2

STUDY OF THE LAND SURFACE

In the last chapter it was suggested that study of the surface of the earth may have been associated with disciplines whose prime purpose often lies elsewhere.

2.1 Disciplines for the land surface

A discipline is defined by the *Oxford English Dictionary* as 'a branch of learning or scholarly instruction'. Instruction is provided in programmes of study which effectively create the academic world inhabited by scholars. Academic disciplines are often regarded as branches of knowledge taught and researched at higher education level, recognized by the academic journals in which research is published and by the learned societies and university departments to which practitioners belong. Although it is useful for academics to distinguish between disciplines, between geology and geography for example, one individual may not understand why the distinction is necessary or why there are differences in approach. Differences between disciplines can be reinforced by syllabi in schools and universities, or by the content of journals and books, and it has been suggested (Martin, 1998) that the way in which knowledge is organized and divided can be the subject of a power struggle so that confrontations almost like tribal wars may develop between disciplines! Against this background it is understandable why Rhodes (Rhodes and Stone, Rhodes et al., 1981; 2008: xii) contended that 'One of the problems with our conventional styles of teaching and conventional patterns of learning at the introductory undergraduate level is that the "subject" – whatever it may be – all too easily emerges as given, frozen, complete, canned'.

Whereas universities in mediaeval Europe had just four faculties (Theology, Medicine, Jurisprudence and Arts), university development in the middle and late nineteenth century saw the expansion of the curriculum to include non-classical languages and literature, science and technology. Each discipline developed its own epistemology or theory of knowledge, so that the philosophy of any one discipline evolved particular methods and concepts. Epistemology also developed as a core area of the study of philosophy concerned with the nature, origins and limits of knowledge. The size of any discipline is limited by what is termed closure, and it has been argued that there may be a spectrum of disciplines: some basic and very detailed, including physics and chemistry, others composite such as geology and geography (Osterkamp and Hupp, 1996). Any discipline has a set of defining practices or **paradigms** according to Kuhn who suggested (Kuhn, 1970: 12) that 'Successive transition from one paradigm to another via revolution is the usual developmental pattern of mature science'. Although some people argue that Kuhn's original paradigm idea is now too limited, it is valuable not least for the way in which it recognizes that a 'paradigm shift' can occur, although paradigms are shaped by both cultural background and historical context.

It is probably inevitable that disciplines concerned with the surface of the earth are composite rather than basic. The first disciplines involving aspects of the land surface of the earth were probably geology and biology. Although it has been argued that several disciplines, including geology, had their origins more than 1000 years ago, geology was really conceived in 1785 when James Hutton, often viewed as the first modern geologist, reflected his belief that the evolution of the Earth required millions of years when he presented a paper entitled *Theory of the Earth* to the Royal Society of Edinburgh. However Hutton's ideas were not extensively promulgated until nearly 50 years later, when they were included in a publication by Sir Charles Lyell in 1830. Geology is now defined in the AGI glossary (see Bates and Jackson, 1987) as 'The study of the planet Earth – the materials of which it is made, the processes that act on these materials, the products formed, and the history of the planet and its life forms since its origin. Geology considers the physical forces that act on the Earth, the chemistry of its constituent materials, and the biology of its past inhabitants as revealed by fossils' (Gregory et al., 2008).

Biology as the scientific study of life, examining the structure, function, growth, origin, evolution and distribution of living things arose also as a single coherent field in the nineteenth century, when individual scholars were very influential: Hutton and Lyell in geology and Charles Darwin (1809–1882) in biology through development of the theory of evolution (Box 3.1, pp. 83) In the previous century Carl Linnaeus (1707–1778) had published the first edition of his classification of living things in 1735, the *Systema Naturae* which introduced a classification scheme employing Latin names for the names of living organisms, paving the way for modern approaches to classification of plants and animals in taxonomy. Some individuals, like the explorer naturalist Alexander von Humboldt (1769–1859), influenced the development of studies of the surface of the earth by the information gained from their travels, and Humboldt is often credited with a formative influence on the development of biogeography.

