shale; in B, resistant rock dips under weak shale abutting core of igneous rock; in C, front retreats in igneous rock

that problems associated with the rising baselevel are ruled out of this discussion; the pediments are everywhere cut on rock.

In A the mountain mass is capped by sandstone or other resistant rock resting on weak shale; retreat of the scarp, and the maintenance of its steepness, is by sapping; it would occur under any climatic conditions, and whether the weak rock at the base is truncated by a planation surface, as in the Book Cliffs (see Fig. 1), or by a late mature surface of low relief, as seen in the Cumberland escarpment (see Fig. 2). This scarp is not a part of the pediment problem.

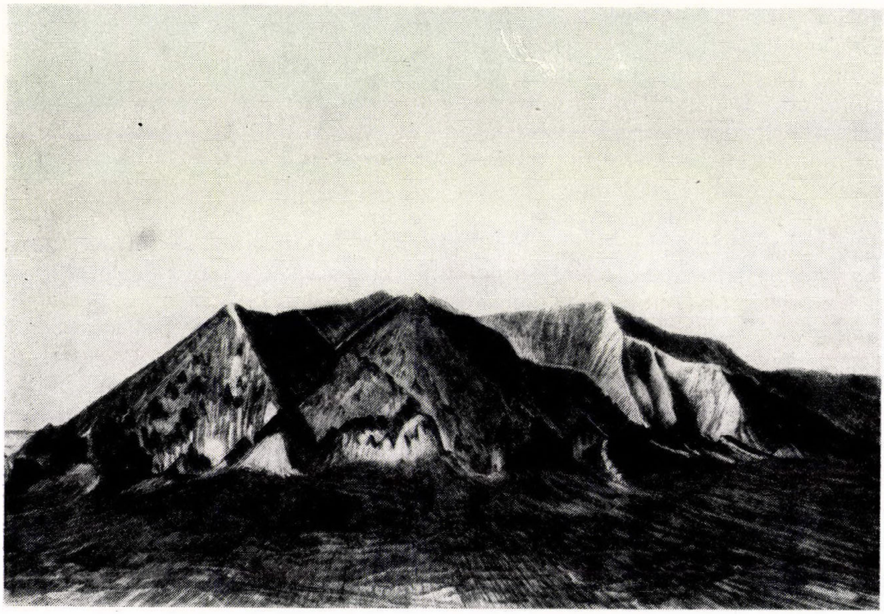


Fig. 14. Hogbacks and pediment, Henry Mountains, Utah; from Gilbert, 1877, Fig. 27

In B the resistant rock of the mountains and the associated hog-back forming strata, if present, dip beneath the weak rock; the scarp tends to remain in place, unless bevelled by extension of the pediment surface. The same diagram serves equally well for Fig. 14, a Gilbert (1877) drawing of another of the Henry Mountains, where the mountain mass is intrusive, or for the Front Range of the Rockies where the range cores are Precambrian crystalline rocks. The Rocky Flats and associated pediments are shown in Fig. 7. The scarp is wholly erosional, controlled by rock resistance; it is not a part of the pediment problem.

Diagram C of Fig. 13 serves to illustrate relations in the Iron Springs district. The same symbol is used for both the mountain mass and the pediment, and both areas are, in fact, shown by the same symbol on generalized geologic maps. But to regard this mountain front as a problem, and to seek an answer in terms of the pediment-forming process, would be like tilting with windmills. You will recall that the crescent of peaks around the western side of the Three Peaks intrusion is unaltered quartz monzonite porphyry, while the eastern pediment, within the crescent, is carved in a part of the intrusion which, because of intense deuteric alteration, weathers readily to gruss; the difference in resistance to erosion between the unaltered and altered porphyry is as great as that between quartzite and sandstone. Similarly, there are granites and granites, and basalts and basalts. Because the differences in mineralogy may be subtle, the hand lens may be as essential to the student of pediments as his map or camera.

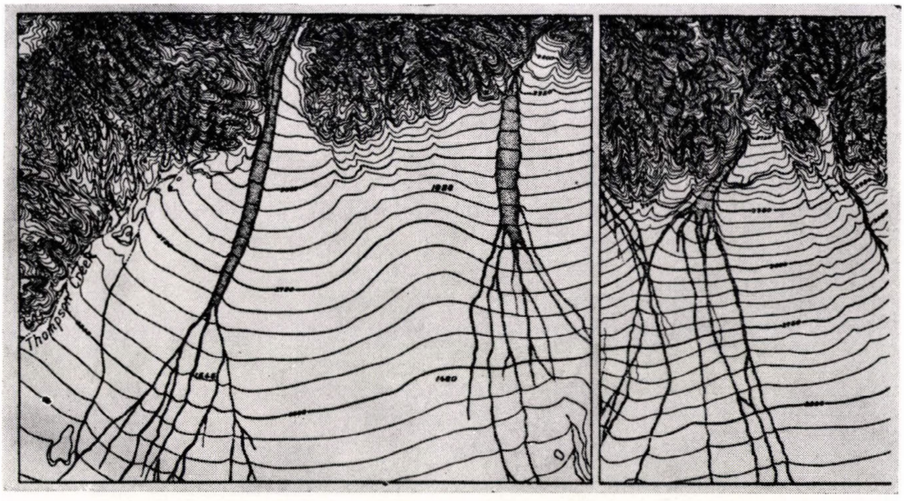


Fig. 15. South base of the San Bernardino Mountains, California; from Johnson, 1932b

I have been eliminating problems that do not exist in order to focus on the real problem of the mountain front – pediment angle. The problem is separable into two, the first where the pediment is produced primarily by lateral planation, and the other where lateral corrasion is negligible.

Figure 15 is one of D. W. Johnson's favorite illustrations, a map of the south base of the San Bernardino Mountains in southern California. It brings out his point that the spurs between streams are trimmed back by, and kept steep by, lateral planation whenever the issuing streams chance to shift against them. I had the good fortune to be with him in this area, where he was not disappointed; the base of the spur is clearly oversteepened by corrasion in many places, and in some places undercut to produce an overhang. The same relations are even more strikingly displayed where vigorous ephemeral streams are regrading fans at the east side of Death Valley, and in many other places.

Similar processes can be seen in operation on a miniature scale in many badland tracts in the Big Badlands of South Dakota, which leaves no doubt that the scarp maintains its steepness as it retreats. This is due in part to a tough blanket of sediment on the upland surface; the sediment resists erosion until sapped by removal of the weak Oligocene sediments that form the scarp. The dominant erosional process on the scarp itself is washing. Schumm (1956, 1962) has presented evidence favoring his view that this process tends to cause parallel retreat. And finally it is a matter of observation in the Badlands that, as on a very much larger scale at the base of the San Bernardino Mountains, runoff from the scarp face, concentrated by the badland ravines, from time to time trims back the intervening spurs by cutting at the base. It appears, then, that all three of the processes that tend to cause scarps to maintain their steepness as they retreat are operative in the Big Badlands: sapping of a resistant layer at the top, washing on the scarp, and basal trimming by-stream corrasion.

It is undoubtedly true, however, that scarps under certain conditions tend to retreat parallel with themselves, maintaining a sharp or rounded angle between the scarp and the pediment, where there is no concentration of flow at the base of the scarp, and hence no sharp increase in transporting power, and if the boulders on a scarp are reduced gradually in size as they move downslope, there should be no angle. There are, however, two processes which may operate separately or together to maintain the angle. First, if the rock composing the

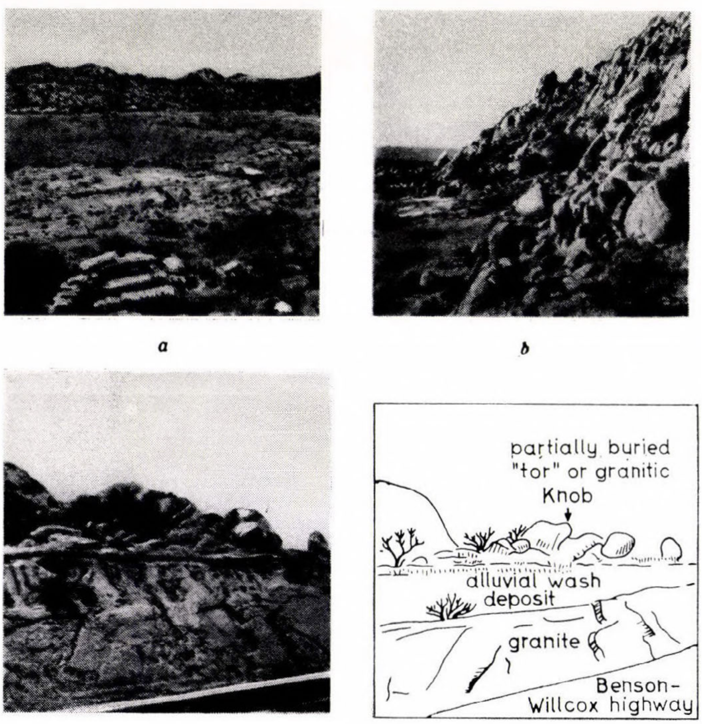


Fig. 16. Features of the Little Dragoon pediment, Arizona: from Tuan, 1959, Plate 9

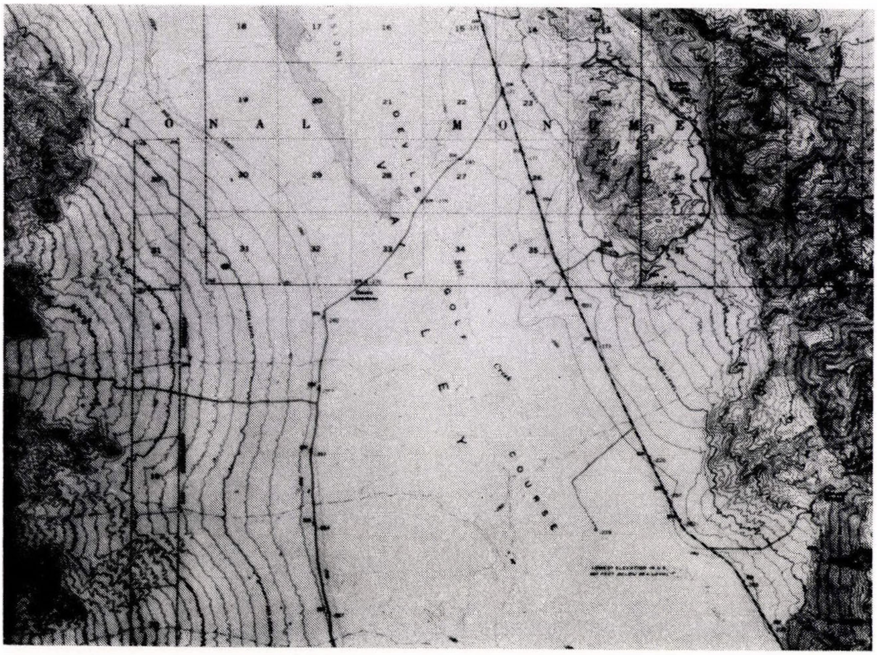


Fig. 17. Death Valley, California; from *U.S. Geol. Survey*, Furnace Creek 15′ quadrangle

boulders weathers thoroughly in place, it may, when it finally rolls down the retreating scarp, shatter into grains or granules capable of being removed by sheet washing. This view was suggested by Lawson (1915) and Bryan (1922) among others; with the aid of students and assistants, I put it to the test at every opportunity, almost always with such satisfying results that I am an addicted boulder-roller.

