18

Long-term landscape development

18.1 Models of landscape evolution

One of the most obvious questions we can ask about landscapes is how they came to be as they are. Indeed, the historical approach to landform analysis was the dominant perspective until the 1960s. Over the past two decades, however, the other obvious question – what are the processes operating in the landscape today and how do they relate to the landforms we see – has become pre-eminent to the extent that studies of landscape development through time have been rather neglected. The detailed work on surface processes over the past two decades has significantly increased our understanding of the relationships between process and form at the small scale and over short periods of time. But the gap between our understanding of landform genesis at this scale and our knowledge of how whole landscapes function at long time scales has been widely acknowledged. A much better appreciation of the role of tectonic and climatic controls over landscape development, coupled with the application of new dating techniques and major theoretical advances, is beginning, once again, to bring the problem of long-term landscape development centre stage. This chapter draws extensively on topics introduced earlier in the book and tries to show how new concepts and data are beginning to osvětlit shed a fresh light on some long-standing problems in geomorphology.

Geomorphology has seen various attempts to systematize the development of landscapes through time by isolating the key factors which determine the way in which landforms evolve. These models of landscape evolution, the most influential of which have been those proposed by W. M. Davis, W. Penck, L. C. King and J. Büdel, have had a profound effect on the kinds of problems that geomorphologists have considered and the ways they have attempted to tackle them.

18.1.1 The Davisian cycle of erosion: peneplanation

The model of landscape evolution usually known as the cycle of erosion was developed by W. M. Davis between 1884 and 1899 and owed much to the evolutionary thinking that had permeated both the natural and social sciences in Britain and North America during the latter half of the nineteenth century. Davis considered that in a similar way to life forms, landforms could be effectively analyzed in terms of their evolution. He regarded landscapes as evolving through a progressive sequence of stages, each exhibiting characteristic landforms. In his view these sequential changes in form through time made it possible to odvozovat, vyvozovat infer the temporal stage of development of a landscape from its form alone.

A second key concept implicit in the cycle of erosion model (although not explicitly referred to by Davis) is that of thermodynamics. The development of the principles of thermodynamics had been a major achievement of nineteenth-century science with ohlas, ozvěna repercussions just as profound as those of evolution. This aspect of the cycle of erosion model has been highlighted only relatively recently and relates closely to systems analysis in geomorphology. The second law of thermodynamics states that in an **isolated system** (that is, one which cannot give off or receive either mass or energy) **entropy** can never increase. The concept of entropy has been applied in many different contexts, but a general definition is that it is a measure of the energy in a system which is unable to perform work. In a system in a state of low entropy there are large differences in the distribution of energy and the flows from areas of high to areas of low energy allow work to be performed. Conversely, in a high entropy system energy is much more evenly distributed and the flow of energy and the performance of work is correspondingly reduced. At the theoretical point of maximum entropy the distribution of energy is entirely uniform and no work can be done in the system.

In strict terms, landscapes are neither isolated nor even closed systems since they are constantly importing and exporting mass and energy. Nevertheless, it has been argued that as the potential energy created by the uplift of a landsurface is the major source of energy in the landscape system it is a justifiable simplification to regard landscapes *as if they are* isolated systems. Given this assumption, the cycle of erosion can be seen as representing a progressive decline in potential energy and increase in entropy as the landscape is eroded. Indeed Davis saw the slope angles and stream gradients at any particular point in the landscape as reflecting the distribution of potential energy expressed as local differences in elevation. The total potential energy of the landscape, and hence its stage of evolution at any given time, could be expressed in terms of its mean elevation above base level (Fig. 18.1(A)).

Although Davis acknowledged numerous complications that could affect the cycle of erosion, his detailed description of the anticipated sequence of forms (Fig. 18.2) was based on several important assumptions: that denudation occurs under a humid temperate climate (which Davis regarded as 'normal') on a uniform lithology, and that the cycle is initiated by the relatively brief and rapid uplift of a landsurface of minimal local relief which does not experience significant erosion during the uplift phase. Given these conditions, he described a series of stages in the cycle of erosion categorized by way of analogy to the stages of human life as **youth, maturity** and **old age**. Davis argued that there would be a progressive decline in slope angles (Fig. 7.25(A)) and stream gradients through time which would ultimately result in the production of a landsurface close to base level with very subdued relief. Such a surface he termed a **peneplain** and consequently Davis's model of landscape development characterized by declining surface gradients through time is often referred to as **peneplanation**. It is important to note, however, that the term peneplain is used by some writers much more broadly to refer to *any* low relief surface however formed. The alternative