Whereas geology was most concerned with rocks and the evolution of the Earth and biology most concerned with life upon it, the discipline primarily concerned with the land surface of the Earth is geomorphology which literally means write about (Greek *logos*) the shape or form (*morphe*) of the earth (*ge*). The name first appeared in 1858 in the German literature but came into general use, including by the US Geological Survey, after about 1890. For some time the term physiography persisted in North America, eventually being used for regional geomorphology. Although originating in geology, geomorphology became more geographically based with the contributions of W.M. Davis (1850–1934) who developed a normal cycle of erosion, wrote more than 500 papers and books and came to have an extremely influential role on the development of understanding of the surface of the earth – an influence which lasted until at least the 1960s (Gregory, 2000).

Early progress in the study of the land surface of the earth was greatly influenced by individuals in particular disciplines. There were also differences between countries. In the twentieth century geology in the UK did not give much attention to the land surface *per se*, with a few notable exceptions. These included Arthur Holmes (1890–1965) who in 1913 proposed the first geological time scale, and wrote his textbook *Principles of physical Geology*, first published in 1944; and J. K. Charlesworth (Finnegan, 2004) who was one of the most important individuals in the development of Quaternary science in Britain, publishing *The Quaternary Era* in 1957. The geological column was so extensively represented in the UK that, at a time of expansion of the range of subbranches of geology, there was so much for geologists to investigate that geomorphology tended to figure within academic geography. In the USA a different situation arose, despite W.M. Davis as a Professor of Geography, because for much of the first three quarters of the twentieth century geomorphology featured in geology departments with notable contributors being Professors of Geology. Only in recent decades has there been a growth of geomorphology in US geography departments.

Wherever geomorphology was located, the disciplines concerned with the land surface of the earth became progressively more specialized throughout the twentieth century, just as the disciplines of biology and geology recognized a series of separate branches. As specialized branches developed, the key role of particular individuals still prevailed but in addition there was a tendency for specialisms to develop in particular places. Thus W.M. Davis, who spent most of his working life in the stable environment of the east coast of the USA, commented, when he retired to the west coast, how he found a very different environment and concluded that 'the scale on which deposition, deformation and denudation have gone on by thousands and thousands of feet in this new-made country is 10 or 20 fold greater than that of corresponding processes on my old tramping ground' (Chorley et al., 1973: 647). It is interesting to speculate how geomorphology may have evolved differently if Davis or his equivalent had spent their life on the west coast of the USA. According to Tinkler (1985: 12) Charles Lyell in 1833 stated 'I occasionally amused myself with speculating on the different rate of progress which Geology might have made, had it been first cultivated with success in Catania where … the changes produced in the historical era by the Calabrian earthquakes would have been familiarly known'. Such examples show how geomorphologists are affected by place and their environment. Someone living in close proximity to the San Andreas fault cannot fail to be influenced by the possibility of tectonic influence on the landscape, whereas earthquake activity is much less significant in Boston and on the east coast of the USA.

Environment is one reason why fashions have been important in the growth of geomorphology but in addition there is the influence of other scientific developments and of the intellectual climate of the times. Thus Sherman (1996) adopted the idea of fashion change (Sperber, 1990) that progress in the goals, subjects, methods and philosophies of science can often be attributed to the emergence of an opinion created by a new fashion leader. Fashion dudes make significant advances in their disciplines and Sherman (1996) instanced Davis, Gilbert, Strahler and Chorley as influencing the course of development of geomorphology, one of whom is introduced in Box 2.1.

One consequence of the growth of academic subdivisions and increased specialization, for geomorphology and for other subjects, was the realization that we should not lose sight of interrelationships affecting the land surface of the earth. To ensure that land surface form and process was not isolated from study of soils, rocks and ecology, a multidisciplinary trend developed, reflected in the growth of environmental sciences and environmental studies. There are at least two environmental sciences: first a single-science, multidisciplinary field that began to develop in the 1960s and 1970s; and second environmental sciences as a generic term for all those disciplines which contribute to, and illuminate investigation of, the environment (Gregory et al., 2008). Environmental sciences are concerned with organisms and where they live, thus embracing the living (biotic) and inanimate (abiotic) components of the earth's surface concentrated in the envelope within 50 km above the surface and a few hundred metres below it. One definition of environmental science is 'the sciences concerned with investigating the state and condition of the Earth' (ERFF, 2003).