The second process, suggested in Fig. 16, has already been mentioned as the *tor* effect, that is, the tendency for differential weathering of uniform rock wherever there is concentration or retention of moisture for any reason. The bearing of this type of differential weathering on the pediment-angle problem has been emphasized by Bryan (1936) and more recently by Twidale (1967). There is no doubt that it works, particularly in rocks in which chemical weathering and/or frost action tends to cause disintegration; in some places it produces not only basal steepening but overhangs, both on small and large scales.

The maintenance of steepness of the "mountain front", and the closely related mountain front-pediment "angle", are not problems where they are controlled by differential erosion of contrasted rock types, nor where there is basal steepening of spurs by lateral planation of streams. Washing, particularly if there is concentration of flow at the base of the mountain front, the tendency of residual weathered boulders which armor the mountain front to disintegrate into granules at its base, and the tor effect, are important factors

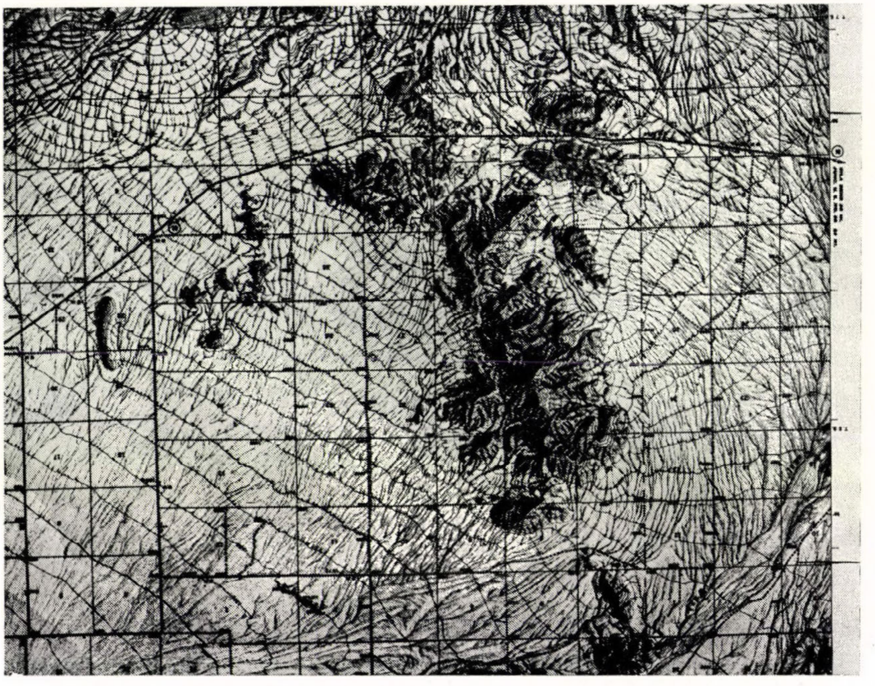


Fig. 18. Piedmont slopes; from *U.S. Geol. Survey*, Antelope Peak 15′ quadrangle, Arizona

in some places. Of course, none of the local bedrock relations or weathering and erosion processes are mutually exclusive. Several may operate in the same or different segments of the mountain front. As in the case of the pediment surface, the "mountain front" is a problem only when we make it so by applying a single explanation to all mountain fronts.

5. PARALLEL TO THE MOUNTAIN FRONT

Finally, we may look briefly at an aspect of pediments that has been treated in a number of special cases which have not, to my knowledge, been considered as parts of a single series of landforms. This may be called the shape of the pediment in profile parallel with the mountain front.

In this connection I am sorry that I must differ from Blackwelder's (1931, p. 137) suggestion that piedmont surfaces formed by aggradation (alluvial plains) are characteristically convex-upward in front of canyon mouths; that is, the alluvial plain grades into alluvial fans at each canyon, while pediments are characteristically straight in profile paralleling the mountain front. The fans on the left in Fig. 17 are at the east base of the tectonically active Panamint Range, and are extending out across the floor of Death Valley, so they are quite certainly alluvial fans. But the fan shape is no evidence of this; both alluvial plains and pediments are, above all, slopes of transportation, and the surface is the same in shape (except possibly for differences in longitudinal profile) whether the surface was built up (as an alluvial plain or fan) or cut down (as a pediment or rock fan). The deciding factor is simply the width of the zone controlled by streams from individual canyon mouths; if the zone is very broad, the surface is a fan apexing at the canyon mouth, whether it was formed by aggradation or degradation.

Fig. 19. Trenched exposure, Big Badlands, South Dakota

Figure 18 is a case in point. The piedmont slopes below this range in Arizona are in some places convex upward, concave, flat parallel to the mountain front, and in some places flat normal to the mountain front. It is not possible to determine from them whether the range is being buried in its own up-building alluvium or is surrounded by pediments.

Exposures or other equivalent data are essential. The exposure in Fig. 19 is good, because I made it myself, in the Big Badlands. The alluvium is 3 to 4 centimeters thick, and rests on Oligocene sediments; this is a miniature rock fan. I have seen such fans, in company with D. W. Johnson and others, from this size to those many miles across. Figure 20 presents the opposite extreme. The main stream issuing from the mountain front (here the Price River from the Book Cliffs) has a narrow valley floor which is the *lowest* part of any profile

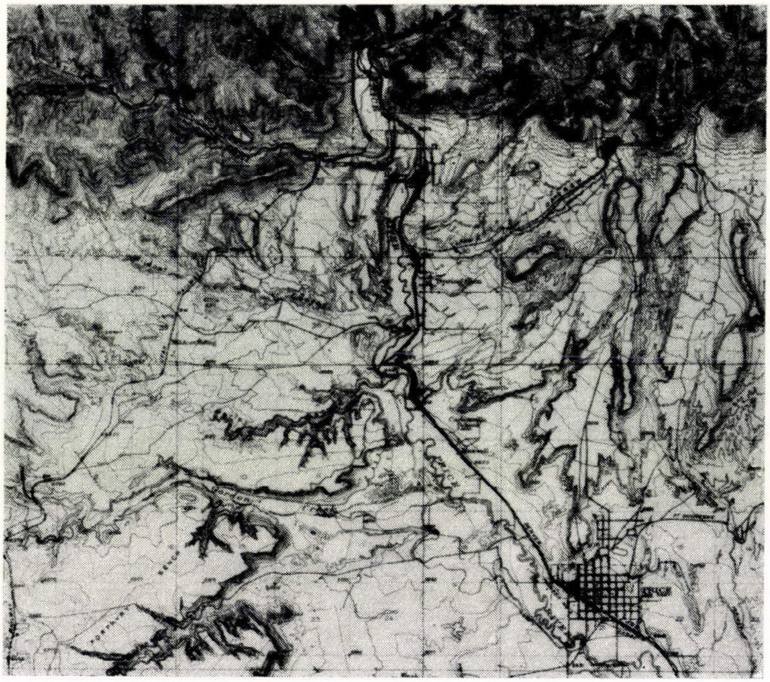


Fig. 20. Book Cliffs, Utah; from *U.S. Geol. Survey*, Castle Gate 15′ quadrangle

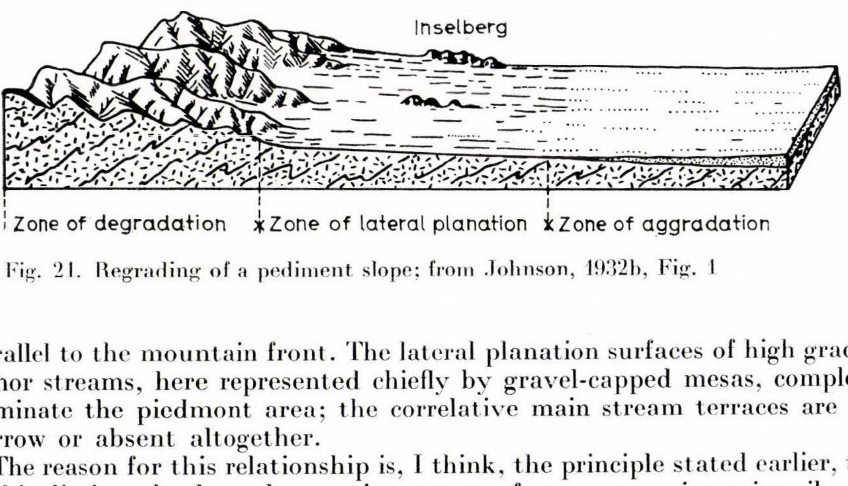


Fig. 21. Regrading of a pediment slope; from Johnson, 1932b, Fig. 1

parallel to the mountain front. The lateral planation surfaces of high gradient minor streams, here represented chiefly by gravel-capped mesas, completely dominate the piedmont area; the correlative main stream terraces are very narrow or absent altogether.

The reason for this relationship is, I think, the principle stated earlier, that, within limits, the lateral corrasive power of streams varies primarily with slope; the low-gradient Price River has opened out only narrow valley floors during the same period, in the same rock, when its high-gradient, ephemeral tributaries have cut extensive planation surfaces, even though their average annual discharge is many orders of magnitude less than that of the Price River.

The relations of the Price and its tributaries is by no means the end of the series. Such low-gradient main streams as the Clark's Fork of the Yellowstone and the Rio Grande in New Mexico and along the Mexican border are edged by extensive planation surfaces wholly or dominantly of side stream origin; in many places the main stream is overlooked directly by terraces cut by its tributaries.

Figure 21, published by D. W. Johnson (1932b) to illustrate his concept of regrading of the pediment slope, so that degradation in a zone near the mountain front may accompany aggradation farther out, is intended to remind us that this paper deals only with pediments formed relative to stable or slowly lowering base level; the whole class of special features associated with the rising local baselevels that characterize much of our Great Basin is not considered here.

Other major aspects of the pediment problem that have not been mentioned in this paper include (1) the effects of retreat of the mountain front in uniform rocks; (2) effects of rising baselevel; (3) the high-level Pliocene pediments of the Rocky Mountains.

In closing, let me say again that what is presented here is what I think is the general consensus in America. It is obvious that there is much yet to be learned.

