5

FORM, PROCESS AND MATERIALS

Approaches to a central concept of form, process and materials have focused on processes, landform evolution, and climatic geomorphology. Although these developed separately until the late 20th century a more holistic approach has recently brought them together, especially fostered by multidisciplinary research. It is now appreciated that advances in macroscale geomorphology have enabled large-scale landform developments to complement small-scale process research. Using covering law models of explanation, it is possible to recognize geographical, geophysical macro geomorphology, and historical approaches

Landform is the subject matter for geomorphology as the landform science, so that it follows that a central concept is the relationship of landform, process and materials. Although manifested in various ways over the last one hundred and fifty years it has not frequently been stated explicitly. However, it has been presumed, although some have recognized a growing emphasis on the 'mutual interaction between form and process in the understanding of geomorphological systems' (Roy and Lane, 2003). This chapter provides a summary of interrelationships (5.1); indicates how distinct concepts emerged during the progressive development of geomorphology (5.2); and surveys the present position (5.3).

5.1 Relating form, process and materials

The relationship between these three characteristics of the Earth's surface can be summarized by a simple geomorphological equation, adapted from a physical geography equation (Gregory, 1978a) subsequently accepted by a number of writers including Yatsu (1992) and Richards and Clifford (2011). The equation was devised to indicate the way in which processes (P) operating on materials (M) over time t produce results expressed as landforms (F). In equation form it can be expressed as:

$$F = f\ (P, M)\ dt$$

Geomorphological investigations can be visualized as concerned with five levels of enquiry as summarized in Box 5.1.

BOX 5.1

A way of summarizing geomorphology (see Gregory 1985; 2000; 2009)

A geomorphological equation, indicating how *processes* operating on *materials* over time *t* produces *results* expressed as a landform, can be expressed as:

$$F = f(P, M)\,dt$$

Investigations can be made at five levels:

- *Level 1: study of the elements or components of the equation* – study of the components in their own right. Some studies can be focused on the description, which may be quantitative, of landforms, of soil or rock character, or of plant communities.
- *Level 2: balancing the equation* – study of the way in which the equation is balanced at different scales. At the continental level may involve the energy balance relating available energy for environmental processes to radiation, and moisture received in relation to locally available materials. Studies of this kind focus upon contemporary environments and upon interaction between processes, materials and the resulting landforms or environmental conditions.
- *Level 3: differentiating the equation* – includes studies analysing how relationships change over time. This requires reconciliation of data obtained from different time scales together with a conceptual approach. Includes impact of climate change and human activity which may be the regulator that has created a control system.
- *Level 4: applying the equation* – when research results are applied to problems, very often extrapolating past trends, encountering the difficulty of extrapolating from particular spatial or temporal scales to other scales for which information is required to address management problems.
- *Level 5: appreciating the equation* – involves acknowledging that human reaction to physical environment and physical landscape can vary between cultures, affecting how the earth's surface is managed and designed

5.2 A theme prevailing in the development of geomorphology and landform science

During the course of the development of uniformitarianism there was an alternation of catastrophism and gradualism, but once the focus on landform relationships with processes and materials was embraced a sequence of geomorphological approaches evolved. It was perhaps inevitable that such approaches would each have a major driver, such as erosion, landscape change or climate. Portrayed by Jennings (1973) as a geomorphological 'bandwagon parade', this can be thought of as a sequence of paradigm shifts (Gregory, 2010: 35, Table 2.5). The emphases on form, process and materials have changed over the years (Richards and Clifford, 2011), but understanding the developing sequence is necessary to appreciate how they each affect contemporary thinking in geomorphology. Whereas we are now familiar with extremely rapid communication in geomorphology (e.g., Gregory et al., 2013) different approaches originated when it took much longer to surmount the obstacles of different languages, there were comparatively few national and international scientific meetings, few scientific journals for the publication of research and dissemination of ideas, and few researchers in the community of scholars concerned with investigations of the surface of the Earth.