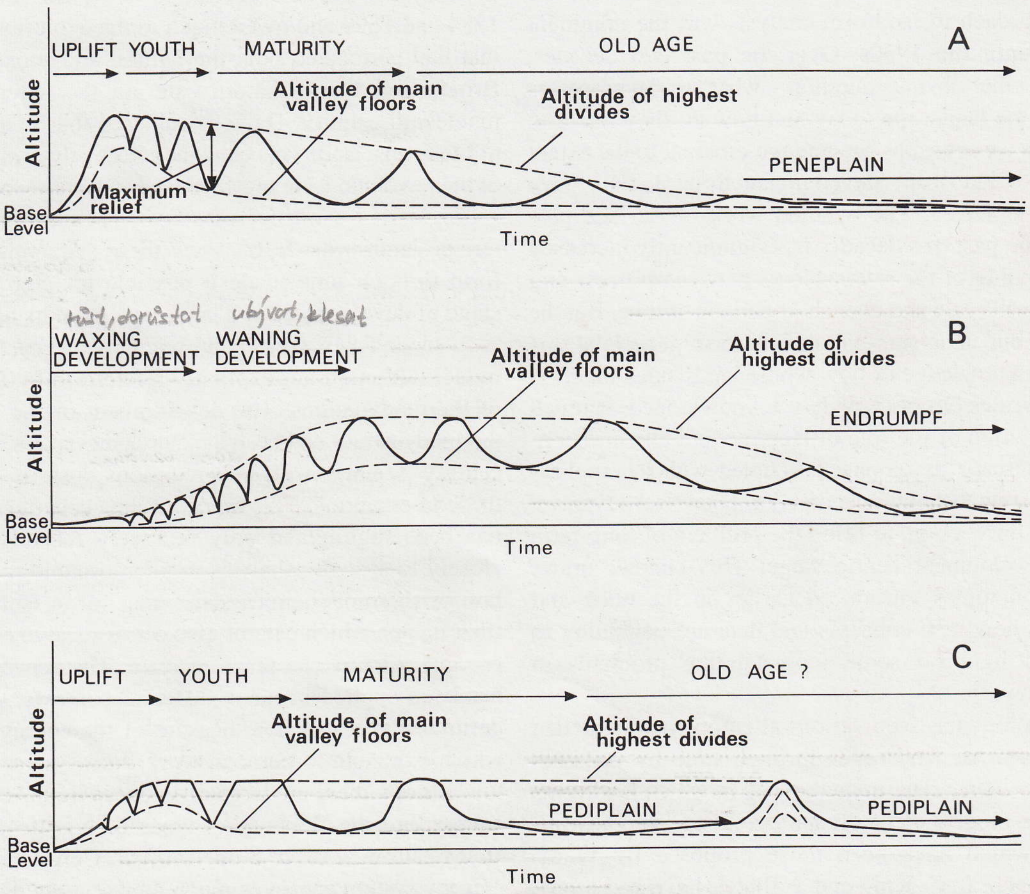

Fig. 18.1 *Schematic representation of the key elements of the models of landscape evolution proposed by Davis (A), Penck (B) and King (C). Note that for simplicity base level is assumed to be fixed through time and that the temporal scale is not necessarily comparable between diagrams. In the Davisian scheme the stage of old age should be regarded as many times longer than youth and maturity. (Modified from J. B. Thornes and D. Brunsden, (1977)* Geomorphology and Time. *Methuen, London, Fig. 6.2, p. 122.)*

