15 Derivation and Innovation in Improper Geology, aka Geomorphology

C. R. Twidale
Department of Geology and Geophysics, University of Adelaide

ABSTRACT

Geomorphologists have contributed to geological understanding in several ways. First, the form of the land surface provides an introduction to various geological phenomena and the first indications of subsurface structure and events, past, present and future. Second, knowledge of contemporary processes, to which geomorphologists have contributed, facilitates the interpretation of palaeosurfaces, of past deposits and of past events. Third, the land surface is part of the record of earth history, which is the core and focus of geology. Over considerable areas of each of the continents morphology provides the only clues to Phanerozoic events. Fourth, geomorphological concepts are of considerable practical or applied significance, for example in the search for minerals, in engineering geology and in planning generally.

Yet geomorphology has lost and continues to lose status in the geological profession, both academic and non-academic (governmental, industrial). Some geologists regard geomorphology as not proper or not real geology. The possible reasons for this are broached and responses discussed. The feasibility of geomorphology severing its ties with geography and geology and 'going it alone' is considered. Though attractive in principle the move is regretfully rejected as impractical. The loss of the geological link is also seen as deleterious, for geomorphology is basically chronological. Geomorphology has been particularly hard hit by recent educational and research trends, and by the shortage of job openings which utilise geomorphological education. The best hope for the future of geomorphology lies in a general return to and acceptance of curiosity-driven education, learning and research, together with success in convincing our geological colleagues of the rigour, value and relevance of our discipline.

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THE ESSENTIAL *MÉNAGE À TROIS*

Geomorphology is, at once, an integral part of both geology and geography. In the opinion of some, and because of its essentially chronological character, it is more closely related to and integrated with the former than the latter. Geology can be regarded as the sum of an infinite number of geographies of past ages, and geography as the geology of the present. But the present is in a sense illusory, for by the time various environmental events have been noted, recorded and analysed, they are part of the past: the recent past, but nevertheless the past. Those events will never be reproduced, for every moment, like every site and every individual, is unique. It is, however, legitimate to generalise, and to group and interpret similar events and features in terms of laws, principles or models. This is the practice in all the sciences, including the supposedly more exact sciences which, despite a determined effort to achieve precision, are also dominated by the idea of approximations.

For geographers, the physical and biological worlds form an integrated whole which forms the backdrop and basis for human activities and which in turn is directly or indirectly modified by those actions. The land surface is a visible part of the physical stage on which biological and human activities take place. As in the theatre, events on stage are the focus of attention, but are profoundly influenced by what goes on backstage, and above and below the boards, in the gridiron and the traps. The land surface is not only an important factor in the complex and spatially varied interrelations that are the essence of geographical study, but also provides evidence of events and processes in the atmosphere above and the Earth beneath. Some geographers are content to take that physico-biological world, of which the form of the land surface is a visible, measurable and, in human terms, comparatively stable foundation, as a passive factor which interacts with others only in terms of responses to natural catastrophic events, such as floods, and in so far as there are reactions to human errors and excesses (e.g. accelerated soil erosion).

Genetic explanation, understanding the land surface, has no part in such anthropocentric, empirical and static views of geography. What does it matter if a surface is Pleistocene or Permian in age? What is important is surely its morphology (relief amplitude, altitude, etc.) and weathering characteristics, and hence soil producing and agricultural potential (e.g. Thrower 1960); though how potential can be predicted without an understanding of the processes involved is not clear. What does it matter whether a volcano is associated with a convergent or a divergent plate junction or a hot spot? What is important is the character of the extruded lava and the character and frequency of eruption. The land surface can be taken as read, without reference to its evolution. Like some practitioners in other disciplines, some geographers are interested in data rather than explanations, in results rather than causes, in the quasi-static present rather than the evolutionary past. They are able, for example, to accept the intrinsic poverty of most Australian soils without linking that condition to the great age of much of the land surface and the implied long periods of leaching.

But other geographers, experienced in the field realities, driven by intellectual curiosity and aware of future possibilities, find questions of origin both interesting and essential to geographical synthesis and understanding. This attitude is of course based in academic interest, and in a conviction of the interrelations of the totality of factors at work at and near the Earth's surface. It is far removed from the cost-benefit accountability presently so much in vogue with those, call them cynics, realists or pragmatists, so many of whom are now involved in the universities, the politics of science and politics, and who, as Oscar Wilde expressed it, know the price of everything but the value of nothing.

Ironically, however, spatial distribution is an essential research tool in many of the natural sciences, but especially in multi-factor studies such as geography and ecology. Geomorphology must also be included in this category. Mapping is a common and obvious way of establishing and investigating distributional patterns. Yet this procedure makes a genetic approach mandatory. In order to produce a map of natural complexes, paradoxically, and if only from a purely pragmatic standpoint, interrelationships must be understood. Every site cannot be investigated, so that having, for instance, established bedrock-landform-soils-vegetation relationships at one site, it is necessary to extrapolate, and then check, at others. This is the basis both of single factor and complex, of detailed and regional, mapping, as exemplified by the well-known and successful broad-scale landscape and land-use mapping procedures adopted by the Commonwealth Scientific and Industrial Research Organisation (CSIRO) Land Research Division, and of detailed soils maps produced by the CSIRO Division of Soils (see e.g. Taylor and Hooper 1938; Christian 1952; Butler 1979). In order to extrapolate with any confidence, it is necessary at least to begin to understand the interrelations of various factors. The rule also applies in geology, for though 'walking the outcrop' is still desirable, time frequently does not permit this laudable practice. Photogeology is increasingly the basis of mapping, calling for genetic linking of form and foundation, of the visible surface and the hidden subsurface.