CLIMATOMORPHOLOGY AND PALAEOCLIMATES OF THE CENTRAL EUROPEAN TERTIARY

by

J. F. GELLERT

1. PENEPLAINS AND INSELBERGS IN CENTRAL EUROPE AND IN THE TROPICS

There has been for some decades a consensus which attributes the origin and evolution of peneplains in the low mountains of Central Europe and of the adjacent regions to a hot humid climate, similar to the climates of many tropical regions of today. This has been justified in a variety of ways. For instance, the valleys dissecting the low mountains of Central Europe, and lending them their mountainous relief in the first place, are accompanied, as it has been proved again and again, by Quaternary terraces up to quite considerable elevations, which proves the peneplains into which they are incised to be older, i.e. Tertiary. On elevated planes in the mountains proper there were observed long ago kaolinite-bearing deposits, a chemical weathering similar to that beneath the Tertiary soft coal deposits whose florae indicate a hot humid tropical climate. Even today, kaolinitic weathering and kaolinite-bearing deposits on peneplains are considered important evidence as to the climatic conditions at the time of peneplanation and indeed as sufficient proof that we are dealing with the remains of a peneplain. This view has its origin in observations made in the peneplain and inselberg regions of the actual tropics, where there are surfaces of planation on top of geological structures, with profound chemical weathering and repeated slopewash as a result of tropical showers. The interplay of these processes, emphatic in particular under semihumid climates with alternating wet and dry seasons, has lately been described in particular by Jessen (1936) and Büdel (1952, 1957a).

One of the typical features of these tropical peneplain landscapes is the presence of inselbergs sitting on these surfaces more or less transitionless, often with a marked, abrupt break ("knick") at the feet of their slope. The term inselberg was coined by W. Penck (1924) in his description of the Franco-Saxonian piedmont treppe, after the residual hills sitting on the lower surfaces in front of the piedmont steps, partly engulfed and even buried by the Tertiary deposits of the Leipsic embayment, which had been pointed out already by his father A. Penck (1887). It was on these grounds that the present author (Gellert, 1931, 1967a) interpreted the hills in the foreland of the Sudetes in Central Silesia, rising singly or in groups above rock surfaces or Tertiary or Quaternary alluvia, as tropical inselbergs in their aspect as well as in their relation to the pre-Neogene kaolinisation at their buried feet, which indicates a hot humid tropical climate. The base of these inselbergs lying in front of the Saxonian and Silesian mountains was correlated by Büdel (1934) with the elevated surfaces in the summit region of the Erzgebirge, likewise dated tropical early Tertiary on the basis of overlying Oligocene sands and gravels and sparse remains of kaolinitic weathering. Herz (1954), who made a detailed study of the lone hills in Northeast Saxony, and H. Richter (1963) have also rightly persevered in considering these lone hills and rises as Tertiary landscape forms (residual hills). A comprehensive morphologic examination of the hilly region of Niemcza in Central Silesia by Pernarowski (1963) gave results pointing in the same direction. Krebs (1942) and lately H. Richter (1963) have, however, pointed out certain differences between the forms of the inselbergs of Northwest Saxony and Central Silesia on the one hand and on the other the classic inselbergs as they appear in the semihumid tropics and semiarid subtropics with distinctly separate rainy and dry seasons of Africa and the Indian sub-continent. Classic inselbergs mostly have steep flanks with usually an abrupt knick between the foot of the slope and the gently sloping footplane, due to rapid weathering and slopewashing of the scree, whereas the Tertiary inselbergs of Central Europe most often possess, as has been observed already by Büdel and described by W. Penck, a flat-concave or flat-convex-concave slope profile. The typical knick of the tropical inselbergs is only rarely developed on the Tertiary inselbergs of Central Europe. Another remarkable feature is that the slopes of the latter are less steep by some 10° than those of the classic inselbergs of the tropics. This has raised the problem of the true morphological nature of these Tertiary residual hills, which can be solved only in the light of the climatomorphological conditions of their origin and of the climate and weathering in central Europe at the time under consideration.

2. THEIR COINCIDENCES AND DIFFERENCES

Just as the classical inselbergs of Africa and other tropical regions, the early Tertiary residual hills and rises of Central Europe, characterized as tropical inselbergs by W. Penck and others, can be classified according to the pattern established by K. Kayser (1957) on the basis of his observations in Northeast Transvaal and Rhodesia. Accordingly, the lone hills and rises in Northwest Saxony belong largely to the category of zonal foreset inselbergs ("zonale Vorgebirgs-Inselberge") of a pediment step in the sense of W. Penck and Herz, whereas many Silesian inselbergs belong to the hard-rock (Härtling) class of "azonal granite inselbergs" or "structurally controlled inselbergs". It is important to note in this connection that even in the semihumid and semiarid regions of the tropics there occur straight and slightly concave inselberg profiles and that in the mountain masses connected with the inselbergs there are scree-covered slopes somewhat less steep than on the inselbergs, sometimes with a less abrupt knick towards the piedmont plane than is attributed to classic inselbergs (Jessen, 1936; Gellert, 1967b).

An analysis of the set of forms and of the origin of inselbergs in the semihumid and arid regions of Africa, carried out by the present author on the basis of relevant literature and his own observations, has revealed that the inselbergs of the semiarid and arid zones e.g. in Southwest Africa (Gellert, 1967b), with their broken profiles and steep slopes, are to be considered polygenetic–polycyclic forms which, originated initially under a semihumid climate with alternating dry and wet seasons, profound chemical weathering and intense slopewashing in the Jessenian (1936) and Büdelian sense (1952, 1957a) and gained their present form under a semiarid or arid climate with dominant mechanical weathering and *shockwise* slopewashing. This morphographic and morphogenetic difference between semihumid tropical and semiarid subtropical inselbergs in the sense of Krebs (1942) once more raises the problem of the climatomorphologic type of the early Tertiary inselbergs of Central Europe. To answer this question, it is necessary first of all to have a clear-cut idea of the type of weathering brought about by the hot humid early Tertiary climate whose influence produced the fossil inselbergs of Central Europe and the peneplains to which they are connected.

3. THE TERTIARY CLIMATES IN CENTRAL EUROPE

It was first and foremost Jessen (1938) who put forward in formulated detail ideas concerning the Tertiary climate which so deeply affected relief evolution in Central Europe, on the basis of his experience with tropical peneplain and inselberg regions plus some recent advances in lithology. He assumed for both the Eocene and the Upper Oligocene–Miocene a hot semihumid climate with alternating wet and dry seasons of the Aw type, with a drier semiarid climate of the BShw type intercalated in the Lower and Middle Oligocene. Bakker concluded (1964) from the mineralogical evidence concerning weathering (clay minerals in particular) upon an alternation of hot arid and hot humid climates (BShw–Aw) in the Palaeocene and Eocene of Central Europe and, indeed, upon a humid tropical climate (Af) for the Upper Eocene, succeeded by another alternation of hot arid and hot humid climates in the Oligocene, with another extremely hot humid tropical episode (Af) at the end of the Oligocene. It is in a similar manner that he inserted into the essentially semiarid (BS) climates of the Miocene a Helvetian episode of humid tropical climate. Bakker (1964) proved these hot humid Af- and Aw-climates with alternating dry and wet seasons, currently restricted to the tropics, to be connected in Africa and other tropical regions with the formation of kaolinite (K) or kaolinite plus illite (Ki), thus confirming the conclusion that kaolinite in the Central European Tertiary indicates hot humid or alternatingly dry and humid climates for the time span in point.

This conclusion concerning the Tertiary climate of Europe is obviously restricted to the averages of temperature and humidity: it will not provide any information as to the morphological efficiency of the weather conditions or as to the weather dynamism which controlled it. In particular, nobody has ever postulated a geographical position in tropical latitudes for Central Europe in the Tertiary. It is consequently not admissible, either, to speak about a tropical climate in the strict sense of the term in connexion with the early Tertiary of Central Europe. On the contrary, all evidence goes to prove that Central Europe occupied then as today a position in middle latitudes. This means, however, that the dynamism and nature of the weather could not correspond to those of the tropics of today, e.g. to the Koeppen–Flohn types Af/TT or Aw/TP, but to a climate of middle latitudes controlled by extratropical west winds (Gellert, 1958a). This Tertiary position of Central Europe, fundamentally identical both in its relation to latitude and to planetary circulation with the position it occupies today, is proved and specified by the presence of saline deposits in Southern Europe and to some extent also in southern Central Europe. They indicate a hot arid zone corresponding to the actual Saharan zone south of Europe. Flohn's (1964) theoretical climatological considerations have led him to a similar result, on the basis of which he constructed a model of planetary circulation for the non-cryogenic climates of the late Mesozoic and the early Tertiary. He computed therefrom, disregarding the oceanic exposure of Europe which was operative even then, for latitudes up to 50° N a subtropical arid zone with mean temperatures from 20 to 26 °C and for the adjacent latitudes up to 65° N a subtropical zone with winter rains, with mean temperatures from 15 to 22 °C. This means that on this ancient "tropical Earth" without glaciated polar caps, Central Europe had a climate of PW type, similar to that of the present Mediterranean, but with far higher temperatures, similar to those recorded today under the Aw climates of the Sudan, on the Lunda Rise and in southernmost China. Observation of the actual PW climate with winter rains in the Mediterranean suggests the winter rains of early Tertiary Central Europe to have often been fairly stormy, entailing shockwise ablation.

This is how the early Tertiary climate of Central Europe, deduced from geology (kaolinitic weathering, vegetation and fauna) and theoretic considerations could—with the exception of winter rains as the main precipitation—in effect resemble the actual periodically humid, semihumid and semiarid climates of regions where climato-morphological processes favour the development of peneplains and the types of lone hills which are generally known as inselbergs.

4. THE TERTIARY INSELBERGS OF CENTRAL EUROPE IN A SEMIHUMID CLIMATE WITH WINTER RAINS

The placing of the early Tertiary inselbergs of Central Europe into the frame of reference of an early Tertiary climate with winter rains whose temperatures and yearly total precipitation quantitatively equalled those of the actual semihumid tropics opens up the possibility of attributing the differences in form between the inselbergs of the actual tropics and even more of the subtropics and the early Tertiary inselbergs of Central Europe, in particular the gentleness of slopes, to differences in the character of the weather in the early Tertiary winter-rain regions of Central Europe, whose dry season between winter rains was less marked than in the actual semihumid and arid tropics with alternating dry and wet seasons and whose irradiation was less intense owing to the higher latitude. It is not at all impossible that under the above-outlined conditions the slopes of inselbergs could not attain the steepness they feature in the actual tropics with a season of extreme drought between rainy seasons and extremely intense irradiation, in particular in the semiarid and arid regions, plus shockwise ablation. The lower relative altitudes of lone hills and rises in Northwest Saxony and also in Central Silesia are furthermore due, apart from these factors, to the structurally preformed lesser height of the piedmont benches from which these forms are etched out as "zonal foreset inselbegs". Only the hard-rock type inselbergs, e.g. the Oschatzer Colm in Northwest Saxony and the Sleza in Central Silesia, have lithologically determined heights comparable with those of the tropical inselbergs. The remodelling of early Tertiary inselbergs in Central Europe by the Scandinavian ice sheet is estimated by all authors to have been rather subordinate and cannot therefore be made responsible for their overall form. The early Tertiary inselbergs of Central Europe have shapes, determined by their latitude and the dynamism of weathering, that differentiates them from the classic tropical and subtropical inselbergs without, however, robbing them of the character of inselbergs emerging more or less abruptly from a peneplain.