A more recent development has been earth system science as the study of earth in terms of its various component **systems**, including the atmosphere, hydrosphere, biosphere, and lithosphere, embracing global cycling of important nutrients and other elements that maintain ecosystems on a planetary scale. However Clifford and Richards (2005) concluded that earth system science (ESS) constitutes an oxymoron, that neither should it be seen as an alternative to the traditional scientific disciplines, or to environmental science itself, nor regarded as a wholesale replacement for a traditional vision of environmental science, but rather as an adjunct approach. Subsequently it was suggested (Richards and Clifford, 2008) that LESS (local environmental systems science) would be a more appropriate focus for geomorphology.

We tend to interpret the land surface according to the way in which it has been studied and at least three alternatives are now perceived: geographical interpreting the morphology and processes; geophysical concentrating upon the broad structural outlines (see Church, 2005; Summerfield, 2005); and chronological focused on the history of change (see **Quaternal Chronology Glossary** p. xxx). A further perspective could be added in planetary terms because it has been suggested (Baker, 2008b) that to be a complete science of landforms and landscapes geomorphology should not be restricted to the terrestrial portions of the earth's surface but could include the landforms of the ocean floors and our neighbouring planets.

Studies of the land surface of the earth developed with successive paradigms against a background where certain developments in understanding gradually became established (see Table 2.1). Although now often taken for granted, many represented great advances in their time, some relying upon a contribution by one individual, others emerging gradually over a number of years. It now seems difficult to believe that the views of Bishop Usher in 1654, that creation occurred on 23 October 4004BC and that the great Noachian flood occurred from 7 December 2349BC to 6 May 2348BC, held sway for so long and required sustained arguments to dislodge. Looking at Niagara Falls has prompted very different reactions (see Figure 2.1).

Table 2.1 SOME FOUNDATION MILESTONES FOR STUDYING THE LAND SURFACE OF THE EARTH

Advance	Particular individuals and dates	Significance
Surface processes	Leonardo da Vinci (1452–1519)	Notebooks show that he may have marked the transition from theoretical to observational and deductive methods but he was succeeded by others including Palissy (1510–1590), Bauer or Agricola (1494–1555).
Hydrological cycle	Pierre Perrault (1611–1680)	Showed for the Seine basin that precipitation was sufficient to sustain the flow of rivers in contrast to the long-held belief that subterranean condensation or return flow of seawater explained the discharge of water in springs and rivers. He probably provided the

(Continued)

Table 2.1 *(Continued)*

Advance	Particular individuals and dates	Significance
		foundation for our understanding of the hydrological cycle.
Natural history	Gilbert White (1720–1793)	Published the *Natural History of Selborne* in 1789, which transformed the way we look at the natural world, by focusing on natural history, so that he was recognized as one of the fathers of ecology.
Superposition	William Smith (1769–1839)	Credited with creating the first nationwide geological map in 1815, embracing the principle of superposition so that he became known as 'Strata Smith'.
Uniformitarianism	Charles Lyell (1795–1875)	Published *Principles of Geology* in 1830 with a subtitle *An attempt to explain the former changes of the earth's surface by reference to causes now in operation*. Uniformitarianism has been thought of as 'the present is the key to the past'. Includes actualism (effects of present processes) and gradualism (surface changes require long periods of time).
Glacial erosion	Louis Agassiz (1807–1873)	Credited with the idea in 1840 that glaciers erode and are responsible for many features in areas not now occupied by glaciers.
Evolution	Charles Darwin (1809–1882) – see Box 3. 1	Published *On the Origin of Species* in 1859 proposing that progressive changes in populations occurred through sequential generations by the process of natural selection. This influenced thinking about aspects of the earth's surface including the cycle of erosion.
Human activity	G.P. Marsh (1801–1882)	In 1864 published *Man and Nature* which illustrated that man is 'a power of a higher