Bauer (1995, also Chapter 16, this volume) points out that because the discipline has interfaces with most of the other natural or applied sciences, there are many logical and useful types of geomorphology Thus, a subdiscipline of engineering geomorphology, for example, could well develop; indeed, some of the more fundamental geomorphological work - on drainage network densities - presently being carried out in Australia is due to civil engineers (see e.g. Willgoose et al. 1991). Engineering is, in the 'civil' sense, perforce concerned with the behaviour of materials, an exercise which is invaluable in the interpretation of landscape, as well as in other areas. One has only to recall the contributions of the likes of Bagnold, Leopold and Langbein, Terzaghi and Skempton, to appreciate the distinguished contributions in matters germane to geomorphology of colleagues from engineering, or with engineering backgrounds. And the introduction of concepts and approaches from other of the natural sciences can also only be beneficial, as for instance in the study of rock glaciers (Wahrhaftig and Cox 1959; Wahrhaftig 1987).

Yet, it is not astigmatic but merely realistic, to perceive geomorphological investigations in a temporal framework, and to recognise links with the past and the constraints on our interpretations of the present imposed by the time element (Baker and Twidale 1991). Geomorphology, like geology and geography, is not only a natural science but an Earth science. We are concerned with a planet almost 5 billion years old and many of our landscapes, regional and local, mega and micro, have their origins in the distant past. Thus, though the Lochiel Landslip, located on the Bumbunga Range, about 115 km north of Adelaide, developed in gently dipping Proterozoic quartzites on 9 August 1974 (Twidale 1986), its origins can be traced back some 700-1000 million years. Its development was, in an immediate sense, due to heavy winter rains, but ultimately and critically to thin lenses of hydrophilic clays which are interbedded with the quartzite, and which provide the lubrication that allowed the quartzite beds to slide downdip over one another. Thus, its origins can be traced to the muds deposited in shallow pools formed behind the beaches of the region in later Proterozoic times. All landscapes are in some measure relic and palimpsest, and to understand the present, account needs to be taken of the geographies of past eras. Similarly, many familiar landforms and landscapes have their origins in magmatic, tectonic or thermal events, or in climatic, weathering, erosional or depositional episodes of the more or less distant past (see e.g. Twidale and Vidal Romani 1994a; Twidale 1994). Whether concerned with the significance of accelerated soil erosion, or the implications of plate motions, a chronological approach imposes an essential perspective on contemporary processes and events that is beneficial not only for professional Earth scientists but also for informed laypersons.

The multifaceted character of geomorphology implies collaboration with colleagues from other, cognate, disciplines (which links are best arrived at not by formal arrangements or regulations, but informally, through friendship and mutual respect and interests). Such cooperative efforts have the potential not only to introduce new concepts, knowledge, skills and perspectives to the study of landforms, but also to bring new concepts and perspectives to those cognate disciplines. Collaboration implies mutual benefits, symbiosis rather than parasitism.

Geomorphology has links with many cognate disciplines, but is at present philosophically and methodologically closest to geology and geography (environmental studies is taken as essentially geography with an applied bent; titles like 'Department of Geography and Environmental Studies' are surely tautological and opportunistic?). Just as where cricket is played is linked to British settlement, where geomorphology resided has varied according to tradition, tempered by personal interest. Thus in the European and British worlds academic geomorphology has been linked administratively with geography. There have been notable exceptions in men like Cotton in New Zealand, Hills in Australia and King in South Africa, Lagasquie in France, each a distinguished geomorphologist based in geology. In the United States, on the other hand, both academic and professional geologists have long been prominent in advancing the discipline, though again there are many exceptions, with geographical geomorphologists responsible for signal advances; and quantitatively the balance may well have changed, for geographical geomorphology is to the fore in the USA, especially in the west. Elsewhere the arrangement varies according to background and historical accident. In Spain, for example, individual interest seems to override administrative base, with geomorphological work flowing from both geologists and geographers; which is as it ought to be.

All three disciplines are retrospective, and in this they are perhaps more overt in their backward look than most; for all sciences are in some degree retrospective rather than predictive, in the sense that they are quite good at explaining what has happened, or what might have happened, in the recent or distant past, but falter when anticipating events. For instance, geophysicists, perhaps the most numerate (and therefore exact?) of solid Earth scientists (in contradistinction to our colleagues whose main concerns are with fluid geophysics, with the oceans and the atmosphere) confidently predicted the depth at which a borehole would intersect the Mohorovici discontinuity beneath the Kola Peninsula, but were proved in error (Kirjuchin and Hetzer 1989; Kazansky 1992).

In theory there ought to be a constant exchange of data and ideas between geomorphologists on the one hand and geologists and geographers on the other. In practice such reciprocal exchanges do not always and everywhere take place. There are many possible reasons for this, but in part it is due to the failure of geomorphologists to capture the attention and interest of their colleagues; there are many exceptions, past and present, but many, perhaps most, of our earth science colleagues remain unaware or unconvinced of the interest and potential significance of geomorphological data and concepts. For whatever reason or reasons, many see geomorphology as a separate and distinct discipline, certainly with historical and practical links with geography and geology, but not essentially either geology or geography.