It is not easy for a student in the 21st century to comprehend the multifarious strands that have produced the geomorphology of today, so that we require a convenient way to encapsulate the inter-relationship of the major founding developments, and to set them into the context of developments in other disciplines which were so influential at the time, permeating geomorphology and other sciences. **Table 5.1** shows the main strands of thinking identified to focus on form, process and materials and underpinning thinking in geomorphology. What is much more difficult is divining the links that have occurred between the several strands, and ascertaining the extent to which similar ideas developed independently in different places. However, a map of past activity of this kind is needed to ensure that the modern outburst of literature and communication is not oblivious of past contributions – we must not re-invent the wheel! There is practical value in knowing the historical development of geomorphology (Sack, 2002).

The inclusions in **Table 5.1** provide a framework that can be augmented and extended. The three major themes – process, evolution and climatic variety – are integrated with external trends which include systems, developments in other disciplines such as hydrology, analysis of ocean cores stimulating research in Quaternary science, remote sensing and the availability of other techniques including GIS and cosmogenic dating. Each of the major themes is explained in detail elsewhere (e.g., Summerfield, 1991; Gregory, 2000, 2010) and expanded in later chapters (11, 15), so that a brief outline is provided here.

The process theme dates from when there was a debate about how the Earth's surface was fashioned, and when actualism and gradualism succeeded catastrophism (see Chapter 3). However the main strand derived from the work of G.K. Gilbert (1843–1918), one of the explorers of the American West, who from the 1880s were demonstrating the power of subaerial erosion in producing landforms. In his later work Gilbert used analogy with physical mechanics and studied landforms as manifestations of geomorphic processes acting on Earth materials (Sack, 1991: 30), with the result that he is now acknowledged to be a brilliant geomorphologist who published a remarkable investigation on the *Transportation of debris by running water* in 1914, anticipating many developments that did not occur until nearly fifty years later. Although there were some subsequent fluvial contributions it was not until 1964 with the publication of *Fluvial Processes in Geomorphology* (Leopold et al., 1964) that a new era of process investigation became widespread, emphasizing physical principles, dealing 'primarily with landform development under processes associated with running water . . . better future understanding of the relation of process and form will . . . contribute to, not detract from, historical geomorphology'. Parallel with the interest in fluvial processes were other strands: coastal, glacial, and aeolian, the latter stimulated by a book on *Physics of Blown Sand and Desert Dunes* (Bagnold, 1941).

The second theme, labelled evolution, and possibly influenced by Darwinian evolution (1859), was introduced in 1895 by W.M. Davis (1850–1934). With the benefit of hindsight we now realize that his approach gave insufficient attention to the formative processes operating, was essentially qualitative in approach, focused on parts of the land surface and ignored others, and did not have a sound scientific foundation (see Chapter 11, **Box 11.1**, **Table 11.1**); however, his work was very intelligible and persuasively presented. The essence of his approach, which appealed to persons with little training in basic physical sciences, was that landforms are a function of structure, process and time, and evolve through stages of youth, maturity and old age. This conceptual model was devised for a 'normal' cycle of erosion applied to temperate landscapes, but alternatives of arid and marine cycles were also proposed, and in the course of landscape evolution there could be accidents, either glacial or volcanic. Land surface was interpreted in terms of the stage reached in the cycle of erosion and came to be dominated by a historical interpretation concentrating upon the way in which landscapes had been shaped during progression through stages in a particular cycle, towards peneplanation. Followers of this approach therefore attempted to identify the stages of long-term evolution of landscapes – an approach later termed denudation chronology (see Gregory, 2000: 38–42). A collection of Davis's influential essays and papers (Johnson, 1953) included 12 educational essays and 14 physiographic essays. This shows the interest that Davis had in geographical teaching, fulfilling the substantial need that existed at the time, and the popularity of his approach was attributed to 12 reasons (Higgins, 1975) with simplicity the first! This approach was followed by others (see Chapter 11), with that of Lester King formalized as 50 canons of landscape evolution (King, 1953: 747–50). These approaches to landscape evolution largely concentrated on the ways in which landscape had been fashioned in the later stages of geological time (see Chapter 13), the Cainozoic, including the Palaeogene, the Neogene and the Quaternary. Although the analysis of Quaternary glacial impacts was being investigated during the 20th century, generating researchers in glacial and later in periglacial geomorphology, it was with improvements in dating that Quaternary Science really flourished and began to evolve as a separate field.