Table 2.1 *(Continued)*

Advance	Particular individuals and dates	Significance
		order than any of the other forms of animated life' and initiated conservation movement. Anthropogenic, referring to activities of humans, used in Russian literature from 1922.
Cyclic change	W.M. Davis (1850–1934)	Proposed that landscape can be understood in terms of structure, process and stage and that there are cycles of erosion whereby the land surface proceeds through stages of youth, maturity and old age.
Continental drift	Alfred Wegener (1880–1930)	His suggestion in 1915 of continental drift was later feasible with the advent of plate tectonics.
Systems	R.J. Chorley (1927–2002) – see Box 2.1	Introduced the systems approach to the study of the land surface of the Earth in accord with general systems theory as suggested by Von Bertalanffy in 1962.
Glacial chronology and oxygen-isotope stages	Cesare Emiliani (1922–1995), Harold Urey (1893–1981), Sir Nicholas Shackleton (1937–2006) – see Box 7.1 – and Neil Opdyke (1933)	Relationships established between stable isotopes and environmental variables, following work by Urey and his students including Emiliani involved studies of the relation between oxygen isotopes and temperature in recent molluscs, and its application to determination of paleotemperatures. Oxygen isotope analysis of calcareous foraminifera within deep-sea cores has been one of the main techniques used for correlation and climatic reconstruction during the past 40 years. Shackleton and Opdyke (1973) identified 22 stages, interpreted the record in terms of continental ice-volume changes and assigned ages to each stage boundary,

(Continued)

Table 2.1 *(Continued)*

Advance	Particular individuals and dates	Significance
		providing a template widely used for correlation and for interpreting the terrestrial record.
Plate tectonics	Harry Hess (1906–69)	Emerged at a symposium in Tasmania in 1956 but had a number of earlier contributing elements including continental drift proposed by Wegener. Later work on sea floor spreading and magnetic field reversals by Hess and Mason was important in leading to construction of the theory in 1961.
Time scales	S.A. Schumm and R.W. Lichty	In 1965 recognized steady, graded and cyclic time scales (see Table 1.3). The geologic timescale had been developed over the period 1800–1850 but this paper showed how it was possible to link time scales to understand the land surface.

2.2 Methods for measurement and analysis

Careful analysis by David Alexander (1982) showed that Leonardo da Vinci (1452–1519) progressed the move to more observational and deductive methods (see Table 2.1). However it took nearly 400 years before real understanding was achieved utilizing methods of investigation which involved basic data collection, analysis techniques, and scenarios for conclusions to be reached.

One of the most important requirements was the availability of maps, not only to locate places but also to give information about the shape and character of the land surface. In the UK the foundation of the Ordnance Survey in Britain in 1795 and the Geological Survey in 1801 were the beginnings of surveys providing basic information. Topographic maps often used contours to depict the land surface so that the spacing, shapes and patterns of those contours had to be interpreted to 'read' the shape of the land. More directly relevant were slope maps, derived by showing that areas of slope of particular angles could relate directly to land use practices, because slope categories could be directly related to angles at which agricultural implements can operate,

Figure 2.1 Niagara Falls

Reactions range from 'there's nothing to stop it', to Mahler 'Fortissimo at last', to scientific investigations made (Tinkler, 1985: 96–8) which include recession rates and flow abstraction (Tinkler, 1993):

Period	Percentage of total flow after water abstraction for power generation	Recession rate m. a^{-1}
1842–1905	100	1.28–1.52
1905/6–1927	72	0.98
1927–1950	60	0.67
Post 1950	34	0.10

Hayakawa and Matsukura (2009) suggest that the decreased recession rate of Horseshoe Falls is related to both artificial reduction in river discharge and natural increase in waterfall lip length, whereas that of American Falls is solely due to the reduction in flow volume.

or to the slopes angles at which mass movements occur. Morphological maps showing the distribution of slopes, were succeeded by geomorphological maps which included specific landforms. Such maps ideally characterize the surface morphology, indicate landform origin, date each section of the land surface, and indicate the rock types, sediments and soils beneath the surface. These requirements could not all be achieved in any one map series so that geomorphological maps produced in several countries each had their particular emphases. In one of the most successful schemes in Poland many physical geographers contributed to a national scheme producing maps at the scale of 1:50,000. Mapping schemes capable of international application were evolved and an approach summarized by Cooke and Doornkamp (1974, 1990) was adapted to conditions in several areas (Cooke et al., 1982), so that for many applied projects, geomorphological mapping was the central technique.

Geomorphological maps of Germany are available online at http://gidimap.giub.uni-bonn.de/gmk.digital/home_en.htm. More than 30 maps are available at two different scales. They were surveyed and generated during the priority research programme *Geomorphologische Detailkartierung in der Bundesrepublik Deutschland* (Detailed Geomorphological Mapping in the Federal Republic of Germany). The programme was funded by the German Research Foundation (DFG) and completed in 1986. The cartographic map consists of 27 maps at 1:25.000 and 8 maps at 1:100.000 scale as well as complementary booklets with annotations.