But all three earth science disciplines considered here are integrational as well as analytical. They are derivative in that they draw heavily for basic concepts, data and techniques on a wide range of cognate natural sciences; and indeed many major advances in the geosciences, as for example in physical dating, have followed from basic discoveries elsewhere. All three disciplines claim distinction for their synthetic, holistic or rounded views that add, and in some instances provide contradictory views, to the narrower reductionist interpretations of physics and chemistry, anthropology and economics; in a sense, geology, geomorphology and geography are testing grounds in the real world for the findings of the systematic disciplines. All three suffer in the eyes of our colleagues from being intrinsically generalist. In addition, as can also be said of both geography and geology, and because of their all-embracing character, geomorphology offers a construction of the mind, as well as a discipline concerned with specific phenomena; for the three Earth sciences endeavour to understand features and events together in their spatial and temporal contexts.

The three have much else in common, but, for the sake of economy, and only for this reason, and *pro tempore*, in this discussion geomorphology, and geomorphologists, are treated as separate and distinct from geology and geography, and from geologists and geographers. Geographical links are considered by Bauer (Chapter 16, this volume). Here the relations of geomorphology and geology are discussed. Obviously this is a personal statement. Essentially factual data form the basis of much of the discussion, as for example in the following section, but it is equally clear that impressions, subjective opinions and speculations loom large in the discussions of the final section. Such is the nature of this particular beast.

LINKS WITH GEOLOGY

Geomorphology is concerned with the evolution of the Earth's surface. Traditionally it has been based in field investigations, supported by various laboratory techniques the nature of which have varied through time; fundamentally, however, geomorphologists have depended on field observations and reasoning therefrom: look and think. Very different interpretations have frequently flowed from the same data, reflecting not so much flawed methodologies as the ingenuity of the human mind. Many of the most enduring of geomorphological discoveries have been based in and stimulated by observations and analyses in the field, where paradoxes and anomalies not only generate ideas and arouse the imagination, but also where those ideas can be tested against reality.

Geomorphological data and concepts have many applications in geology. Some are academic, others practical or applied, and yet others concerned with testing ideas or creating a receptive intellectual climate. The academic contributions of geomorphology to geology can be considered at three levels. First, the land surface provides the budding geologist with his or her initial impression of the Earth in all its variety - continents and oceans, mountains and plains, ice sheets and deserts, volcanic craters and limestone caves. Even to begin to understand the reasons for such variations is to broach basic questions concerning the explanation of past events in terms of present processes, the extent to which subsurface structure finds expression in morphology, and the degree to which past events are reflected in the contemporary landscape. These first impressions are important, for they have the potential to open new vistas for students; yet they are frequently ignored or mistakenly taken as read by modern specialists.

Second, even for an experienced geologist, an understanding of the land surface provides invaluable clues to subsurface structure and to past events. For instance, a knowledge of contemporary processes is essential to any understanding of ancient deposits, whether sedimentary or volcanic. Again, an awareness of forms and controversies is invaluable, so that palaeoplanation surfaces of contrasted morphologies do not imply different climatic environments, and palaeopediments do not necessarily imply aridity or semi-aridity. The study of features resulting from modern earthquakes permits better interpretation of palaeoseismic forms and stress fields. The present is the key to the past.

The greater the degree of understanding, the broader the background brought to the study of landforms, the greater is the potential for germane criticism of ideas and the development of new interpretations. As Pasteur pointed out, chance favours the prepared mind. Certainly, the best field men I have known and worked with, people like Hills and Opik, Wopfner and Jennings, Wahrhaftig and Hutton, each had (and in one instance happily still has) a marvellous 'eye for country', reflecting an eclectic view of the Earth sciences, and a holistic view of the planet. Hills for example made signal contributions to virtually all aspects of geological science, being perhaps best known for his work in structural geology and physiography, yet achieving his Fellowship of the Royal Society of London for his work on fossil fish. And many others, like Gilbert and Gilluly, Rubey and Rodgers, have demonstrated that breadth of interest need not be incompatible with profundity of expertise. Thus, Rubey was able not only to speculate rigorously and imaginatively on the origin of the oceans but also to make critical contributions to the understanding of river activity. These men were generalists whose broad interests and intellectual capacities implied not superficiality, but an enviably coherent view of the Earth.

Third, geology is concerned to understand and interpret the history of the Earth. Historical geology or stratigraphy *is* geology and is concerned with an infinite number of palaeogeographies, superimposed one upon the other to produce the present palimpsest landscape. Yet most commonly stratigraphers restrict themselves to the sedimentary, igneous and metamorphic records and neglect evidence from the erosional side of the coin and concepts derived from such investigations. They are the poorer for such self-imposed restrictions, for to ignore or neglect the evidence manifested in the land surface is deliberately to overlook a major source of information and ideas.

Some Examples of Academic and Applied Interactions

Though geomorphologists are in some countries employed in environmental capacities, the generalist and non-particular nature of our interests and approaches reduces the opportunities for employment. Thus in many countries flood hazards and coastal protection are the provinces of the engineer rather than the fluvial or coastal geomorphologist. Geomorphologists can provide an unequalled general setting of a particular problem, but, in most instances, not specific data and solutions. Particular areas of interest such as palaeosurfaces have been explained so clearly that if and when they become of economic importance (see below) they are readily understood and become part of 'proper' geology!