5. CONCLUSION

This result of a climato-morphological and palaeoclimatological consideration and analysis suggests that a climato-morphological form analysis, especially of the more ancient forms of the relief, should take into consideration, to a much greater extent than has been usual thus far, besides the climatic parameters revealed by lithologic examination, also the dynamism of the climate and the resultant character of the weather in the relevant geohistorical period.

THE ORIGIN OF GLACIS

by

B. DUMAS

Pediment and glacis evolution is a problem much discussed by American geomorphologists with large area available for study in the western United States, as well as by French geographers who have tended to focus their efforts on North Africa (Dresch and his pupils), on the Sahara (Birot, Coque and others), on the Middle East and Spain.

Many difficulties could have been avoided if all authors had consistently used the same terminology. There are, however, two terminologies in current use:

(1) The Anglo-American terminology which means by pediment all plane forms of slightly concave longitudinal profile and of gentle slope, irrespective of whether they are modelled in hard rocks such as granite, gneiss or limestone or in soft rocks such as clays or marls.

(2) The French terminology, recently proposed, which restricts the term pediment to forms developed over a coherent wear-resistant rock mass (gneiss, limestone). Similar topographic forms modelled in unconsolidated or little resistant deposits in place are called glacis.

The present paper is concerned solely with glacis, and the interpretation of their evolution. The line of thought below is based on observations made by the author in Eastern Spain, in the rich coastal region between Valencia and Murcia. The glacis which have developed in the depressions of this region are not less remarkable than those of the Western United States or of North Africa.

The study of these forms has led us to the following conclusions:

(1) A glacis profile generally includes two elements of different origin:

(a) a piedmont glacis which is the dominant feature in areal extent,

(b) slope glacis of much more limited areal extent, upslope from the piedmont glacis.

(2) The process modelling the piedmont glacis is lateral sweep by peak flow-offs.

1. FIRST CONCLUSION: THE AREAL DOMINANCE OF FLUVIALLY MODELLED GLACIS

The general profile of the glacis and the surface which corresponds to it have so far erroneously been considered a single coherent entity. This assumption, wrong in particular as regards the upper reaches of glacis, has led to no end of misunderstanding. The author's analysis of the glacis of eastern Spain has led him to make a fundamental distinction between piedmont glacis, on the one hand, and slope glacis upslope from the piedmont glacis, on the other: these latter represent the transition between the piedmont glacis and the structural reliefs even farther upslope (Dumas, 1966a).

(A) ELEMENTARY PIEDMONT GLACIS AND THEIR COALESCENCE INTO A SINGLE GLACIS DOWNSLOPE

These forms derive without exception from the coalescence of a chain of elementary glacis fans whose general outlines much resemble those of a very flat alluvial fan. It is these glacis fans that make up the vast glacis surface which extends over many kilometres, both lengthwise and across. In the regions of Jumilla and Yecla near Villena, all depressions in soft rocks are modelled into glacis, except the diapirs of the gypsum- and salt-bearing Triassic which are active up to this day.

These piedmont glacis are perfectly preserved by cappings of calcareous crusts analogous to American caliche, which plays the role of a hard rock as far as resistance to erosion is concerned.

Not all the elementary glacis fans which form the integrated piedmont glacis can invariably be recognized. These glacis, merging into the reliefs upslope, define "embayments" of triangular form, whose upslope tip sometimes penetrates into the hard rocks of the structural relief.[1]

Downslope, these elementary glacis coalesce quite rapidly. Upslope, their tips invariably merge into ravine bottoms. In summary, elementary glacis divide upslope and coalesce downslope.

These elementary glacis can no more be distinguished once their radii have intersected, that is, where the individual cones do not merely lie side by side but overlap more and more as one progresses downslope (Dumas, 1966b).

There are as many elementary glacis as there are embayments which dissect the structural relief upslope. The relative importance and the spacing of the ravines incised into this relief in prolongation of the tips of the elementary glacis are highly variable, however.

In some instances, there are ravines of considerable drainage area joining drainage organisms of the first order (in Horton's terminology). The elementary piedmont glacis which belong to them constitute a hierarchy of many levels. If the mouths of the big ravines are sufficiently far apart, there come to exist on the flanks of the depressions veritable glacis cones particularly conspicuous in their upslope portions. The general transverse profile then takes the shape of an inverted garland with a convexity corresponding to each glacis cone.

In other instances, ravines are close-spaced and of moderate size. The elementary glacis which issue from them are of a comparatively slight importance. The transverse profile of such a set of elementary glacis is much

[1] It was D. W. Johnson (1932a) who after G. K. Gilbert (1877) first emphasized their geomorphological importance.

smoother. This type of glacis should not, however, be opposed to piedmonts where the glacis cones are sharply distinct: both belong to the same generation of forms.

(B) SLOPE GLACIS UPSLOPE FROM THE PIEDMONT GLACIS

Between the upslope tips of the elementary glacis there are slopes which have been classed, by many authors, with the piedmont glacis, but which merge into rock ledges in the case of "frontal glacis" and to the reverse sides of cuestas in the case of "reverse glacis".[2] Their profile simulates a continuation towards the structural slopes of the piedmont glacis, although these latter merge, as we have shown, into the ravine bottoms.

These glacis slopes are genetically distinct from the piedmont glacis. They bear a colluvial cover of varying thickness, reduced in some instances to a few pebbles. There are two main types according to whether the glacis slope is sculptured in hard or soft rock:

In soft rock, a colluvial cover will smooth out the fluctuations, if any, of the rock surface: we have here a case of simple topographic matching of slopes which takes care of transitions between fronts, tilted structural slopes, fault scarps or flexures on the one hand and the piedmont glacis on the other. In short, these matchings between slopes come about by means of a detrital veneer which joins the structural reliefs upslope to the piedmont glacis in the depressions.

In hard rock, the colluvial cover is invariably just a thin veneer. The transverse profile is convex rather than flat. These slopes are simple matched divides between two adjacent tips of elementary piedmont glacis. The concavity of their longitudinal profile is strongly emphasized. There may be a break ("knick") marking the line of contact between the slope glacis and the elementary piedmont alluvial glacis.

Slope glacis cover an area insignificant as compared with that of the piedmont glacis and their evolution follows the general laws of slope evolution. It is at their bases that the elementary piedmont vial glacis begin to overlap.

On the other hand, the areal extent of the piedmont glacis of fluviatile origin is quite considerable.

2. SECOND CONCLUSION: GLACIS ARE MODELLED BY THE LATERAL SWEEP OF PEAK FLOW-OFFS

The morphogenetic role of fluviatile-type water flow is incontestable since the elementary piedmont glacis obviously emerge from the ravines incised into the structural relief upslope. Contrary to the slope glacis which merge into the structural relief, the piedmont glacis penetrate more or less profoundly into the mountain mass, to blend into the bottoms of the ravines from which they issue.

[2] Terminology proposed by Dresch (1957a).

Sometimes piedmont glàcis form upslope over the soft-rock border of a hilly region and are modelled in the same soft rock. The elementary glacis then depend on the valley bottoms which dissect these hills. This topographic layout divides up into three geomorphologic domains:

(1) an impluvium with its drainage area in the hills,

(2) a concentration of run-off in the valley bottoms between hills,

(3) the lateral sweep of flow-off which controls glacis formation downslope.

Even if the relief upslope from the glacis is just a mountain root, it will be surrounded by glacis slopes. These are in turn surrounded by piedmont glacis, provided the precipitation, which falls mainly onto the glacis slopes, is of a sufficient quantity. The streams which dissect them concentrate the run-off and pour it onto the piedmont glacis.

Farther downslope, the fluviatile-type flow-off sweeps the entire piedmont. The sweeps of the individual flows tend to overlap, so that the waters of different drainage areas, all, of course, coming from the same upslope relief, will often cross at one or several points of the glacis in the process of evolution. It is this overlap of the sweeps which brings about the coalescence of the elementary glacis into a single piedmont glacis.

It is the increased downslope of the sweep amplitude that makes the transverse profile of the integrated piedmont glacis so flat. The concavity of the longitudinal profile is due to exactly the same causes in the case of piedmont glacis as in that of river beds. It is, then, by lateral planation that fluviatile sweep sculptures a glacis of erosion (or of ablation).

There are two circumstances proving the connection between lateral sweep and its alluvial deposits and lateral planation which entails the flatness of the glacis of erosion:

(1) The bedrock is brutally truncated without any visible weathering.

(2) Peak flow-off guirlands which can be identified by their characteristic arrangement and by the presence of very big allochthonous boulders which must have been transported and deposited by violent floods: they directly overlie the bedrock, as in river beds. The planation which has sculptured the glacis of erosion is a result of the lateral displacement of the axes of fluviatile-type organisms. This translation does not, however, necessarily imply the continuity in time of the flow-off.

There are two possible cases, depending on the configuration of the base of accumulation:

(1) In the zone of transition between the tips of the elementary glacis and the overlaps where the integrated glacis begins, the ground surface is a glacis of accumulation which masks and fossilizes ravines previously incised into the soft bedrock. In certain instances there are veritable "badlands" buried under the deposits of the elementary glacis. The intensity of this fossilized uneven relief invariably decreases downslope. The fill had first risen in the ravines before overflowing their walls. The dynamism of incision which invariably dominates the relief farther upslope influences also the upper portion of the piedmont and is but gradually attenuated downwards.

(2) Beneath the integrated piedmont glacis there is a flat base of accumulation. This is called a covered glacis. It is superposed onto a glacis of erosion which is the result of lateral planation and which is of limited efficacity. Lateral planation

is impossible if the stream beds are too deeply incised. This is why the surface of the lower reaches of a glacis of erosion tends to be flat in the transverse sense because the incisions, if there were any, could by no means be too deep here.

3. GENERAL CONCLUSIONS

In both cases, the arrangement of the accumulated deposits confirms the fluviatile origin of the glacis. Flow-off is an azonal morphogenetic agency. One should, then, encounter glacis in the cool temperate regions of today as well as in the tropics or in the Mediterranean arid and semiarid zones, or in regions with a temperate or hot continental climate. As a matter of fact, however, the formation of glacis is restricted to the geographic limits of the four last-named morphoclimatic regions.

Indeed, glacis are not exclusive feature of this or that morphogenetic system. It is futile to ask whether they belong to the periglacial or the semiarid system, for instance, or to attempt to suit the geographical boundaries of the relevant palaeoclimate to the recorded occurrences of glacis.

Glacis are due exclusively to lateral sweep by episodes of peak flow-off. The bio-climatic conditions required to permit the interplay of these flow-offs are of three sorts:

(1) Absence or discontinuity of the vegetal cover (the temperate and tropical forest seems to be an unsurmountable obstacle: the light Mediterranean woods are less intractable).

(2) Violent and spasmodic precipitation giving rise to peak flow-offs (and peak loads of waste) and lateral sweep by the flow-off directly at the foot of moderate relief with light rainfall.

(3) A certain tendency of accumulation, due to the large volume of disposable waste liberated by various agencies of comminution and weathering acting upon the relief.

Accumulation tends to raise the stream beds and thus promotes lateral sweep.