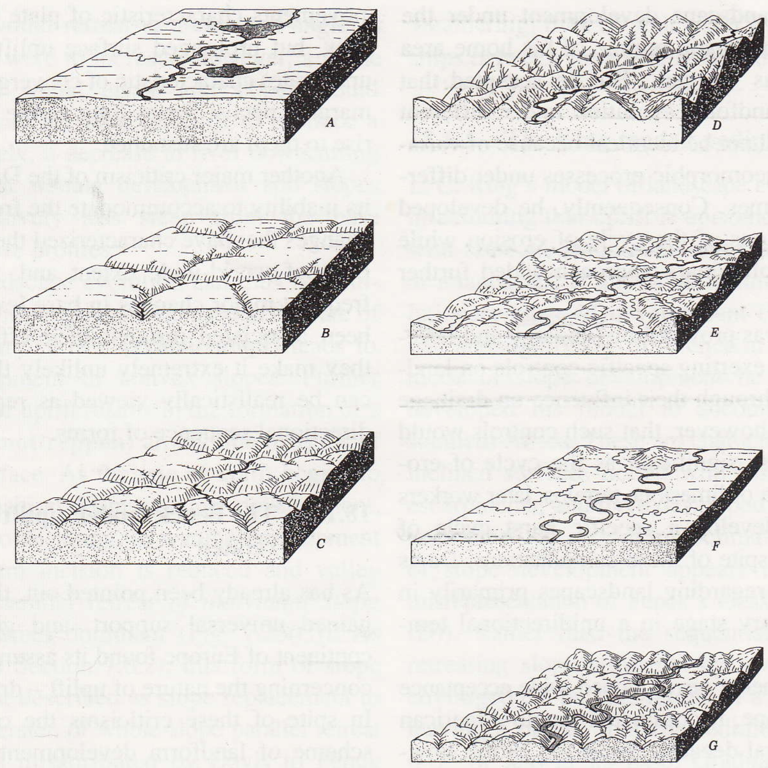

Fig. 18.2 The Davisian cycle of erosion under a humid climate. The assumed starting-point is a landsurface with little local relief, either a peneplain developed during the previous cycle as shown in (A) or an emerged submarine surface. Uplift leads to rapid incision of the landsurface by rivers. In early youth (B) narrow river valleys separate broad areas of largely uneroded uplands and river gradients are irregular with waterfalls, rapids and lakes formed in response to lithological variations. These channel gradient irregularities have been eliminated by the end of middle youth, and by the end of late youth (C) major rivers are graded and lateral erosion enables the development of narrow floodplains in their lower courses. The flat uplands which have been steadily reduced in area during youth as the drainage network has grown are eliminated altogether by the beginning of maturity (D). This is the stage of maximum local relief and the drainage network becomes fully integrated and closely adjusted to structure. Hereafter local relief begins to decline as the graded river channels, which by this stage have spread far up tributary valleys, are lowered progressively less rapidly than interfluves. Associated with this change is the reduction in average slope angles, as the steep slopes of youth which are close to the stability angle of the partially weathered debris are transformed into lower gradient slopes as the active basal removal of debris ceases. Throughout maturity, floodplains become gradually wider and major rivers develop meandering channels. By late maturity (E) local relief has been significantly reduced and the landscape comprises gentle valley-side slopes and extensive floodplains. As old age is reached (F) the entire landscape is graded and floodplains are several times broader than the active meandering belts within them. The mean elevation of the landsurface, already close to base level, is lowered further only very gradually. Note, however, that in regions remote from the coastline to which rivers are flowing the developing peneplain will remain well above base level since river channels must have a certain minimum gradient in order to transmit water. Low rates of erosion allow the accumulation of thick weathering mantles which, in progressively masking the underlying bedrock, gradually free river channels from structural controls. None the less, particularly resistant lithologies may allow erosional residuals, known as ***monadnocks****, to survive into late old age. Finally, renewed uplift will initiate a new cycle of erosion (G). (From A. N. Strahler (1969)* Physical Geography *(3rd edn.) Wiley, New York, Fig. 27.1, p. 466, drawn by E. Raisz.)*

spelling 'peneplane' which is used occasionally is certainly misleading as Davis in no sense envisaged the development of a planar surface as the ultimate product of the cycle of erosion.

As we have mentioned, Davis acknowledged the presence of factors that might complicate the stately progression of landscapes illustrated in Figure 18.2. The cycle might be interrupted by renewed uplift at any stage which would cause **rejuvenation** of the landscape through the development of youthful forms which would coexist with older forms and thereby create a **polycyclic landscape**. The simplest assumption was that such uplift would only manifest itself as a fall in base level at the downstream extremity of drainage basins (normally at the coastline), and would lead to the gradual encroachment of steeper river gradients and slopes upstream through the drainage systems of the uplifted landscape (Fig. 18.2(G)).

A second complication Davis noted was climate. Davis effectively represented landscape development under the humid temperate morphoclimatic regime of his home area of the north-east USA as 'normal'. But he accepted that the detailed nature of landform evolution under different prevailing climates would not be identical because of variations in the intensity of geomorphic processes under different morphoclimatic regimes. Consequently, he developed 'arid' and 'glacial' versions of the cycle of erosion while later disciples of his evolutionary approach added further variants.

A third complication was provided by lithology and structure which Davis saw as exerting specific controls on landscape evolution largely through their influence on drainage patterns. He maintained, however, that such controls would become progressively less significant as the cycle of erosion proceeded. In the case of limestone terrains, later workers found it necessary to develop a specific karst cycle of erosion. Nevertheless, in spite of these complications, Davis maintained the value of regarding landscapes primarily in terms of their evolutionary stage in a unidirectional temporal sequence.

Although his cyclic scheme never gained wide acceptance on the continent of Europe, it dominated Anglo-American geomorphology for several decades. Since the 1950s, however, both the theoretical utility and the empirical validity of the cycle of erosion have been increasingly challenged. What, then, are the major criticisms of the model? Although contemporary critics have tended to focus on the rather vague understanding of surface processes evident in Davis's formulation of landform development in general, and slope development in particular, perhaps the most fundamental problem with the cycle of erosion arises from the assumptions concerning the rates and occurrence of uplift.