A climatic focus probably had its origins in Russia where soil scientists such as Dokuchaev (1846–1903) and his student Sibirtsev identified broad zonal patterns of soils related to climate. Dividing the land surface of the Earth into major zones as a basis for considering how different landforms occur in world landscapes, climatic geomorphology found favour in Europe and Russia because it could embrace the way that soil and vegetation types are associated with particular zones, reflecting also the morphoclimatic zones recognized in France (Tricart, 1957). In qualitative terms, phenomena could be regarded as zonal if they were associated with the climatic characteristics of latitudinal belts, whereas azonal phenomena are non-climatic such as those resulting from endogenetic processes; extrazonal phenomena are those occurring beyond their normal climatic limits such as sand dunes on coasts rather than deserts; and polyzonal phenomena are those which can operate in all areas of the Earth's surface according to the same physical laws. Such zonality provided the basis for 13 morphoclimatic zones (Tricart and Cailleux, 1965; 1972). An energy balance foundation was used to provide a quantitative climatic basis for geographic zonality. Subsequently, three generations of geomorphological study were recognized (Büdel, 1963) in a system (see Chapter 11) introduced in Germany which became more widely known after a paper by Holzner and Weaver (1965), and was also gradually refined to culminate in eight climato-morphogenetic zones. A scheme of nine morphogenetic systems was introduced in the USA (Peltier, 1950; 1975), each distinguished by a characteristic assemblage of geomorphic processes, stimulating interest in periglacial environments in particular.

It might appear that materials have attracted less attention than process and form, although an early geological approach to geomorphology believed that many features, including remnants of erosion surfaces, could be ascribed to the control by lithology on surface form. Awareness of the importance of lithology was particularly evident in limestone areas and karst geomorphology was named from the Dinaric karst region of Slovenia where features had been recognized as early as 1893 (Cvijic´, 1893; Benac et al., 2013). In karst areas field monitoring of solution processes produced some of the earliest measurements of erosion in the mid 20th century and it was from these that many subsequent process investigations stemmed. Karst is best developed on carbonate rocks which occur on some 14% of ice free continental areas (Ford and Williams, 2011) but related features also occur on other soluble outcrops such as gypsum (e.g., Doğan and Özel, 2005) and rock salt. Extensive research since the classification by Cvijic´ (1893) has meant that processes and landforms (**Figure 5.1**) have been well documented. Ford and Williams (2011) argue that karst punches above its weight in geomorphology because caves contain deposits that can now be radiometrically dated for many millions of years, the dated geomorphic history for karst regions provides a time scale for the evolution of surrounding areas, and the palaeoclimatic record of speleothems is more accurate and precisely dated and of higher resolution than the records from deep sea or ice cores.

Material properties analysed in relation to process and form benefit from the range of techniques now available for the analysis and description of the characteristics of rocks and superficial deposits (**Table 5.2**). The high degree of variability of material properties inhibits easy incorporation into landscape models (see **Table 11.3**) but has also stimulated greater links between weathering research with soil science. Soil geomorphology has been identified as the integration of pedology and morphology (Gerrard, 1993), demonstrating general relationships between soils, weathering and geomorphology (Birkeland,1974), and a more recent emphasis upon theory and process of soil genesis in relation to geomorphology (e.g., Schaetzl and Anderson, 2005). The significance of variations in material properties can have considerable import as shown by the difference between warm and cold glacier ice, and different conceptual active layer systems can respond differently to climatic change or disturbance based on the thermal properties of the material and ice/water content (Bonnaventure and Lamoureux, 2013). It is now possible to consider material properties at very large scales related to tectonics (Koons et al., 2012) because the heterogeneity and anisotropy of material strength are fundamental aspects of active orogens so that the description of the strength field in terms of mechanical evolution can extend present Earth surface models, expressed in landscape geomorphometrics of anisotropy and spatial patterns of complexity. Thus the lack of detailed investigations of material properties is now being redressed with the techniques which have become available.

Each of the themes, concentrating on aspects of form, process and materials, provided concepts in the sense of 'abstract ideas, general notions or units of knowledge vital to the development of scientific knowledge', as defined in Chapter 1 (pp. 2–3). Each evolved influenced by external developments, which included the theory of evolution (Darwin, 1859); the growth of hydrology and especially the influence of Horton (1945); developments in Quaternary science including the foundation of INQUA in 1928 and revolutions in dating, especially deep sea cores and cosmogenic dating; and developments in ecology and in philosophy – and not least the impact of systems thinking.