Lateral mobility is a result of the discontinuity in time of flow-off and of the tendency of the stream beds to overfill. Its consequence there is a discontinuity in space: instead of generating a fixed linear stream bed, flow-off sweep generates a flat surface. This surface is the glacis.

THE PROBLEM OF PEDIMENTS AND MORPHOTECTONICS

by

M. V. PIOTROVSKY

1. INTRODUCTION

The problem of pediments is strictly speaking the problem of the evolution of the system "slope-and-pediment". The latter problem in its turn is part of a broader one—that of "slope-and-foot surfaces".

This article considers the mechanism of slope retreat, the formation of pediments by denudation, and the preformation of pediments and foot surfaces by block tectonics. Some information on the study of pediments in the USSR is also given.

The above-mentioned systems are of various origins and have various geological structures. However, their elements have—even on different continents and in different territories—remarkably similar features. This similarity shows that these forms develop according to the same general laws of the graded profiles of streams and slopes.

Real pediments are planation surfaces formed by denudational slope retreat under various climates, not limited to desert pediments only.

2. FORMATION OF PEDIMENTS

From the very beginning, real pediments develop entirely by denudation according to the laws of graded profiles. The retreating slope can be initially a fault scarp or the side of a valley dissecting any uplift. Pediments will develop below these slopes provided the latter have a relatively stable baselevel of denudation. Such a base may be a subsided block below a fault scarp or the bottom of a graded valley.

The dominant element in the mechanism of slope retreat is, in the author's opinion, the undermining of slope foot. This is caused by the saturation of the slope feet with water flowing down over the slopes and through their scree cover. This flow maintains a permanent or semi-permanent horizon of ground water in the waste sheet along the foot of the slope. This moisture intensifies weathering and causes an abrupt increase in the mechanical mobility of the waste sheet. Increase in mobility is aided by the subsurface downwashing of clayey material. This material accumulates in the lower part of the waste profile and, becoming oversaturated below the ground-water horizon, it serves as a lubricant of the coarser material.

In this manner the slope foot becomes a zone of undercutting. In Russian this zone can be named by the miners' term "zaboy"—"the working face".

The characteristic stages and forms of retreating slopes are the following: a non-graded rock scarp of maximum inclination (more than 30°), a scree slope of straight profile about 30° (often crowned with remnants of scarp), and a "residual" slope, straight or slightly concave (18 to 22°), usually strewn with remnants of scree. The latter slopes often have "pedestals" of 8–10°. Pedestals are the initial forms of pediments. Their waste sheet is usually in blocks, boulders and rock fragments which creep down the slopes. On the pedestals, this coarse material undergoes further weathering to finer fractions. The lower edges of the pedestals may be bordered with mature pediments of straight or slightly concave profile (about 2 to 5°). In humid climates, mature pediments have a waste sheet 1 to 3 m thick, consisting usually of loam and sandy loam with rock debris.

The evolution of these forms can be described as follows. In the first phase, the foot of the slope retains its initial position. The mechanism of undermining is operative but it "makes no headway". It merely transmits the coarse material creeping in abundance down the scarp and scree slope. Within the ground-water horizon the angle of repose of the talus decreases abruptly to 8 or 10°; this talus then begins to slide, forming small ephemeral landslides with ledges and niches 1 to 2 m high. Undermining thus removes the foot support of the talus and intensifies its creep. The creeping mass will obliterate again and again the landslide ledges. This repeated burying of the zone of undermining does not permit strongly weathered bedrock material to slide ahead. If no displacement of the undermining zone can take place, the scarp becomes progressively gentler and turns first into a scree slope, then into a residual slope. When the residual-slope phase is attained, the amount and coarseness of the creep mass decrease enough to permit the gradual undercutting of the bedrock at the foot of the slope. The slope then begins to retreat and acquires a rock pedestal. Thus the foot of the slope becomes "the pediment angle". But undermining again intensifies creep on the slope, and this creep automatically stops the further migration of the pediment angle. Migration starts again when creep becomes somewhat weaker. In this way the pediment angle and the "residual" slope retreat together. This slope keeps its characteristic declivity until there is a complete obliteration of the hill. Really parallel retreat is restricted to residual slopes. At this stage the watersheds acquire a characteristic "residual" appearance and further become separated into isolated remnant hills. Therefore the term "residual" is aptly chosen for this stage.

As the slope retreats, the transit of coarse material towards the lower parts of the pedestal gradually diminishes. Then denudation begins to remove not only the waste sheet but also the bedrock and transforms the edges of the pedestal into mature pediments. Hence pedestals retreat together with the slopes, keeping their width of about 300 to 400 m.

Thus slopes, pedestals and pediments appear as a balanced self-regulating system. The profile of this system is graded automatically and maintained that way by the downslope movement in various proportions of products of weathering and water. During the evolution of such a system, its dynamic equilibrium progressively shifts towards diminishing indices. These principles were clearly expounded in "The Geographical Cycle" by W. M. Davis (1899), a great pioneer of the concept of self-regulating natural systems. L. C. King is absolutely wrong in saying that pediment formation disproves the Davisian concept. On the contrary, pediments are the best expression of and proof for Davis's general idea of graded relief profiles and their self-regulation.

The principal outlines of pediment formation were correctly laid down in W. Penck's scheme of waning development of the relief. Penck pointed out that a moisture content increasing downslope results in an increased mobility of the waste-sheet. But he believed this increase to be gradual and failed to perceive the mechanism of undermining; this is why he could not fully explain the parallel retreat of slopes. The principle of undermining by ground water was proposed much later by P. Birot (1949).

During his investigations in 1961 in the Aldan region, the author independently reached conclusions similar to those of P. Birot. Moreover, he noted some additional features due to the presence of permafrost which explained the evolution from scarp to residual slope as described above.

The above discussion has been concerned with the humid type of pediment formed by an interplay in various proportions of creep and fluvial processes. The Siberian or permafrost type distinguished by D. A. Timofeev also belongs to the humid types. Its rock scarps are being destroyed mainly by cryofraction and the ice-wedging of fissures, causing slides of rock blocks. Cryogenetic processes, effective also on the residual slopes have been little studied so far. Their main outlines are as follows.

The main process of transit is "slow solifluction", i.e. permafrost creep, but fluvial processes are also present. Subsurface wash on the slopes and pedestals, continuing through the scree, concentrates especially along the stone strips. On mature pediments with a loam cover, this wash erodes the bare soil in the frost fissures and mud spots. Undermining is highly active. Permafrost causes the ground water to appear at the foot of the slope even though the latter is in contact with the alluvium which is impermeable since it is frozen. The waste-sheet of the pedestal, thus abundantly wetted, undergoes continuous cryoturbation. This creates an uneven microrelief with frost fissures which intensify infiltration and the wetting and creep of the waste sheet.

Solifluction and subsurface wash on the one hand, linear erosion and sheet wash on the other, join forces in cryogenetic dells, the most typical feature of mature Siberian pediments with loam sheets up to and more than 3 m thick. These dells are long hollows with slight to inconspicuous relief, but more swampy than the inter-dell strips. Dells follow exactly the lines of steepest descent, forming peculiar parallel and subparallel patterns perfectly recognizable on airphotos and much different from the branching patterns of normal erosion ravines. These dells somewhat concentrate flow-off but their erosional incision is limited. Larger dells do not, in contrast to erosional ravines, digest and behead the minor ones. Recent investigations have revealed these dells to migrate laterally. Although cryogenetic dells are extremely widespread, the mechanism of their evolution has not yet been sufficiently studied. Apparently the concentration of water along the dells intensifies the cryofraction of material to the silt fraction. Furthermore, K. L. Mitt (1959) attaches a great significance to subsequent fluvial wash in the dells. A. I. Popov (1959) attributes the same role to intensified solifluction along dells.

Wherever the soils on Siberian pediments contain much ice, the concentration of surface waters or the destruction of the plant cover can result in an intensive melting of ground ice and in subsequent thermofluvial erosion and thermokarst. These processes will develop very fast and in a self-intensifying manner insofar as they cause a progressive concentration of surface water in the hollows.

In Siberia, pediments usually form the main parts of so-called "terrasouvals". In Russian geomorphological terminology, an uval is a smoothed height without a definite foot line; in popular language it also means a gentle slope, especially a foot slope. The term "terrasouval" has been proposed by explorers of the Kolyma region, to emphasize the presence of alluvial terraces on such slopes. Terrasouvals have the appearance of valley pediments, often with slightly stepped lower edges. These edges can really be terraces sculptured by the lateral migration of streams. I. P. Kartashov proposed all terrasouvals to be river terraces, coalesced and modelled into a uniform slope by mass wasting processes (see also his contribution to this volume). We may well believe it to be the prevailing type in parts of the Kolyma region explored by I. P. Kartashov. But over wast territories of the Eastern Siberian Highland, the Transbaikal and the Urals, terraces form at most one third of the whole width of terrasouvals which ranges from about 100 m to 1 km and more. The rest is pediment cut in rock and covered with a thin veneer of waste. Remnants of pre-Quaternary weathering products are also occasionally found. In several regions, terrasouvals widen downstream into vast pediplains. The ages of the pediments and of the oldest alluvia contributing to the terrasouvals vary in different regions from Quaternary to Palaeocene (indeed, even Upper Cretaceous). The characteristics of the terrasouvals: their dissection, gradual rejuvenation, burial, etc. depend on the particular history of the relevant region. For instance, in permafrost regions cryogenetic dells are typically developed.

All the features described above have been thoroughly studied in the USSR in connection with the prospecting and mining of placers.

The author has not personally studied desert pediments. Apparently, the main factor of their formation is erosion by heavy downpours. The main element of the slope retreat mechanism may be the undercutting of slopes by perennial streams on the peripheries of proluvial cones. But probably this process may be extremely intensified by a weathering mechanism at the pediment angle described above. The presence of such weathering in deserts, semideserts and savannah regions has been established (Ruxton, 1958; Twidale, 1962). Also, early photographs of the pediment angle, made by W. M. Davis (1938) in the Arizona desert clearly show the absence of traces of lateral erosion by valley streams.

3. THE ROLE OF BLOCK-FAULTING IN THE FORMATION OF SLOPE-PEDIMENTS AND SLOPE-FOOT SURFACES

The mechanism of denudational slope retreat is sufficient in itself to form pediments. But even real pediments and slope-foot surfaces will survive and acquire contrasting steep and gentler slopes owing to other agencies. In an erosional relief, we have the contrasting valley slopes and river profiles; in a block-faulted relief, there are the fault scarps and the gentler relief on top of sunken blocks.

Block faulting may play various roles in pedimentation. Firstly it may increase the rate of slope retreat. Existing estimates vary widely and observations are contradictory; this rate obviously varies over a broad range. One of the main relevant factors is fault density and the intensity of the neotectonic rejuvenation of the fault pattern. Slopes coinciding with fracture zones will retreat very fast by a "slicing" of rocks along joints. This situation is quite common since valleys usually develop along fracture zones. When slope retreat emerges from such zones and enters the more solid blocks, the rate of retreat decreases abruptly. The patterns of residual hills and pediments formed in this way have the aspect of a denudational relief adapted to a block-faulted structure.