Enthusiasm for geomorphological maps was limited, because their production, certainly for whole countries, was prohibitively expensive. Therefore information already routinely collected by national mapping agencies was used wherever possible. However, a difficulty with many mapping series is that they require many years to complete and then need constant revision and updating. National topographic agencies undertaking this task include the United States Geological Survey (USGS) established in 1879 to collect data on land, water, energy and mineral resources. Information on other aspects of the character of the land surface included soil data – the national soil survey in the UK dated from 1949, and approximately half the area of continental USA was covered by soil maps 1899–1935 (Barnes, 1954). More integrated interpretative approaches focusing on integration of several aspects of the physical landscape, include the land systems method (e.g. Cooke and Doornkamp, 1990; Mitchell, 1991; Verstappen, 1983), which can now be effected by databases and GIS, as remote sensing has greatly enhanced the availability of information about the land surface of the earth (Lillesand et al., 2004).

Process data are also required for the land surface, including hydrological measurements, glacier surveys and coastal information. The first records made of river stage included those for the Elbe at Magdeburg 1727–1869 (Biswas, 1970); continuous river discharge measurements have been made on the river Thames since 1883; and there were c.1200 river gauging stations throughout Britain by 1975. Continuous measurements of streamflow in the US began in 1900, with the basic network of gauging stations established during the period 1910–1940, so that by 1950 observation occurred regularly at about 6000 points. Permanent records have been made by tide gauges at coastal sites in the UK since 1860. Such growth in environmental monitoring emphasizes how recent the acquisition of data on physical environment has been, often for much less than 100 years. Many data sets and satellite imagery can now be downloaded (for example, The Global Runoff Data Center, UNEP, 2006).

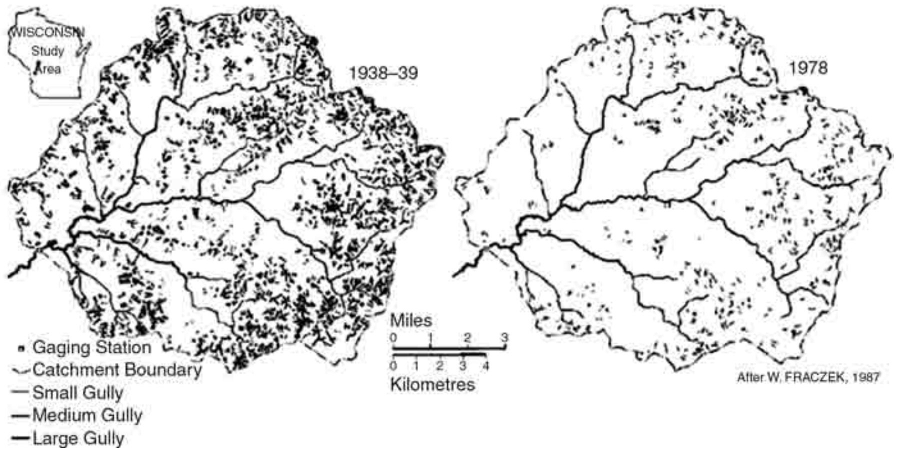

Figure 2.2 Decrease of drainage density 1938–78 in the upper Coon Creek basin (adapted from Fraczek,1987 by Trimble, 2008)

Analysis of drainage density and other data suggests that present flood peaks are a fraction of those of the late 1930s (see Figure 8.4).

Information on change can sometimes be obtained by comparing topographic maps of different dates. However more frequent surveys are often required in the case of glaciers for example. When using maps produced by national agencies it is important to understand the conventions used for the description of land surface features shown on particular map scales and editions for any one map series. Thus in the case of the drainage network some maps show rivers and streams that flow at 'normal winter level', others may show the extent of stream channels regardless of whether water is flowing in them or not, and there are differences in conventions used not only from one map series to another but also from one scale to another. The range of historical sources available for comparisons at different dates (Hooke and Kain, 1982) and data and artifacts for dating geomorphological processes over the past century or more (Trimble, 2008) can be valuable (see, for example, Figure 2.2).