Presumably due to the lack of quantitative data when he was writing, Davis was never very specific about actual rates of uplift and denudation. The estimates he did give, such as the 20–200 Ma for the peneplanation of the fault-block mountains of Utah, indicates that he envisaged extensive time scales. Our current knowledge of uplift rates (see Chapter 15) suggests that few areas of the world remain stable for periods of tens of millions of years or more, and therefore it seems that polycyclic landscapes are likely to be the norm rather than the exception. Furthermore, isostatic uplift is an inevitable consequence of denudational unloading as the cycle runs its course. As a result, continuous crustal uplift, ačkoliv albeit at a declining rate through time, will affect the entire duration of a cycle of erosion and greatly delay the attainment of full peneplanation. As we have seen in Chapters 3 and 4, inter-plate and intra-plate tectonic mechanisms give rise to quite different temporal and spatial patterns of uplift, and in neither case does the elevation of the landsurface take the form of geologically brief, discrete episodes of rapid surface uplift. Epeirogenic movements characteristic of plate interiors usually involve slow, but prolonged surface uplift, while the high crustal uplift rates characteristic of convergent and oblique-slip plate margins persist for as long as the plate interactions giving rise to them are sustained.

Another major criticism of the Davisian model arises from its inability to accommodate the frequent and rapid climatic changes that have characterized the Quaternary. These have been of world-wide extent and, in conjunction with the frequent major changes in base level with which they have been associated through their effect on global sea level, they make it extremely unlikely that landscapes anywhere can be realistically viewed as representing a simple unidirectional sequence of forms.

18.1.2 The Penck model: uplift and denudation related

As has already been pointed out, the Davisian model never gained universal support, and geomorphologists on the continent of Europe found its assumptions – especially those concerning the nature of uplift – drastically over-simplified. In spite of these criticisms the only coherent alternative scheme of landform development to emerge prior to the Second World War was that of W. Penck. Penck's ideas have never been popular among English-speaking geomorphologists both because of his rather obscure writing style and terminology, and because the majority of geomorphologists unable to read German had to rely for several decades on misleading representations of his views by Davis and other writers.

Penck's ideas on uplift differed significantly from those of Davis (Fig. 18.1(B)). Whereas the latter assumed brief episodes of rapid uplift punctuating prolonged periods of stability, Penck argued that, in orogenic belts at least, active uplift could continue for a considerable time and in such situations Davis's notion of evolutionary stages of landscape development would be pochybný, nejistý of dubious value. On the basis of the evidence from sedimentary sequences flanking the Alps, Penck considered that rates of active uplift initially increased slowly before reaching a maximum and then declining gradually.

In certain circumstances Penck thought that periods of increasing and decreasing rates of uplift might be reflected in slope forms. This link could arise from the effect changing rates of crustal uplift could have on rates of river incision. High rates of crustal uplift, Penck argued, would raise river channels further above base level and thus increase their gradients. This would lead to an acceleration in river downcutting until the rate of incision matched the rate of crustal uplift. The converse situation would apply during a decline in the rate of crustal uplift, with rates of river incision decreasing as downcutting reduced channel gradients. Penck considered that a uniform rate of river incision would give rise to straight slopes which would retreat at a constant angle. If the rate of downcutting were to increase, however, a phase of **waxing development** would ensue and slopes would steepen progressively from the base upwards to produce a convex profile. Conversely, a decrease in river downcutting could create a phase of **waning development** and slopes could become progressively less steep from the base upwards, creating concave profiles.

Penck's model of landscape evolution can thus be summarized as follows. An initial gradual increase in the rate of crustal uplift of a primary surface (**Primärrumpf**) leads to the widespread development of convex slopes. Further acceleration in the rate of uplift results in the formation of a series of benches (**Piedmottreppen**) around the margins of the primary uplifted surface. As the rate of uplift begins to decline there is a transition from waxing development, characterized by rapid downcutting, to waning development where the rate of stream incision is reduced and valley widening through the parallel retreat *of individual slope elements* gradually becomes dominant (Fig. 7.25(C)). As noted in Chapter 7 (see Section 7.6.2), this form of slope evolution is perhaps best described as slope replacement to distinguish it from the version of whole-slope parallel retreat advocated by King and misattributed by Davis to Penck (Fig. 7.25(B)). The steepest slope elements forming free faces retreat most rapidly leaving behind basal series of lower angle debris slope segments. The retreat of free faces eventually leads to the formation at drainage divides of large residual hills, or inselbergs, which are flanked by pediments. The eventual elimination of inselbergs leaves a landscape termed by Penck an **endrumpf** consisting entirely of slowly retreating, low angle concave slopes.