A process much more important, however, is the direct preformation of slope-pediments and slope-foot surfaces by block movements. The explanation of these forms is based on a scheme given by W. Klüpfel (1926). Klüpfel distinguished uplifted blocks forming mountains, subsiding ones, forming the depressions of accumulation, and intermediate oscillating blocks with "Schachtelrelief". In the latter the different surfaces of denudation and accumulation converge and often coalesce. These surfaces are of exogenic origin but the entire relief is a system of slope-foot surfaces preformed by block faulting. A fair example of this kind of relief is provided by the mountains, pediplains and depressions of the Lower Amur basin. Here, the boundaries between pediplanes and mountains have remarkable zigzag courses. W. Penck suggested that such boundaries were the results of erosional dissection and slope retreat rather than faulting. Now it is clear that in many cases (in the Amur basin in particular) these zigzags are typical results of block morphotectonics. Their general course is controlled by great complicated fault zones and their zigzags by intersecting faults and fracture zones.

Extensive piedmont surfaces are usually complexes of relatively low-lying blocks including pediplanes, blocks with "Schachtelrelief" and parts of depressions slightly uplifted after subsidence. Parts of such systems can have the structure of uplifted mountain blocks, bearing remnants of the same planated surfaces. Other parts may be covered with young deposits: proluvial, alluvial, lacustrine and marine. It is possible to reconstruct from the surfaces of such variously displaced blocks a single common preceding foot surface provided they have a common graded profile. Such a profile will develop during periods of relative rest. If the surfaces of the blocks bear young non-resistant deposits (Tertiary sands, clay, argillites, etc.) the graded profiles and new surfaces of planation will develop very fast. Graded profiles may be partly due to aggradation (Mandrych *et al.* 1968, Makkaveev, Berkovich *et al.* 1968, Makkaveev, Mandrych, and Chalov, 1968).

The piedmont surfaces usually penetrate into the mountains in the form of branching valley pediments which can be denudational ones but often are "tectonopediments". This latter type of form may develop also within the mountains, independently of foot surfaces. The concept of tectonopediment was developed by the author, but the term was proposed in 1964 by the geomorphologist M. M. Surikov. The term "block tectonic pediment" would be more exact but in Russian it is less suitable.

Tectonopediments include block steps in block-faulted valleys, inclined and having the appearance of typical pediments. Their mosaic patterns are, however, unlike those of denudational valley pediments: their longitudinal profiles are also broken by block displacement. Increase of steepness in the lower reaches of a slope due to the rejuvenation of the faults and abrupt changes in the thickness of the veneer of loose sediment on a pediment also point to the structural preformation of the latter. Being structurally preformed, these forms subsequently undergo a denudational grading. Their upper parts widen by slope retreat, i.e. go on evolving as real pediments.

The excursions of the Symposium in Hungary and the subsequent trip to Czechoslovakia were most interesting and instructive. We could observe many examples of piedmont surfaces whose main features were preformed essentially by block faulting. Here the upper levels of the relief are old planated surfaces; the lower pediplane-like levels are subsided blocks mostly covered with Cenozoic continental and marine deposits and modified by erosion and slope wasting. The graben valleys of the Moravian massif, partly filled with Cenozoic deposits, are good examples of another related form of relief. They are similar to the tectonic valleys of the Amur basin, the Transbaikal, Aldan region and Stanovoi ridge.

In conclusion it is in place to offer some information as to the study of pediments in Russia and the USSR.

Pediment relief in Russia and the USSR was described by many explorers. But it was only about 15 years ago that the term pediment and the problem of pediment development entered Soviet literature to any significant degree.

In 1932 V. A. Varsanofieva described the multilevel relief of the Northern Urals in terms of W. Penck's concept of piedmont benchlands. This interpretation was exposed to strong criticism by S. G. Boch and I. I. Krasnov who explained the stepped relief of the Urals by differential block displacements and assumed the upper levels to be goletz terraces (surfaces of altiplanation). V. A. Varsanofieva showed in her subsequent publications that her critics oversimplified her views. D. V. Borisevich proposed for the Central Urals a scheme similar in principle to that given by V. A. Varsanofieva. He accepted the concept of pedimentation and proposed (1954) that steep slopes at first become somewhat gentler and then undergo parallel retreat, as forms of equilibrium, but did not explain how this equilibrium came about. N. V. Bashenina (1948) refuted the scheme of benchlands for the high levels of the South Urals but described the lower planated surfaces with their residual hills as pediments of a specific dry-steppe or semidesert type ("melkosopochnik").

It seems that the geologist B. A. Maximov was the first Soviet explorer to have used in his report in 1937 the term "pediment" for the Shilka basin (Transbaikal). He adopted the definition current in the foreign literature of those years that pediments are desert forms and wrongly considered the Shilka pediment as evidence of an earlier arid period. Later on, forms of slope-pediments were described in the basin of the Selemdsha (a tributary of the Amur) by A. I. Mordvinov who developed some interesting ideas concerning the theory of slope evolution. His ideas were similar to those proposed much later by A. Wood. To our great regret, both B. A. Maximov and A. I. Mordvinov fell during the Great Patriotic War.

The geologists A. N. Mazarovich (1939) and E. V. Milanovsky (1940) described two planated surfaces from the Lower Volga basin, the lower one of which they regarded as the Akchagyl abrasion platform. The author studying this region in 1938 and 1940, subdivided the lower surface into levels, showed the upper level to be a typical pediment of Neogene age (1945) and interpreted the relief in terms of the slope-retreat concept. The latter was further used by the author during his study of the Kazakhstan "melkosopochnik" in 1939, of pediments of the Transbaikal in 1944–46, of the Zeja and Selemdsha basins in 1948–49, of the Middle Urals in 1951–55, the Aldan region and Stanovoi ridge in 1961–68. These studies established the vast extent of pediments on USSR territory and suggested that pediment formation is possible over a wide range of climates. They also made it possible to consider the mechanism of slope retreat and to emphasize the role of block faulting in the preformation of pediments (Piotrovsky, 1954, 1961, 1964).

The pediments and pediplanes observed by the author were mainly of Tertiary and Cretaceous age and had been formed under warm and relatively humid climates (including subtropical conditions). In Siberia and the Far East they had continued to develop during the Quaternary, under permafrost conditions, as Siberian pediments. Narrow Quaternary pedestals in the valleys had formed here entirely under such conditions. Here the single basic forms had kept on evolving while developing climatic variants. In the Transbaikal and the Aldan region the author has observed that in the valleyheads pediments merge into stepped goletz terraces. Hence, the different climatic types of pediments can survive and merge into one another.

The problems of pediments were briefly considered by F. A. Grachev (1962). N. V. Bashenina expanded the pediment concept to goletz terraces, and proposed the undermining of the slope as the main common feature of all types of pediments. She also distinguished and analyzed the climatic types of pediments (Bashenina, 1960, 1965, 1967).

The planated surfaces, including pediments of the Lower Volga basin and the Pre-Ural region are now studied in detail by many explorers [A. P. Rozhdestvensky, S. K. Gorelov, A.V. Vostriakov and others; cf. "Problems of planated surfaces" (1964)]. Tertiary surfaces of denudation were correlated here with marine surfaces of accumulation.

The Kazakhstan pediments were described by Z. A. Svarichevskaja (1965). N. V. Dumitrashko, applying the benchland scheme to the Caucasus, emphasized that planated surfaces can form also during the waxing stage of mountain development (N. V. Dumitrashko and others, 1964).

D. A. Timofeev is noted as one of the Soviet geomorphologists most interested in the problem of pediments. He studied the pediments of the Olekma–Aldan watershed and distinguished a flight of levels. It was likewise D. A. Timofeev who distinguished the Siberian pediment as a new type. He pointed out that permafrost conditions are similar to arid conditions in that both are favourable to sheetwash and consequently for pedimentation (Timofeev, 1959, 1963a, 1963b, 1965).

Yu. F. Chemekov (1964—cf. "Problems of planated surfaces"), V. P. Chichagov (1966), V. V. Nikolskaya, D. A. Timofeev, and V. P. Chichagov (1964) described pediments in the Transbaikal and the Amur basins. During the last ten years pediments, slope processes and deposits in their relations to morphotectonics and geographical conditions have been studied by the Transbaikal Expedition of the Geographical Department of Moscow University (Simonov, 1966, 1968).

In summary, the pediment concept is being extensively used by Soviet geomorphologists who have recognized vast expanses of pediments of various types in USSR territory. The main investigations into pediments are being carried out in Siberia and in the Far East. They are based on large volumes of prospecting data especially concerning placers.

VALLEY PEDIMENTS OR DENUDED TERRACES (TERRASOUVALS)?

by

I. P. KARTASHOV

According to the classic concept of Davis, mountainous regions are reduced to denudational plains by the gradual flattening of slopes and lowering of "worn-down" interfluves. An alternative to this concept is the idea of slopes retreating "parallel to themselves" and so maintaining their steepness. This retreat results in the formation of gently sloping denudational surfaces, the pediments. The growth of pediments and their coalescence lead to the formation of pediplains. Nowadays the popularity of this idea is certainly increasing. The most vigorous supporter of the pediplanation concept seems to be L. C. King (1953, 1962), who believes all denudational plains in all climatic zones to be pediplains.

There are also some supporters of the pediplanation concept among Soviet geomorphologists.

Many authors believe the relics situated at various altitudes of planation surfaces to be of different ages. According to the Davisian concept, a zone of dissected topography has to be situated between peneplains of different ages, joining them by gradual transitions. Hence, geomorphologists proposing that denudational plains originate by the gradual flattening of slopes are forced to consider adjacent plains of different altitudes as the relics of a single plain uplifted to different heights by tectonic movements. Geomorphologists convinced that such adjacent plains at different altitudes were not formed contemporaneously are forced to accept the pediplanation concept, even if they cannot explain the pediplanation mechanism. It should be noted that so far nobody has explained the mechanism of the "parallel" retreat of slopes in any environment.

E. V. Shantser (1965) has recently discussed the evolution of slopes under the effect of denudation processes (chiefly of sheetwash) and concluded that the flattening of slopes is a general law, whereas the maintenance of steepness and "parallel" retreat are restricted to certain slopes and result from local geological structure or from peculiar processes of destruction.

As has been noted by many authors, the retreat of slopes at constant or even increasing slope angle occurs when some laterally acting process of destruction affects the base of a slope. Such processes include the undercutting of slopes by streams, wave action, and frost weathering (nivation) near the summer snow limit. Somewhat less typical is the abrasional retreat of slopes under the effect of moving glaciers and aeolian processes (deflation). These processes can all form gently sloping surfaces, resembling pediments in shape; wave action can also create extensive plains, resembling peneplains or pediplains. In some cases, these land forms can be mistaken for features due to slope denudation, but for the most part their origin can be established without difficulty.