Surfaces and time

The morphology of the Earth's surface reflects past events, and most of the processes responsible for denudation in the past are still active, so that an understanding of the genesis of contemporary landforms offers evidence germane to the interpretation of past events. Indeed, in some areas, as for instance much of southern Africa, the Yilgarn Craton and the Hamersley Ranges of Western Australia, and the Gawler Ranges in South Australia, the land surface provides much of the evidence of events and conditions in these regions over vast periods of geological time. Such cratonic regions have been stable and unaffected by marine transgressions over most of Phanerozoic time, so that it is the correlation of planation surfaces and associated weathering and fluvial forms with valley deposits and the sedimentary sequences of adjacent basins, plus the chronology of fluvial and aeolian forms and sequences, that allows a chronology of events to be determined (see e.g. Jutson 1914; van der Graaff et al. 1977; Twidale et al. 1985; Campbell and Twidale 1991). It is for good reason that Lester King stated that '... the great plains and plateaux ... record in a relatively simple manner the geomorphological history of the continents' (King 1950, p. 101).

In addition to Earth history, however, several geomorphological concepts impinge on geological interpretation. For example, the links between the erosional and depositional records are not always clear, though as Kennedy (1962) has suggested, there ought to be direct correlations between volume and type of sediments contributed to depositional basins and the character of the source areas on the one hand and the erosional style - the relationship of uplift, stream dissection and wasting - on the other.

The paradox and problems presented by contrasted rates of geomorphological activity evidenced in the landscape, pose intriguing intellectual dilemmas with possible impacts, for example in basin studies and in planning. Some areas change quickly, but others are evidently stable, or essentially so, over periods of scores, or even hundreds, of millions of years (e.g. Twidale 1976a, 1994; Twidale and Vidal Romani 1994b). How stable is stable, and how frequently, both spatially and temporally, can rapid change be anticipated, for instance in the coastal setting and in areas prone to mass movements?

Unconformities denote significant stratigraphic events, and are also of interest to geomorphologists, for they are widely re-exposed as exhumed surfaces and forms (see e.g. Falconer 1911; Ambrose 1964; Twidale 1994). Their characteristics vary according to the nature of the preserving event. Regoliths rarely survive marine transgressions, lacustrine or fluvial burial, or glaciation, but they are preserved by aeolian or volcanic deposits. Even fragile forms like barchans are preserved beneath lava flows (e.g. Almeida 1953), thus permitting the reconstruction of palaeowind directions. Many erstwhile unconformities are exposed as exhumed forms and surfaces, particularly marginal to cratons. Exhumed surfaces can be confused both conceptually and in the field with two-stage or etch forms, and it is critical to stratigraphic interpretation to distinguish between the two, for one implies a hiatus during which there was burial and re-exposure, the other the formation and stripping of a regolith. Two-stage, or etch, forms have long been recognised (e.g. Hassenfratz 1791; Falconer 1911), and they carry several additional implications. For example, they have two ages, one relating to the period of initiation, the other to exposure (e.g. Twidale 1990). Also, they are azonal, for though different processes may well be involved, they are determined by conditions in the regolith, not in great measure by atmospheric climate.

In some areas, the nature and age of surfaces have economic implications. Thus, many years ago (Jack 1931; see also Wopfner 1964) it was shown that the planation surface eroded in Proterozoic and Palaeozoic strata west of the Eromanga Basin in northern South Australia is exhumed from beneath a cover of late Jurassic and early Cretaceous strata. The former extent of that cover, i.e. of the present exhumed surface, has now become of economic significance, for opal appears to be associated with the base of the Mesozoic sequence. New opal fields, like that at Mintabie, are now being sought and developed on Precambrian and Palaeozoic terranes from which the previous Mesozoic cover has been stripped.

Weathering and the regolith

The regolith is regarded by some geologists as a nuisance concealing the solid or 'real' geology, but investigations of the weathered mantle, including duricrusts and alluvial deposits, have proved rewarding in the search for gold, diamonds and nickel (e.g. Whiting and Bowen 1976; Marshall 1988; Clarke 1994). Also, processes active in the regolith result not only in continuing landform development but also in engineering hazards. Thus, during the planning of the Alice Springs-Darwin railway link in the early 1980s numerous dolines or sinkholes developed in the laterite of the Sturt Plateau, in the northern, monsoonal, Northern Territory, were located. They are still developing and it is of critical importance to determine their origin so that a least-risk route, avoiding fracture swarms and palaeovalleys, both of which sites are conducive to the silica solution responsible for the features, can be found over the Plateau (Twidale 1987a).

Nature of landforms

The nature of a landform or surface, whether erosional or depositional, is important when considering underground water supplies and oil and gas potential. Thus, whether a piedmont fan feature is an erosional pediment underlain by bedrock, with at most a few metres of regolithic cover, or an alluvial feature underlain by a thick wedge of sediments, is of some practical significance, as well as being of academic interest. The two morphologically similar features can be distinguished using various surficial criteria, such as remote sensing imagery, drainage density, and catchment characteristics (Bourne 1996; Boume and Twidale 1996).

Fractures

The relationship between structure and surface expression is all important in photogeology and reconnaissance exploration. Many of the relationships are obvious, others subtle. As Hills' work on lineaments demonstrated (e.g. Hills 1961), many of them are fractures and the surface expression provides important clues not only to subsurface structure but also to targeting deeply buried potential mineral deposits, as for example the Olympic Dam deposits in the and interior of South Australia (O'Driscoll 1986; Woodall 1994). Again, though at a vastly different scale, the Norseman gold discoveries of the years immediately preceding and following the Second World War were greatly assisted by Cloos's (1931) experiments on deformation and the development of sets of shears (Campbell 1990). Other examples are detailed by Heidecker, Moore and Campbell in the *Festschrift* dedicated to Hills (Le Maitre 1989).