Although Penck's emphasis on the response of drainage systems to changing rates of uplift provides useful pointers as to how we might attempt to integrate tectonics into models of long-term landform development, his scheme as a whole is untenable (neudržitelný) as it pays insufficient attention to other factors affecting landform development. In particular it fails to acknowledge the importance of changes in river discharge which might arise as a result of climatic change, and it also underplays the role of lithology and the nature of weathering, both of which can significantly affect relationships between stream activity and slope form.

18.1.3 The King model: pediplanation

L. C. King's model of landscape evolution resembles Davis's in assuming that uplift is episodic and rapid in comparison with rates of denudation, and that the overall morphology of a landscape at any point in time is diagnostic of its evolutionary stage of development (Fig. 18.1(C)). The essential, and significant, difference in King's scheme lies in the mode of slope development he proposed. King initially developed his model to account for the landscapes of southern Africa. These are characterized by extensive, gently inclined surfaces dotted with inselbergs and separated by escarpments, and have developed under predominantly arid to tropical wet–dry morphoclimatic regimes. King's notion of slope development appears to owe much to Davis's misrepresentation of Penck's ideas (compare Figure 7.25(B), (D)). Rather than the sequential replacement of parallel retreating slope segments by lower angle elements, King envisaged the parallel retreat of a single free-face slope unit leaving a broad, concave pediment sloping at an angle of 6–7° or less at its base. Gradually over time, pediments coalesce to form **pediplains** and this mode of landscape development is therefore called **pediplanation.**

King considered that once pediment surfaces have been formed they persist with little change until the next phase of surface uplift promotes a new cycle of river incision and escarpment retreat which consumes existing pediplains and creates new ones. As in the Davisian model, the dating of such denudational episodes can be described in terms of the timing of the fall in base level initiating each new landscape cycle. None the less, the landsurface itself is diachronous because in King's model landscapes essentially develop through backwearing as escarpments experience parallel retreat; landsurfaces, therefore, are progressively older away from escarpments (Fig. 18.3). Consequently, it is possible to talk of the local age of a landsurface, and even to refer to a terminal age determined by the final removal of a pediplain remnant.

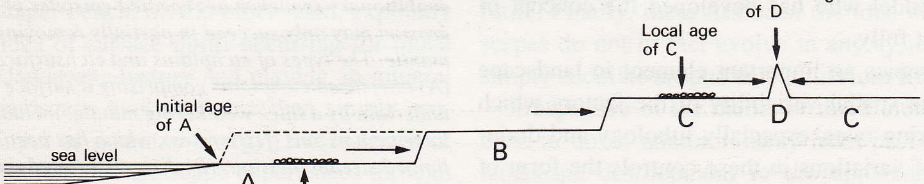

Fig. 18.3 Different criteria for defining the ages of erosion surfaces according to the model of landscape development proposed by L. C. King. The surfaces labelled A–D were initiated during three episodes of base level fall. Each is diachronous and deposits on the surface may be capable of yielding a minimum local age at that point. The final elimination of the last remnant of a particular surface (D) gives its terminal age.

King originally envisaged episodes of uplift occurring predominantly along continental margins as the result of a delayed isostatic response to denudational unloading. He considered that such isostatic uplift would only take effect once an escarpment had retreated over a critical threshold distance. This mechanism of discontinuous isostatic uplift is based on a misunderstanding by King (and other geomorphologists since) of how the crust responds to changes in load. The response is, of course, continuous on the geological time scale of denudational cycles (see Section 2.2.4), although flexural isostasy does provide a possible means of generating surface uplift along passive margins experiencing escarpment retreat (see Section 4.2.3). Subsequently, King advocated the somewhat ill-defined mechanism of **cymatogeny**, involving the upwarping and flexure of continental margins as a result of active subcrustal processes, as the means by which new cycles of pediplanation could be initiated. Although modern concepts of passive margin tectonics have now replaced King's ideas about uplift mechanisms, the notion of widespread and long-term escarpment retreat has gained new
popud, hybná síla
impetus from recent attempts to understand the evolving morphology of passive margins following continental break-up.

18.1.4 The Büdel model: etchplanation

Although having little impact on the development of Anglo-American geomorphology, the ideas of J. Büdel have exerted a considerable influence on workers in the continent of Europe, especially in Germany. Büdel's key notion concerning landscape development is that of a 'double surface of levelling'. In regions covered with thick weathering deposits, especially the relatively stable shield areas of the humid tropics, denudation of the landscape occurs simultaneously through the removal of material from the surface – largely, it is thought, by sheet wash – and by ongoing chemical decomposition at the weathering front. This combination of deep weathering and surface removal produces an **etchplain** (or an **etchsurface** where an uneven basal surface has been exposed) and the overall process is termed **etchplanation** (Fig. 18.4). Elements of this model of landscape evolution can be traced back to the British geologist, E. J. Wayland, who worked in Uganda in East Africa in the 1930s, but it is Büdel who has developed the concept of etchplanation most fully.