As is well known, slope denudation can create steep slopes retreating "parallel to themselves" in horizontal and gently dipping layers of alternating weak and resistant rocks. In such cases, however, a flattening slope originates below the steep, retreating one which is formed over the outcrops of the resistant layer. This flattening slope will assume the shape of a pediment only where the resistant layer is situated not far above a valley floor or another resistant layer. Pediplanation in areas of such geological structure can create structural benches at various heights above the valley floor level. However, a regional denudational plain will originate under such conditions only after the complete destruction of the "armor" of resistant layers, and the "parallel" retreat of slopes plays no part in determining its final form.

The study of morphology of interfluve slopes in the mountainous regions of the USSR and of the loose deposits on these slopes gives no ground for claiming pediplanation to be one of the main modes of land forming in these regions. Land forms believed by supporters of the pediplanation concept to be results of the "parallel" retreat of slopes often prove to be forms of a different origin.

So-called valley pediments (Nikolskaya *et al.*, 1967; Piotrovsky, 1961, 1964; Timofeev, 1963b) are striking examples of such forms. These are gently sloping (1 to 15°; most frequently 4 to 7°) surfaces extending along river valleys. Their lower parts tend to blend into horizontal floodplain or terrace surfaces, whereas their upper parts join the steep slopes of interfluves with a break in the slope. These surfaces are sometimes separated from the floodplains by escarpments; the break separating them from the steep interfluvial slopes is sometimes a transitional zone rather than a line; there are also stepped valley pediments. Not infrequently, considerable parts of these surfaces are sculptured in bedrock. The loose deposits of valley pediments often contain no rounded material, although pebbles and gravels have been recorded on some of them even by authors ascribing them to slope denudation (Nikolskaya *et al.*, 1967; Piotrovsky, 1961).

For these land forms, the term "terrasouval"[1] is widely used by geologists studying placer deposits. The loose deposits of terrasouvals as well as the configuration of the bedrock surface underlying them have been fairly thoroughly studied in numerous prospecting pits and boreholes. These data leave no doubt that the origin of terrasouvals has nothing in common with pediplanation or the "parallel" retreat of slopes.

Figure 1 shows a section through one of the most typical terrasouvals of the northeastern USSR. The bedrock configuration, the occurrence of rounded alluvial material, the concentrations of placer gold, none of which occurs in the slope (colluvial) deposits (Kartashov and Shilo, 1960), all indicate that the terrasouval, now sloping at an angle of about 5°, had originated at the expense of a series of river terraces. Remains of bedrock scarps formed by river abrasion and of lower horizons of terrace alluvia containing placer gold show that there was no "parallel" retreat of terrace escarpments. The terraced surface has been transformed into the gently sloping surface of the terrasouval, apparently by slope denudation, which destroyed terrace lips and was accompanied by the

[1] The second part of this compound word, the "uval", means in Russian "an elongated elevation with roundish slopes and without a pronounced foot, which does not rise above the surrounding landscape by more than 200 m" (Barkov, 1948).

accumulation of colluvia and alluvia moved by slope denudation. Incidentally, such an alluvium should be defined rather as a heterogeneous alluvial-colluvial facies of loose deposits.

A wealth of data accumulated while prospecting numerous terrasouvals permits us to affirm that all terrasouvals are fluvial-denudational land forms, river terraces reworked by slope denudation, having attained various stages of

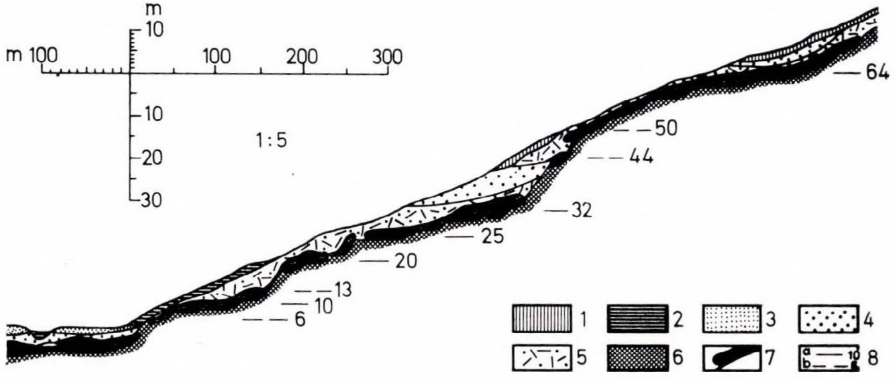


Fig. 1. Cross-section of a typical terrasouval in the northeastern USSR (drainage area of the Kolyma River)

(1) Peat, (2) Clay, (3) Silty sand, (4) Gravel, (5) Gravel with angular debris, (6) Bedrock, (7) Concentrations of placer gold, (8) (a) Proved and (b) Hypothetical terrace socles and their heights in meters above the bedrock bottom of the floodplain

this process. Not a single terrasouval can be considered a pediment formed by the "parallel" retreat of a slope, without the participation of fluvial processes.

Figure 2(A)ashows some detailed cross-sections of some terrasouvals of the northeastern USSR. It should be noted first of all that colluvial deposits without any rounded material are widespread on the surfaces of terrasouvals. These surfaces are often completely covered by colluvia, so that a lack of data concerning the structure of the veneer of loose deposits may lead to false ideas as to the origin of some terrasouvals.

The alluvial-colluvial deposits of the terrasouval facies differ sharply from the colluvium in that some rounded material is invariably present. Lithological differences between terrasouval facies and terrace alluvium, often preserved on terrasouvals, are not so conspicuous. Rounded and angular debris occur together not only in the terrasouval deposits but also in some varieties of alluvium. Moreover, some varieties of terrasouval deposits will contain no angular debris [Fig. 2(B)]. The main difference between terrasouval deposits and alluvium is in the mode of occurrence, that of the terrasouval deposits being similar to that of colluvium.

Terrasouval deposits may be fully absent from terrasouvals considerably reworked by slope denudation, and terrace alluvium will be preserved only in restricted areas, under a cover of colluvium [(Fig.2(C)] At this stage, the bedrock outcrops often occupy most of the terrasouval surface. There was a terrasouval which was shown as an area underlain by Triassic shales even on the detailed geological map. The geologist in charge of prospecting in this region was an exceptionally keen observer; this was how the buried alluvium with a fairly rich placer in it came to be found at all on this terrasouval.

The further reworking of terrasouvals by slope denudation can and sometimes will lead to a complete destruction of all traces of former terraces. Terrasouvals become gently sloping bedrock surfaces overlain by just a sheet of

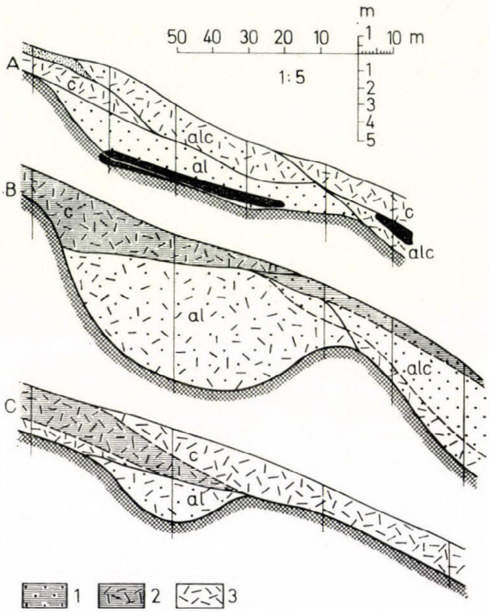


Fig. 2. Detailed cross-sections of parts of some terrasouvals in the drainage areas of the Indigirka (A, C) and Maly Anyuy (B) rivers

(1) Clay with pebbles, (2) Clay with angular debris, (3) Angular debris, Genetical indexes: al — alluvium, c — colluvium, alc — alluvial-colluvial deposits (terrasouval facies), solid lines — boundaries between deposits of different origin; dashed lines — boundaries between lithological varieties of deposits of the same origin, vertical lines — prospecting pits or boreholes; for the rest of signs see Fig. 1

colluvia here and there. Such terrasouvals can be distinguished from the "genuine" pediments by means of a comparative analysis of the topographic pattern, and of correlation between terrasouvals at different stages of development. The direct genetical relation of such "pediment-like" surfaces to terrasouvals of an undeniably fluvial-denudational origin can be proved in most cases.

Inadequate comparative geomorphological analysis and sometimes, apparently, a lack of data concerning the loose deposits and the bedrock configuration are the main reason for the erroneous opinion that valley pediments are widespread in the USSR.

In conclusion, I should like to discuss some terminological problems. Tuan (1959), who has studied in detail the classical pediments of southeastern

Arizona, attaches to the term "pediment" a purely morphological meaning. He means by pediments gently sloping bedrock surfaces of any origin, fringing steep slopes. Unlike him, many Soviet authors give to this term a genetical connotation, restricting it to such gently sloping surfaces as have originated by the "parallel" retreat of steep slopes due to slope denudation. Since geomorphologists are primarily interested in the origin of land forms, the genetical meaning appears to be preferable.

The term "denudation" has two main meanings in the geomorphological literatures of various countries. It is often applied to the removal of loose materials by any exogenous process, resulting in a lowering of the Earth's surface. Thus denudation is considered opposite to the accumulation of loose deposits which in turn results in a rise of the Earth's surface. However, the combination of slope processes, including mass wasting, creep, sheet and rill wash, etc., is also referred to as denudation (Tuan, 1959). In the Soviet Union, Yu. A. Bilibin has attached such a meaning to the term "denudation" as early as 1938. I believe that, in order to avoid confusion, the term "denudation" should be used only in this restricted sense. The combination of all slope processes has no other name, and these processes are often inseparable under investigation. Moreover, the first, broader meaning of the term has a rather widely used synonym—destruction. Applying the term "denudation" as recommended here, one has to bear in mind that denudational processes can be not only destructive, but also accumulative. The formation of colluvial trains in the back parts of terrasouvals is an example of denudational accumulation.

The term "abrasion" has a very broad meaning in American literature, being often used as a synonym of the term "destruction". In most of Soviet literature, on the contrary, this term has a meaning restricted to wave action only. F. P. Savarensky (1939) has somewhat extended this meaning, by giving the name "river abrasion" to the process of lateral undercutting of interfluve slopes by rivers. I believe it reasonable to apply the term "abrasion" to all processes of destruction which are directed not vertically but laterally. Such processes have been listed above.

PEDIMENTS ON THE NORTHEASTERN BORDER OF THE THURINGIAN FOREST

by

E. ROSENKRANZ

Considering the orographical features of Thuringia one might reasonably expect to encounter some well-developed pediments in the region. The Palaeozoic horst of the Thüringer Wald rises as a fault block of 12 to 15 km width above its surroundings which are modelled in largely Triassic rock. Uplift exceeded 1,000 metres locally, although intense degradation reduced the level differences to between 300 and 500 m. The small width and large relative altitude of the block entailed an intense dissection. For this reason remnants of Tertiary planated surfaces are few and far between. Most of the mountainous region is presently under a regime of destruction, which has been active since the late Tertiary so that reconstruction of the geomorphological evolution of the Thüringer Wald is a task fraught with difficulty. Krähahn (1964) succeeded in demonstrating a number of remains of planated surfaces and planated forms in the central mountains which he arranged into a multi-stepped bench system. Below the summit-level there are remains of five lower planated surfaces or levels of planated forms, respectively, the youngest of which blend into the recent valley forms. No accurate dating of these planated surfaces is possible. Clay mineral examinations suggest a late Pliocene weathering for the middle of the five levels just mentioned.