Fracture patterns have a profound influence on various facets of landform development at scales ranging from continental to site (see e.g. Hills 1961; Zernitz 1931) and can be related to the morphology of continents, sedimentary basins, massifs and bornhardts, as well as occurrence, shape and alignment of such features as boulders, flared slopes, rock basins and gutters. Yet, commonplace though they are, fractures in general are poorly understood and none more so than those usually referred to as offloading or pressure release joints. That this terminology stands is a measure of the confidence geologists have in the implied explanation. And it is seemingly logical and persuasive (Gilbert 1904). Yet there is more than one logic, and various geologists and geomorphologists (e.g. Merrill 1897; Twidale 1964) have over the years drawn attention to anomalies between the alleged expansive and tensional environment implied in Gilbert's hypothesis and the common, indeed characteristic, occurrence of sheet fractures in bornhardts.

Many of the latter are of the same lithology as that in which the adjacent plains are developed. The residuals are most likely preserved because the rock compartments on which they are developed, are in compression, causing fractures to be suppressed and thus scarce or absent; in contrast to the high fracture densities of adjacent compartments which are thus vulnerable to groundwater penetration, to weathering and to erosion (Twidale 1982a, b). Holzhausen (1989) has shown experimentally that stress trajectories in a compressed partly confined block describe a convex upwards pattern. Various other lines of morphological and structural evidence, as well as general argument, can be brought to bear on the question at the very least calling into question the universal validity of the offloading hypothesis (e.g. Vidal Romani et al. 1995; Twidale et al. 1996), and highlighting possible stress conditions that are of practical importance to engineers and planners (e.g. Twidale and Sved 1978; Wallach et al. 1993). Thus studies of palaeoseismicity, fracture patterns and landforms, and their implications for plate tectonics during both the present migrations and former cycles (e.g. Nance et al. 1988), have considerable practical applications. Also, the tendency of fractures to adjust to landsurfaces, the plane of least principal stress, means that the geometry of palaeosurfaces is of practical interest to engineers engaged in deep excavations.

Again, investigations of fracture patterns and densities at the surface and at depth in relation to the storage of liquid nuclear waste (Bles 1986) have revealed that surface patterns provide a reliable indication of pattern at depth. Incidentally and inadvertently they also strengthened the interpretation of inselbergs based in variations in fracture density (e.g. Mennell 1904; Linton 1955) by allowing reliable extrapolation of surface patterns to higher compartments that have been eliminated by erosion (Twidale 1987b).

Drainage patterns

Fractures also have a marked influence on drainage patterns, which thus provide invaluable clues to rock type and structure (e.g. Zernitz 1931). The patterns developed by river systems are, however, frequently misunderstood, even by astute field geologists, as for example the significance of entrenched meanders (e.g. Campana 1958). Structurally anomalous drainage patterns are likewise commonly misconstrued (e.g. Madigan 1931). Some transverse drainage can be referred to catastrophic events such as diversion by faulting or folding, volcanism, ice sheets or glaciers. Some, and in particular antecedence, inheritance and superimposition, carry considerable implications for stratigraphic history (see e.g. Marr 1906; Harris 1939; Cotton 1948, p. 56; Lees 1955; Bowler and Harford 1966). But others reflect the basic locational stability of rivers. Rivers are prime examples not only of the impacts of unequal activity (Crickmay 1932, 1976) but also of positive feedback or reinforcement mechanisms; for, once established, their growth implies the gathering of more and more water, both surface and subsurface, and the increasing and enhanced dominance of the river as a master element in the regional pattern. Thus, many drainage anomalies reflect the deep erosion by master streams of fold structures, the geometry of which changes with depth: they can be attributed to stream persistence and valley impression (Oberlander 1965; Twidale 1966, 1972).

Drainage patterns and their evolution are significant in the search for minerals such as diamonds, uranium and gold, and the investigation of palaeochannels can be similarly rewarding (e.g. van der Graaff et al. 1977; Clarke 1994). Thus the Yeelarrie uranium discovery of the late 1960s and early 1970s was based on the realisation that the ore was concentrated in a buried but extensive palaeodrainage channel (Cameron 1991), and a similar genesis is advocated for the uranium deposits of the Narlaby Channel, on northern Eyre Peninsula (Bourne et al. 1974; Binks and Hooper 1984).

Verification

Geomorphological field investigations have brought to light problems of interest to other scientists and have also devised means of testing theories and problems posed by others. For example, during routine morphological mapping of the Beda Valley, southern Arcoona Plateau, South Australia, silcrete was located in two settings, valley floor and scarp foot. The former occurred in sheets, the latter as skins rich in titanium oxide (anatase), and the chemistry and mineralogy of the two differed. This led not only to the development of various new ideas on the origin of silcretes, but also raised the question of the solubility of titanium in natural conditions (Hutton et al. 1972, 1978; Milnes and Hutton 1974; Hutton 1977). The conventional chemical wisdom is that crystalline silica is of relatively low solubility in the ambient temperatures and chemical environments found at and near the Earth's surface (e.g. Krauskopf 1956), but its occurrence in river waters (e.g. Davis 1964), the widespread development of siliceous speleothems (e.g. Vidal Romani and Vilaplana 1984), and the obvious dissolution of silcrete and siliceous skins demonstrate that in some natural conditions silica is soluble. The solution of opaline forms of the mineral resulting from hydrolysis of quartz is especially important and, as in many other weathering processes, the presence of bacteria may be critical.