5.3 A view of the present position

Although there are obviously many links between the approaches (5.2) to form, process and material relationships, the differences that emerged came to be regarded as timeless and time bound approaches (see Chapter 1) associated with the two quite different viewpoints of geomorphology identified by Strahler (1952) as dynamic (analytical) and historical (regional) geomorphology. Any discipline develops towards more and more specialist branches and at least 24 have been identified as recently employed in books and research papers. These branches could be classified (Gregory and Goudie, 2011a: Table 1.5) according to purpose (Quantitative, Applied, Engineering), analysis (process, climatic, historical, structural/tectonic, karst, anthropogeomorphology) and process domains (Aeolian, Coastal, Fluvial, Glacial, Periglacial, Hillslope, Tropical, Urban, Weathering, Soil-geomorphology or Pedogeomorphology, Mountain geomorphology, Extraterrestrial geomorphology, Seafloor engineering geomorphology), as well as multidisciplinary hybrids (Hydrogeomorphology, Biogeomorphology). In addition to the identification of such sub branches there have been other diversifying trends. For example, geomorphology has been described as becoming a more rigorous geophysical science, but also as becoming more concerned with human social and economic values, environmental change, conservation ethics, the human impact on environment, and social justice and equity issues (Church, 2010).

With the development of so many branches of geomorphology, and new ones continuing to be created such as ice sheet geomorphology (e.g., Fleisher et al., 2006), it is perhaps inevitable that a more holistic approach has been sought. Whereas the first part of the 20th century saw the emergence of several branches of geomorphology, the second part witnessed the creation of many more subdivisions – fragmentation that has been characterized as investigating more and more about less and less, the so-called fissiparist or reductionist trend. The 21st century is seeing the culmination of efforts to realize a more **holistic approach**, namely a return to the 'big picture', and a holistic approach is also advocated within many branches including coastal, glacial, arid and fluvial. A holistic approach essentially means relating to, or being concerned with, complete systems rather than with the analysis of component parts. The holistic trend has affected other disciplines (in geomorphology being compatible with a systems approach and able to reinforce it). It had been suggested (Baker and Twidale, 1991) that while commendable in spirit, progressive initiatives to establish research traditions in landscape evolution, climatic geomorphology and process studies all encountered fundamental limitations as unifying themes. Therefore they stressed the need for a 're-enchantment' of geomorphology, which could arise from a new connectedness to nature. With hindsight the differences between approaches have not appeared to be so great, and for example the approaches of Gilbert and Davis to geomorphology can be regarded not as mutually exclusive but instead as complementary (Small and Doyle, 2012). The new techniques available, providing opportunities for all branches, appeared when there was increasing awareness of the need to counter the greater specialist emphasis upon components of the land surface without sufficiently acknowledging the links between them. For example, linkages between components (e.g., Brierley et al., 2006) can emphasize the ways in which nested hierarchical relationships between compartments in a catchment demonstrate both connectivity and disconnectivity in relation to geomorphic applications to environmental management. As there has been a greater general awareness of environment, and hence with applications of geomorphology, so the holistic nature of many problems demanding solutions has been appreciated. Such requirements have encouraged multidisciplinary research so that, as with other environmental and earth sciences such as the interface of geomorphology and ecosystems ecology (e.g., Renschler et al., 2007), hybrid disciplines have been fostered, including ecogeomorphology and hydrogeomorphology. Multidisciplinary investigations have been encouraged and 'biogeosciences' are rapidly expanding (Martin and Johnson, 2012), with investigations over a wide range of temporal and spatial scales. Added to these trends has been the greater attention given to macroscale geomorphology triggered by significant advances in plate tectonics (Summerfield, 2000) which, coupled with advances in cosmogenic dating, has led to a renaissance in understanding the development of large-scale Earth landforms.

Such progress towards the replacement or at least supplementation of the reductionist methodologies so successful for the progress of physics in the last century by a new holism is suggested (Baker, 2011) to afford a prospect for transcending the long-standing divide between historical and process studies. But what are the ways available to achieve this?