In the humid tropics an important element in landscape development is the spatial variability of the factors which determine weathering rates, especially lithology and drainage. As a result of variations in these controls the form of the weathering front is highly irregular, and the depth of the weathering mantle does not necessarily bear any relationship to the form of the ground surface. During periods of tectonic and climatic stability rates of weathering and denudation are roughly in balance and the depth of the weather-

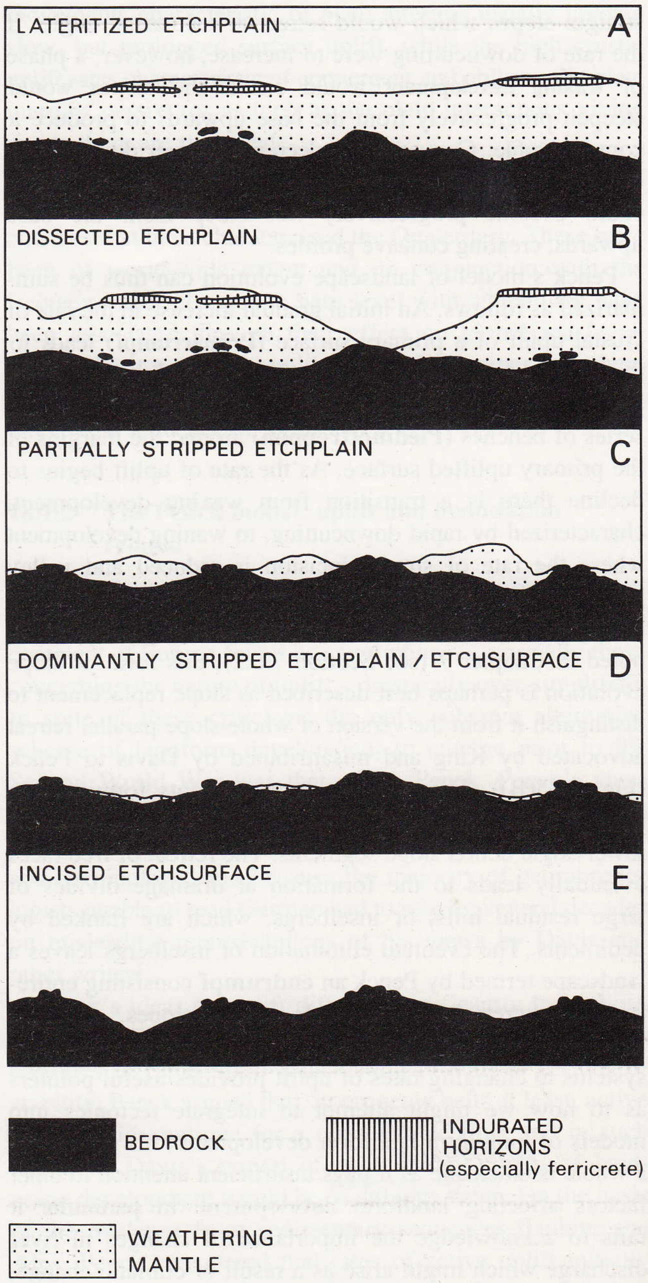

Fig. 18.4 *The development of different types of etchplains and etchsurfaces. The diagrams do not necessarily represent an evolutionary sequence as repeated episodes of accelerated erosion may only succeed in partially removing the weathering mantle. The types of etchplains and etchsurfaces illustrated are: (A) lateritized etchplains comprising a surface of low local relief underlain by a thick weathering mantle, including indurated lateritic horizons (ferricretes), which has been subject to only limited stream incision; (B) dissected etchplains in which accelerated stream downcutting promoted by climatic change or uplift leads to the development of well-defined valleys, fringed in places by duricrust breakaways, and the very localized exposure of bedrock and the formation of tors; (C) partially stripped etchplains characterized by widespread stream dissection and the extensive stripping of the weathering mantle,*

including resistant duricrust layers, to reveal numerous rock outcrops in the form of tors; (D) dominantly stripped etchplains representing a very advanced stage of stripping in which the weathering mantle is retained only in deep pockets along the weathering front and where some of the exposed bedrock has also been subject to erosion (forming an etchsurface where significant relief is present); (E) incised etchsurfaces in which the basal bedrock surface has been extensively modified by fluvial erosion, almost certainly as a result of a significant change in base level rather than climatic change. (Diagrams and descriptions of etchplain and etchsurface types based on M. F. Thomas (1974) Tropical Geomorphology, *Macmillan, London, Fig. 41, pp. 236–8.)*