In a series of papers Hunter and Rubin (e.g. Rubin and Hunter 1985) have highlighted an apparent anomaly between past and present deserts. In the stratigraphic record there are thick sequences of sands evidently deposited in desert dunes of the longitudinal (linear, seif) type, which also dominate modern dunefields. At present, in some deserts at any rate, the dunes are separate entities resting on genetically unrelated substrates (see e.g. Wopffner and Twidale 1967, 1988; Mabbutt and Sullivan 1968). In order to produce sequences like those preserved in the stratigraphic record it is necessary to postulate that linear dunes migrate laterally, but in central Australia the field evidence, as well as a consideration of reinforcement principles, suggests that they do not (e.g. Nanson et al. 1992). Other explanations must be sought for the origin of the ancient dune deposits. For exarnple, did the thick dune sequences form in actively and rapidly subsiding basins?

Geomorphological concepts are also useful in either testing or applying concepts devised by scientists in other areas. For instance, it has been suggested that the rate of cosmogenic nuclide accumulation in surface exposures can provide absolute dates for those surfaces (Lal 1991). Some early results are at odds with either stratigraphy (e.g. Phillips et al. 1990) or dates produced by other physical methods (e.g. Wells et al. 1990, 1992). The reasons may lie in the retention rates of the nuclides, which may reflect the weathering and permeability of the host rock, or the date of exposure of the bedrock surface, i.e. whether the surface is of etch origin or whether it has had a soil cover or covers since its essential initiation. For these reasons, the stepped inselbergs of northwestern Eyre Peninsula and other regions (Twidale and Bourne 1975; Twidale 1982a, c) are particularly suitable for testing the cosmogenic nuclide method, for the steps separating the treads are flared slopes which are sufficiently steep to have been devoid of a regolithic cover since their exposure. The treads on the other hand, though altitudinally and temporally distinct and now mostly devoid of soil, may have carried a cover in the past and dates from them could well be anomalous or misleading. In addition, rates of erosion can be misleading, for there is no indication of any variation through time. Also, geomorphological theory suggests that most surfaces are diachronic or palimpsest, so that any dates obtained for a particular section would most likely be misleading. On the other hand the method is suitable for dating palaeoseismic and other catastrophic events.

Intellectual climate

Scientific advance comes through the conception and development of outrageous ideas, and it is essential that, just as a free society, as defined by Adlai Stevenson, is one in which it is safe to be unpopular, so unconventional explanations must not be ridiculed and automatically ruled out of court. The value of a principle is the number of things it explains, and many useful concepts have begun life in controversy and extreme scepticism, if not disrepute. If the data and argument following from an idea seem valid, and the cause involved is worth while, tenacity is justified: but tenacity and enthusiasm, not dogmatism. There is surely call for an intellectual climate which allows for rational consideration of concepts alien to the conventional wisdom, for reasoned debate rather than entrenched confrontation.

Thus, the suggestion that some landscape elements are of great antiquity conditions the mind at least to contemplate the possibility of a great age for seemingly vulnerable, and hence, by implication, youthful, deposits and surfaces. To take a simple exarnple: on emerging from the Mt Lofty Ranges, the River Torrens near Adelaide has deposited a train of boulders, cobbles and gravels. These deposits remain essentially unlithified. Moreover, during the Miocene the immediately adjacent area to the south was a marine embayment. The location and character of these sediments suggest a youthful, later Cainozoic, and possibly Pleistocene age. The coarse, fluviatile deposits can, on another interpretation, however, be traced laterally into fossiliferous Eocene paludal or lacustrine deposits, in which case the sediments and the ancient Torrens to which they are genetically related are also Eocene. This is consistent with a widely, though not unanimously, held view of the regional geology and geomorphology, involving planation and weathering of the upland followed by block faulting beginning in the Eocene (for review and earlier references see Twidale 1976b).

Once possible antiquity is allowed, evidence can be taken at face value rather than circumvented or rejected out of hand. For instance, it may seem impossible for coastal dunes, even dunes protected by calcrete, to survive at least 20 million years, yet this is the conclusion dictated by the field evidence for the Ooldea and Barton ranges, in the arid interior of South Australia (Benbow 1990).

While not neglecting detail, it is also important to retain some perspective concerning global scale features and problems. Megageomorphology, which implies a global view of landscape patterns and evolution, will in due course become recognised as an essential adjunct to the study of many aspects of geology. I have in mind the behaviour of planation surfaces and their implications for plate tectonics, for isostatic principles, and for models of landscape evolution additional to those already suggested (e.g. Davis 1899; King 1942, 1953; Hack 1960; Crickmay 1974, 1976; Twidale 1991). Consideration of the nature and limitations of river erosion is also germane to models of landscape evolution (e.g. Crickmay 1976; Twidale 1991) as well as for the duration and ultimate significance of accelerated soil erosion. The significance of two-stage development remains underestimated. The relationships between weathering and erosion, and in particular the erosion of regoliths, with its implications for the character of basin deposits (e.g. Nahon and Trompette 1982), have still fully to be appreciated. The solar system cannot be ignored in the quest for understanding the Earth, for it provides indispensable pictures of the planet as it was billions of years ago, as well as providing examples of landscapes in extreme aridity and processes operating at scales rarely, if ever, attained on this planet (see e.g. Baker et al. 1983; Wilhelm 1987).