Adopting a more holistic approach directs attention to more comprehensive explanation in geomorphology. One general way is to employ the Covering Law model of explanation, also known as the deductive-nomological model (DN model), a formal view of scientific explanation, used since the mid 20th century, and particularly associated with the philosophers Carl Hempel and Karl Popper. This deductive explanation follows from the operation of general scientific laws with initial condition statements or premises forming the *explanans* which elucidates what is described as the *explanandum*. The DN model proceeds from laws to statements of particular initial conditions to explanation (see Haines-Young and Petch, 1986; Rhoads and Thorn, 1996). Recognizing that the defining features of a scientific explanation rest on the operation of general scientific laws, awareness of deductive reasoning and of the existence of alternative approaches may be why geomorphology has been much more methodologically concerned and explicit since the mid 20th century (Small and Doyle, 2012). Using an approach of this kind, Richards and Clifford (2011: 55) provided a summary diagram demonstrating the ultimate unity of geomorphology (**Figure 5.2**) which requires general 'laws' concerned with the functional nature of landforms, the immanent properties of Earth surface processes, and the adjustment of form to process.

More specific ways to achieve a holistic approach have underlined reviews and statements about future needs and foci such as the US National Research Council's committee on Challenges and Opportunities in Earth Surface Processes (see Murray et al., 2009). Prompted by governments requiring society benefits from their research funding, there has been the perception that few environmental challenges are likely to be solved by a single discipline because integrated approaches and interdisciplinary collaboration are often required. Individual suggestions have also been made, such as that of Lang (2011), to develop a computer modelling framework – an 'Earth surface simulator' – which would combine process understanding and evolutionary information to provide a unifying platform comparable to GCM technology. This could represent dynamic process interactions, including interfaces to the lithosphere, biosphere and atmosphere.

It has been suggested that three alternative foci can now be perceived (Gregory, 2010): geographical, interpreting morphology and processes; geophysical macro geomorphology, concentrating upon the broad structural outlines (see Church, 2005; Summerfield, 2005b); and chronological historical/Quaternary, focused on the history of change. However, these are much more connected, perhaps requiring a holistic approach, than approaches established in geomorphology since the late 19th century. Specialisms have greatly increased, with scientific compartmentalization, so that for example understanding the advantages and limitations of particular dating techniques is in a different realm from understanding GIS procedures. But the understanding of landforms, for practical management purposes in particular, may require forms of overarching collaboration as much as a highly focused specialism.

FURTHER READING

The third volume in the series on the history of the study of landforms introduces climatic geomorphology and global changes; the two preceding volumes provide detailed background to other developments:

Beckinsale, R.P. and Chorley, R.J. (1991) *The History of the Study of Landforms or The Development of Geomorphology Vol. 3: Historical and Regional Geomorphology 1890–1950*. London: Routledge.

Brierley, G.J., Fryirs, K. and Jain, V. (2006) Landscape connectivity: the geographic basis of geomorphic applications, *Area,* 38: 165–74.

Ford, D.C. and Williams, P.W. (2011) Geomorphology underground: the study of karst and karst processes. In K.J. Gregory and A.S. Goudie (eds), *The SAGE Handbook of Geomorphology*. London: Sage. pp. 469–86.

Gregory, K.J. (2010) *The Earth's Land Surface*. London: Sage. (See especially Chapters 3, 4.)

Huggett, R.J. (2011) Process and form. In K.J. Gregory and A.S. Goudie (eds), *The SAGE Handbook of Geomorphology*. London: Sage. pp. 174–91.

Rhoads, B.L. and Thorn, C.E. (1996) Towards a philosophy of geomorphology. In B.L. Rhoads and C.E. Thorn (eds), *The Scientific Nature of Geomorphology*. Chichester: Wiley. pp. 115–43.

Richards, K. and Clifford, N.J. (2011) The nature of explanation in geomorphology. In K.J Gregory and A.S. Goudie (eds), *The SAGE Handbook of Geomorphology*. London: Sage. pp. 36–58.

Summerfield, M.A. (2005) The changing landscape of geomorphology, *Earth Surface Processes and Landforms,* 30: 779–81.

TOPICS

1. Search for other subdivisions of approaches in geomorphology: do they accord with the suggestions in Table 5.1?

WEBSITE

For this chapter the accompanying website **study.sagepub.com/gregoryandlewin** includes Figures 5.1, 5.2; Tables 5.1, 5.2; and useful articles in *Progress in Physical Geography*. References for this chapter are included in the reference list on the website.