ing mantle varies little. But a change in climate, or increase in the rate of crustal uplift, can disrupt this steady state by generating an increase in the rate of river incision or, in the case of climatic change alone, through the disturbance of the vegetation cover. During such a perturbation of the geomorphic system the weathering mantle may be partially, or even wholly stripped. As the landscape is lowered in response to the more vigorous erosional activity, water tables will fall. This will tend to increase rates of water throughput at the weathering front and in turn lead to an increase in the rate of weathering.

Etchplains can assume a range of forms depending on a number of factors including the lithology and structure of the local rocks (which influences the depth of the weathering mantle), the intensity and duration of erosional episodes and the morphology of the basal weathering surface. Various types of etchplain can be produced as a result (Fig. 18.4), and this has led to some confusion over the application of the term.

18.1.5 Classic models of landscape evolution: summary and assessment

At this point it is probably useful to summarize very briefly the essential elements of what might be described as the classic models of landscape evolution, before seeing in the following sections how the problem of long-term landform development is currently being tackled. The cycles of erosion envisaged by Davis and King are similar in that they both assume that surface uplift occurs as more or less discrete pulses which punctuate the progressive erosional development of the landscape. Penck, on the other hand, explicitly incorporated the idea of surface uplift occurring for much longer periods of landscape history and playing an integral role in how the landscape evolves rather than simply providing an initial input of potential energy. But in terms of the changes in form that the landscape experiences through time, King is much closer to Penck in proposing that backwearing generally predominates over downwearing (although, as we have pointed out, Penck's and King's conceptions of exactly how slopes retreat were different). With particular respect to King's form of parallel retreat, it has been pointed out that this could not occur in any strict sense over large horizontal distances because of inevitable variations in rock strength associated with what might be quite subtle changes in lithology. While clearly accepting this point, it is useful to retain the notion of parallel retreat in a broad sense in order that it can be contrasted with the idea of a progressive decline in slope gradients in the landscape through time.

The distinction between backwearing and downwearing is important because of the different isostatic responses to which we would expect them to give rise. Isostatic compensation of a landscape experiencing extensive downwearing would not, in general, lead to any surface uplift, whereas flexural effects along the kind of sharp topographic discontinuity formed by a major escarpment could lead to localized surface uplift (see Section 4.2.3). It is, of course, possible, and indeed likely, that both downwearing and backwearing occur simultaneously, although the latter may be slow with respect to the former. Slow downwearing is, in fact, just what is implied by Büdel's notion of etchplanation, and it certainly seems that we cannot assume that once pediments are created by escarpment retreat they necessarily remain immune from the effects of weathering and erosion. Indeed, if we accept the evidence for generally warmer (and probably also wetter) climates in the Cretaceous and Early Cenozoic (see Section 18.4.3) then very ancient landsurfaces are unlikely to have remained untouched by episodes of deep weathering even in regions which are now predominantly arid.

Although the subject of intense debate during the first half of this century, over the past two or three decades there has been relatively little discussion among geomorphologists about the relative merits of the classic schemes of landscape evolution discussed here. Many have regarded them as being so deficient in their treatment of exogenic geomorphic processes that they are barely (sotva, stěží) worth serious consideration. While accepting the value of the idea of progressive landscape change through time, others have rejected the specific models of landform change proposed as oversimplified and inadequate. Yet other geomorphologists have pointed to the important effects that lithology or changing morphoclimatic regimes have on the way landforms evolve through time, and have argued that these factors render the search for an all-embracing model of landscape evolution (marný, zbytečný) futile. Finally, there has been the idea that in reality landscapes do not in fact evolve in any systematic manner but simply oscillate around an equilibrium form.

Irrespective of the merits of these views, their effect has been to direct attention away from problems of long-term landscape development to the apparently more (povolný) tractable questions posed by the nature of shorter-term, and smaller scale, geomorphic change. None the less, this situation is now changing as a result of both conceptual and technical developments since the mid-1970s. One has been the attempt to integrate a modified version of the concept of dynamic equilibrium into the notion of progressive landscape change embodied in the principle of evolution. Another has been the revolution in our knowledge of tectonic processes that has occurred over the past two decades and in particular the way that this has immeasurably improved our understanding of the nature and causes of uplift. Finally, there have been major advances in the dating of geomorphic events and the ability to estimate long-term rates of denudation (see Section 15.4). It is to these themes that we turn next.