Thus, geomorphology benefits enormously from geological mapping and analysis, and from the application of geological concepts. But geomorphology has in turn contributed much to geology through its role in mapping, in its analyses of the erosional as well as depositional aspects of earth history, of the reconstruction of subsurface conditions from surface morphology, of the meaning of planation surfaces, and by process studies in terms of the present providing the key to the past. Many of its contributions are even of applied significance; they are 'relevant'! Like the biological, medical and engineering sciences, all of them concerned with various aspects of nature in all its complexities, geomorphology is in considerable measure derivative. Geomorphologists have, like others, taken ideas and tested, developed and enhanced them in the field, in their real-world settings. They have been able to place them in temporal context, for instance to analyse the significance of long-period cataclysmic events as compared to the gradual effects of various processes (e.g. Wolman and Miller 1960; Baker 1973).

THE PROBLEM: THE ORPHAN ANNIE SYNDROME

Geomorphologists have offered and delivered data and concepts of obvious academic and practical value to geologists. Yet, despite this, there are problems. Geomorphology can at once be construed as the study from which both geology and geography emerged and also as derived from both disciplines. Following this second analogy, both putative parents frequently disclaim their offspring with the result that in places, and from time to time, geomorphology is orphaned. And despite Oliver Twist being regarded by some as being fortunate to live in such an exciting orphanage, the geomorphologist's lot, like the policeman's, is not an 'appy one.

The problem can be examined in two contexts. First, geomorphology is regarded by some academic colleagues as lacking rigour. It is, like geology and geography, disparagingly regarded as a 'soft' or derivative science in contradistinction to such 'hard' or basic disciplines as chemistry and physics. Geomorphologists are perceived by their peers in the systematic natural sciences as derivative generalists, concerned with the collection and coordination of data derived from the systematic sciences and in a series of spatial and temporal contexts. These critics are either unaware of, or totally misunderstand, the intellectual effort represented by, say, a geomorphological map (and producing a legend!). They regard fieldwork as an excuse for a holiday. They have no comprehension either of the difficulties and problems that arise in correlating raw data in space and in the immensity of time, or of the implications for the systematic sciences of anomalies that come to light in the complex real world.

Second, though geomorphology does not lack definition, identity, or interest and support, both in the academic world and generally, its usefulness is perceived, and in the main with good reason, to be academic and general. In hard economic times, like those many countries and universities are now experiencing (though governmental priorities also come into play), geomorphology is seen by some, in terms of cost-benefits, i.e. numbers and employment opportunities, as academically and economically non-viable, and as war-ranting only low priority. Geomorphology is no longer a formal or required component of several distinguished geology schools. In the United States the rejection has been most pronounced in the Ivy League institutions, but several other eminent geology schools do not now offer formal courses in geomorphology.

Geographers, too, can find geomorphology superfluous to their needs and interests. This has happened in some departments in the United States, and in Australia the distinguished biogeographical and geomorphological group at the Australian National University, once graced by such as Donald Walker, Joe Jennings and Jim Bowler, has now been subsumed in the Department of Archaeology, with the rider that any geomorphological research shall be related to matters human and thus be germane to the overall archaeological functions of the institution. In my own university, geomorphology was initially, and for historical reasons, based in geography. Then, in the 1970s, the geographers decided that geomorphology, and other physical disciplines, were not part of mainstream geography, and geomorphology was transferred to and delivered out of geology (Bowie 1982). In the early 1990s, geography found a renewed interest in things physical, including geomorphology, while geology, in financially pressing times, developed higher priorities. On such whimsies is the fate of geomorphology - and geomorphologists - determined.

That poor performance is not the reason for geomorphology being regarded as dispensable is demonstrated, beyond any possible doubt, by the distinction of many of our American colleagues who, once retired or otherwise out of sight and mind, have not been replaced; giving an innovative twist to the meaning of 'irreplaceable' (R.W Young, personal communication, August 1995)! Some geologists still perceive geomorphology as not quite scientific; as more akin to natural history, a term used pejoratively of what are seen to be amateurish pursuits which are unsuitable and inappropriate to a rigorous intellectual discipline (shades of Newton, White, von Humboldt and Darwin!).

At present, the acceptance of geomorphology as a discipline varies directly with the economic well-being of academia and with the desirability and perceived viability of cultural--educational pursuits. Given ready funding, geomorphologists will be tolerated in the geological household, but it takes a geologist of eclectic views to welcome the discipline in hard times. Though, like George Eliot, I personally do not desire a future that will break ties with the past, and think it impractical and imprudent to do so, it might be asked why geomorphology does not simply ignore and abandon its past, and, to resume an earlier metaphor, set up house on its own, instead of cohabiting, frequently in some discomfort, with either geology or geography? Could geomorphology stand independently as a bridge, as distinct from a link, between not only geology and geography but also between several other disciplines, a concept voiced by Dusty Ritter (personal communication, November 1995)? This is an attractive idea, one that could readily be sustained in academic terms, and one I had entertained before Dusty revived my interest in its possibilities. But I fear I must still, reluctantly, rule it out of court as desirable but impractical.