The border of the mountain is rather precipitant morphologically. The transition between mountain and foreland takes place in a narrow, structurally controlled zone of flexures and faults. Uplifting presumably took place in repeated steps. In such surroundings, the presence of a pediment might be expected. In reality, the morphology of the northeast border of the mountains, which will be discussed in more detail here, reflects a different set of processes.

The lithology of the Buntsandstein and Muschelkalk sequences and the spatial position of these formations provide favourable conditions for the development of bedding-plane benches. From Gräfenroda where the Buntsandstein first crops out, towards the east where its outcrop area grows broader, the southern boundary of the Muschelkalk (particularly of its Wellenkalk member) is a conspicuous scarp, which forms the dominant feature of this region for several kilometres. It is, however, the westernmost and easternmost sections of this scarp that are of particular interest. East of Jena, the scarp is "erased" by the late Tertiary surface of planation of East Thuringia. This surface, without fluctuations in its altitude, truncates both Buntsandstein and Muschelkalk. It is only the subsequent dissection of this region since the late Tertiary that has "etched out" the scarp, especially in the environs of Jena. In the westernmost section, near Gräfenroda and farther west, spatial conditions are somewhat disturbed inasmuch as the Muschelkalk stands almost upright on the mountain border, whereas quite near by, to the northeast, it is nearly horizontal again. In this section, the Muschelkalk is truncated at several localities by forms of planation which, although they bear several features of a pediment, should nevertheless be regarded as stream terraces. Particularly conspicuous along the Zahme Gera, they are absent from the borders of the Wipfra, which is really unconnected with the Thuringian Forest, as its valley does not reach back into the mountains. They are also absent from

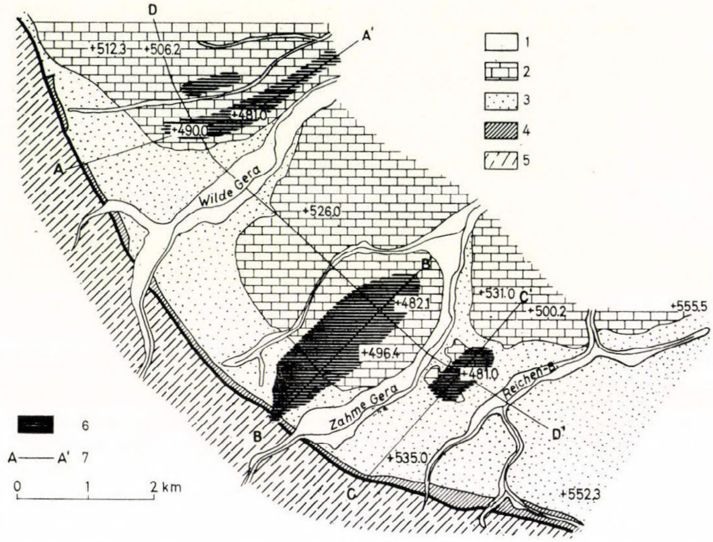


Fig. 1. Northeast border of the Thuringian Forest between the Wilde and Zahme Gera rivers (south-southeast of Erfurt)

(1) Quaternary, (2) Muschelkalk, (3) Multicoloured sand-stone, (4) Zechstein, (5) Red bedding plane (Thuringian Forest), (6) Terraced pediments, A-A' Profiles

along the Ilm, which enters into Muschelkalk area only at some distance from the mountain border, at the town of Stadtilm: its sections farther upstream traverse a narrow zone of Zechstein and then a Buntsandstein area. These terraces had probably existed earlier also along the Ilm, but were preserved only in the Muschelkalk area.

The fluvial origin of these forms is quite obvious. They follow the above-named stream valleys and bear fluviatile deposits. On the plateau of Gossel there are remnants of gravel; northeast of Gräfenroda and on the Steinberg there is gravel several metres thick, whereas east of Geraberg there is only a sparse sprinkling of gravel. These gravels cannot be dated accurately, although they are certainly early Pleistocene deposited by the precursors of the said streams.

These gravel levels had originally begun directly by the examples of the Steinberg and the Geraer Berg. In the remaining cases, connections with the mountain border were severed by the intense destruction of the Buntsandstein. Subsequent depressions came to exist, on whose northeastern border the Muschelkalk exhibits a conspicuous scarp.

These terrace pediments lose breadth in a northeasterly direction, towards the Thuringian Basin, and the streams traverse the Muschelkalk in steep narrow gorges. The Gera leaves the Muschelkalk zone by crossing the line of dislocation at Arnstadt.

The slopes of these surfaces are very gentle, not much above 1°, much gentler than is "normal" with pediments. It is not known, however, whether the slope of the rocky basement is steeper. The gravel up to 3 m thick that is borne by

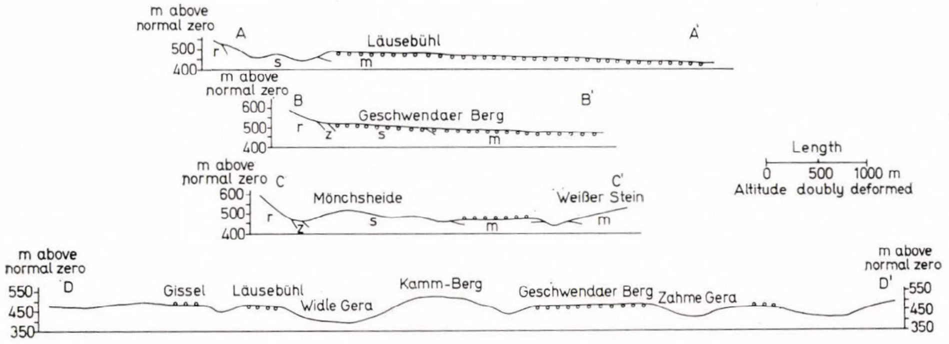


Fig. 2. Synoptic map of the foreland of the Thuringian Forest and of the Thuringian Hills

these surfaces consists almost exclusively of the porphyries of the Thuringian Forest, with boulders of up to 20 cm size. In their bulk they are, however, of gravel size and even contain clays locally.

The individual surface elements do not coalesce into a contiguous pediment zone. Residual projections of Muschelkalk locally rise 40 to 50 m above them.

Also to the northeast of these plane forms, the Muschelkalk locally lies substantially higher. Clearly, the load-bearing and erosional power of the rivers diminished considerably after their issue from the mountains into the foreland. Pediment formation sets in after even a slight spreading in breadth of fluvial activity. This is confirmed also by the gentle slopes of the terrace pediments in their present positions. As we have seen, these slopes only slightly exceed one degree.

Another conspicuous feature is the almost table-like flatness of the pediment surfaces. It proves that these surfaces have not been noticeably denuded or remodelled since the early Pleistocene. The very small slope angles obviously exclude all manner of solifluction.

These terrace pediments cannot be traced farther northeast. About the town of Rippersroda there is an area which had undergone some subsidence in the Pleistocene. The Early Pleistocene gravel is underlain here by latest Pleistocene deposits. The subsidence cannot be accurately dated, and it is consequently impossible to tell whether the early Pleistocene gravels, and hence the terrace pediments, participated in the subsidence. The grades of the Early Pleistocene rivers cannot therefore be reconstructed.

A question of particular importance for relief evolution in this region is the relation of the pediments, of the remains of late Tertiary planated surfaces (if any), to the scarps developed particularly in the lower and upper Muschelkalk. An analysis of these problems produced the following results.

In the eastern portion of the region studied, the pediments lie deeper than the late Tertiary planated surface, that is to say, they are incised below the

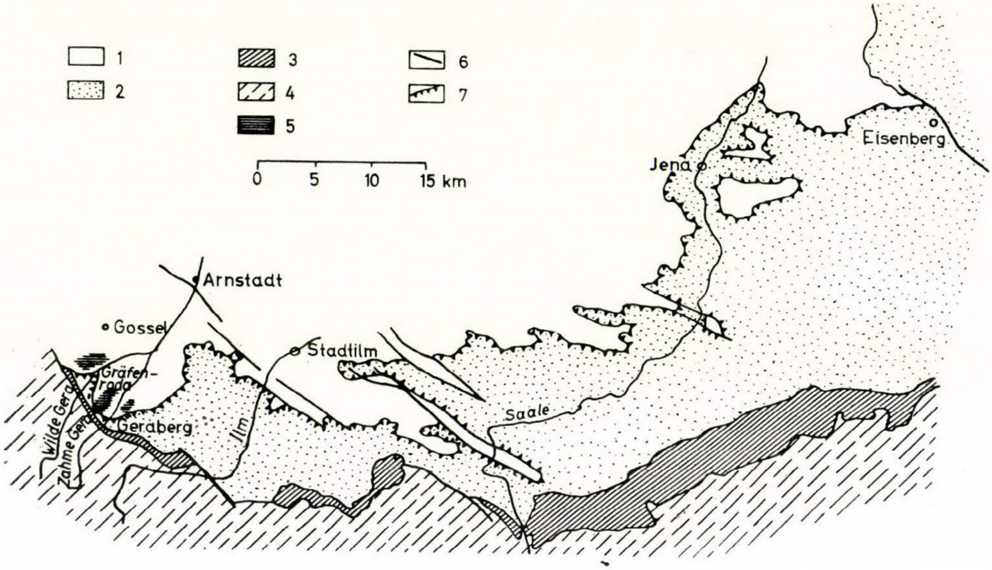


Fig. 3. Profiles of the pediment on the northeast border of the Thuringian Forest

(1) Muschelkalk, (2) Multicoloured sandstone, (3) Zechstein, (4) Substratum, (5) Terraced pediments, (6) Disorders, (7) Muschelkalk-step

level of planation of the foreland. On the other hand, in the western part of the region, the early Pleistocene gravels lie almost flush with the planated surface. The altitude of the pediments depends on the depth of incision of the rivers at the time when pediment evolution was initiated.

As regards the dating of the Muschelkalk scarp, the pediments prove that at the time of their evolution the scarp of the lower Muschelkalk had already existed in places. It did not yet exist, however, in the state of the late Tertiary planated surface, which truncates the Muschelkalk (particularly its lower term) at whatever altitude they meet, which explains the considerable fluctuation in the height of the Wellenkalk scarp.

As to the absence of true pediments from the northeastern border of the Thuringian Forest, one is reduced to surmises. Typical of a climatic region with arid or semi-arid traits, pediments are particularly widespread in the Mediterranean region. The low mountains of Hungary, similar in their geological conditions to those of Germany, are accordingly accompanied by pediments locally. This tends to support the hypothesis that the German mountains lack pediments only because they once lacked the climatic conditions necessary for their development.

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