18.2 Landscape stability and change

18.2.1 The Hack dynamic equilibrium model

One reaction to the evolutionary thinking embodied in Davis's notion of a cycle of erosion was the proposal by J. T. Hack that landscapes could be better understood in terms of 'dynamic equilibrium'. In rejecting the idea of progressive change in the form of the landscape through time, Hack resurrected the approach of G. K. Gilbert focusing on the continuous adjustment between force and resistance. He argued that in landscapes that have experienced a long period of denudation there will be a mutual adjustment between lithological controls and prevailing surface processes. In the ideal case where base level, surface processes and lithology remain constant through time, the form of the landsurface remains unchanged since the whole landscape is lowered at a constant rate. Relief, slope angles and stream gradients are adjusted in such a way that each unit area yields the same sediment load; regions of resistant rock have steep, rugged relief, whereas areas of less resistant lithologies have subdued relief and gentle slopes. (Note that in the sense we have already defined the terms (see Section 1.3.4) this model is essentially one of steady-state equilibrium.) The major shortcoming of this approach as a general landscape model is that, while this condition of uniform lowering might apply to particular areas of limited extent, it cannot apply to entire drainage basins in the long term. This is because the lowering of the surface of a drainage basin towards base level necessarily involves a reduction in the gradient of trunk streams, and this will eventually affect tributary basins. A further problem with Hack's dynamic equilibrium concept is that climatic change and tectonic activity are likely to lead to changes in the nature and rates of processes through time, while progressive surface lowering will expose different lithologies. The maintenance of a 'dynamic equilibrium' assumes a rapid adjustment to such changes but there is abundant evidence in some landscapes of the survival of relict landforms. It appears that the concept of 'dynamic equilibrium' is likely to be most applicable to parts of slowly eroding landscapes which have not experienced major climatic shifts and which are effectively isolated from base level changes.

18.2.2 The dynamic metastable equilibrium model

In Chapter 1 we discussed how the idea of equilibrium in a landscape was linked to the temporal and spatial scale being considered (see Section 1.3.4). However, we have yet to consider exactly how a landscape composed of individual components in a steady-state equilibrium can experience progressive lowering in the longer term. This problem has been addressed by S. A. Schumm who has proposed that these ideas of landscape stability and landscape change can be reconciled by incorporating the concept of episodic erosion (see Section 9.5.1) into a decay equilibrium model of landscape evolution. The key element of Schumm's model is that valley floors are lowered episodically rather than continuously. This could occur through the accumulation of sediment from the upper parts of a basin covering the bedrock of the valley floor. Periodically this sediment is removed and the bedrock of the valley floor is lowered. Such valley floor incision may be promoted by external factors, such as a major flood (see Section 9.5.2), but it might also arise as a result of the breaching of a geomorphic threshold due to sediment deposition, causing the channel gradient to reach a threshold of instability.

This situation can be described as one of **dynamic metastable equilibrium**, and differs from the concept of dynamic equilibrium in that the reduction in channel bed elevation takes place discontinuously not progressively. Under conditions of dynamic metastable equilibrium, phases of steady-state equilibrium are punctuated by adjustments involving the breaching of either extrinsic or geomorphic thresholds which shift the steady-state equilibrium to a new level (Fig. 18.5). Schumm argues, therefore, that it is possible to replace the Davisian notion of progressive, gradual change through time by a model of landscape evolution in which change occurs in a step-like manner (Fig. 18.6). Interesting-

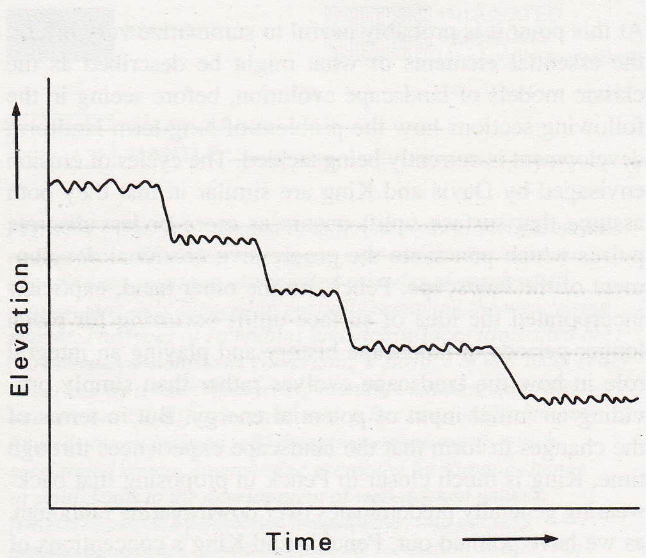

Fig. 18.5 Schematic representation of dynamic metastable equilibrium. Compare with Figure 1.9(C).