A comparison may be drawn with another branch of Earth science that is of mixed parentage, has from time to time found itself understandably confused as to its place and purpose, and has occasionally asserted its independence and gone its own way, namely palaeontology or paleobiology. Because of its commercial connections, palaeontology has a stronger funding base than does geomorphology. On the other hand, separation from other geological sciences robs palaeontology of its essential stratigraphic background, as well as depriving geology *sensu lato* of essential inputs to and critical aspects of Earth history.

Many of the same arguments apply to geomorphology, though they are perhaps less obvious and less pressing. Quite apart from the problem of numbers, nowadays so crucial in university thinking and funding, geomorphology shares interests with many other disciplines in the natural and social sciences; a large 'gene pool' of ideas and concepts is advantageous, if not essential. Of these cognate disciplines, geology and geography are historically and intellectually the closest. Geomorphology has obvious and genuine links to environmental studies, but the latter is basically applied and in such a context, and in the worst-case scenario, basic science tends to be neglected and even to be subordinated to political and economic requirements. Thus, though in theory an independent geomorphology has much in its favour, it is a Utopian dream, for the realities of academic life argue against such an arrangement.

Geomorphologists are concerned to explain the present landscape. Yet, taking a coldly rational viewpoint, and thus ignoring the factors of tradition and personal relationships (either of which can have an overriding local influence), some favour geology as the chosen partner, first because of the chronological imperative, but also, and from a purely practical point of view, because many necessary or desirable facilities are common to geology and geomorphology. Though it does not sound either spectacular or obviously useful, geomorphology's main claim to a secure home in geology or geography, or both, rests on its being concerned with an integral part of Earth history, and with providing perspectives on time, space and process. These are vital, yet tenuous and in many instances intangible, links; but, then, many of our intellectual, cultural, historical and ethical underpinnings and beliefs are similarly tenuous. They are no less real for being intangible, though they are vulnerable to being shed, at least temporarily, and if convenient or advantageous to do so. A chronological and spatial perspective is to geologists as air is to humans; essential, critical, but taken for granted, until it either runs short or is threateningly polluted. This is not to suggest that geomorphology has a monopoly on understanding Earth history - far from it - but geomorphologists have made significant contributions. They have, perhaps, been too successful in explaining their thinking in so far as complex ideas have been presented in language understandable by all, in contrast to the jargon-laden obscurities of others. If to be incomprehensible is to be intellectually respectable, most geomorphologists have failed.

The past decades have been dominated by specialists, many trained in physics or chemistry and applying their knowledge and expertise to geological and geomorphological problems. The various methods of physical dating of rocks come readily to mind. Their contributions have resulted in enormous advances in knowledge of the Earth. But the need for a multidisciplinary attack is demonstrated by the team approach to research that is nowadays so commonplace. Even with such arrangements, however, there is still a need for a broader perspective, not only because of the multiplicity and variety of causative factors, but also arising from the need to see those complexities and factors in the context of an entity. Broader and more generalist integrative perspectives are or ought to be an integral part of scientific inquiry. It is to be hoped (and I am optimistic – super-optimistic according to Dusty! - that common sense will eventually prevail) that current intellectual and academic climates will change. My optimism is based in the likelihood that sooner or later it will be accepted, even by politicians, that long-term investment in research and education is essential to any developed and civilised (they are not necessarily the same thing) nation's well-being.

Many of the problems afflicting geomorphology, and other basically academic, curiosity-driven disciplines like classical studies and philosophy, stem from the present intellectual, or rather anti-intellectual, climate. In particular the attitudes born and nurtured in political correctness (which is so much in vogue but which has perverted language and logic, thought and justice, and which is anti-intellectual and anti-common sense: see e.g. Bloom 1987; Howard 1994; Hughes 1994), with the emphasis on immediate relevance and cost-benefits, must surely soon be seen for what they are, and abandoned. Political correctness is at once responsible for the diminution and humiliation of such prestigious research institutions as the United States Geological Survey (USGS) and Australia's CSIRO, and for the utter debasement of the university ethos. The politically correct find it convenient not to appreciate either the need for long-term investment in science and education, or the need for an educated, as opposed to a trained, electorate; or is it, to paraphrase Voltaire, that once the electorate becomes capable of critical analysis and thought, all is lost? Of the earth sciences, geomorphology has suffered as much as any from this philistine attitude. Appreciation of the wide-ranging perspective, a return to scholarship, learning and education, and the acceptance of curiosity as a valid reason for inquiry, can only benefit geomorphology. Eventually, necessity will compel a reversion to sound educational practices and to a recognition of integrity as an integral requirement of academic life.

The structural foundation of landscape studies is so all-pervasive and obvious that it has been taken for granted and neglected. Similarly, the role of geomorphology in the totality of geology was so obvious to, and accepted by, the great figures of the past that there was never any need to justify it - until the present. And it is, despite the growing appreciation of the role of geomorphological investigations in mineral exploration, a point of view difficult to justify to an accountant. We must persevere with a holistic and non-reductionist view of the evolution of the Earth's surface. The wide-ranging general outlook is our strength. As Eiseley (1961, p. 91), put it, for James Hutton: 'A landscape is not a given thing, shaped once and forgotten, but rather a page from a continuing biography of the planet.' Whether notionally geologists, geographers or geomorphologists, and presuming that we seek to understand, we surely ought to read *all* the pages, not just that which appeals to our sectional and vested interests.

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