All of the data needed for an investigation are seldom available from previously collected records, maps or surveys. Field techniques are therefore necessary to acquire information, often quantitative, for analysis, and are for two major purposes – to collect information on the shape and composition of the land surface and to measure processes. A great range of measurement techniques is now available, some very innovative (see Table 2.2).

In addition to mapping as noted above, detailed surveying may be required using techniques to map landscape materials; to obtain details of depth and thickness of superficial deposits by coring or geophysical techniques; to describe the character of landscape-forming materials including rock, sediment and soils; and to date changes (Dackcombe and Gardiner, 1983). Secondly, measurements of process effectively provide information on the

Table 2.2 SOME RECENT TECHNIQUES THAT HAVE TRANSFORMED INVESTIGATIONS OF THE LAND SURFACE (SEE GLOSSARY, PP. 000)

Purpose	Technique	Example of application
Site characterization and location	**Electronic distance measurement** (EDM)	Rapid field survey
	Close-range digital work station	Improved field monitoring
	Global positioning systems (GPS)	Rapid field survey
	Digital elevation models (DEMs)	Compute short-term spatial changes
	Digital camera, digital mapping	Coastal landform change
	Terrestrial photogrammetry	River bank erosion
	Ground penetrating radar	Sediment variations
	Airborne radar and radio echo-sounding	Basal ice conditions, water volumes in lakes in ice sheets
Process measurements	Digital loggers	Water quality monitoring, turbidity monitoring
	Continuous monitoring	Sand traps for aeolian events, bedload monitoring
	Acoustic Doppler velocimetry	3D velocities in rivers
	Magnetic techniques	Beach sediment sources
	Magnetic resonance imaging	Infiltration into soils
	O^{18} Deuterium	Hydrograph separation
Laboratory analytical techniques	Automated analysis	Greater number of samples can be processed and more properties analysed
	Scanning electron microscopy	Grain characteristics in sediments to indicate transport conditions
Modelling	Generalized linear modelling	Glacier surging, landslide susceptibility

transfer or flux of energy or mass within the physical environment of the land surface. However, because there is an infinite number of points in space and time with several process elements which could be measured at each point, a sampling strategy has to be used to select from what is an infinite population. Process monitoring may require empirical measurements over several years because existing records may not be available with spatial and temporal frequencies sufficient to meet the requirements of research programmes. Additional measurements can be obtained from small experimental areas but the enthusiasm for small instrumented areas encountered a number of problems including lack of control, replicability of measurements, insufficient representativeness, accuracy of data, and problems of finding suitable methods of analysis for the large amounts of data collected. However the development of process measurements often required where there are no regular national monitoring frameworks for process measurements, can provide the basis for significant research as shown by Professor Des Walling (see Box 8.1).

In view of the difficulties of establishing and maintaining process measurements alternative methods of obtaining data are available. *Experimental investigations* embrace a range of approaches which include field plot experiments; laboratory hardware models which attempt to use scaled down versions of the real world; and analogue models which employ a different medium for investigation. Measurements by rainfall simulators, flumes, wave tanks and wind tunnels are examples, and their potential has probably not been fully explored (Mosley and Zimpfer, 1978) but the difficulty of overcoming the scale problem and of relating the observations to geophysical event sequences have been most evident. *Theoretical approaches* do not require the establishment of a monitoring framework, or long periods of time for empirical data collection, with theoretical models capable of application to much larger areas or systems than those that can be monitored in field experiments. However they require basic conservation equations, including energy and water balance equations, and they necessarily depend upon stipulating simplifying assumptions. They have been used most effectively for relatively simple morphological sequences where there is a clear relationship between the existing system and the processes operating upon it, as on hill slopes.

Methods for investigation of the land surface have recently benefited from great strides in techniques of remote sensing and GPS, in GIS and real time computation, and in dating techniques, for which some of the great advances are listed in Table 2.3. Remote sensing has not only revealed details previously only dreamed of, but can also easily provide frequently repeated imagery and access aspects of the land surface not previously possible. LiDAR (Light detection and ranging) uses laser pulses, has many applications including detection of faults, measurement of land uplift, monitoring glacier changes as well as measurement of forest canopy characteristics and can be used very effectively in conjunction with GIS. Ground positioning systems (GPS) use a constellation of 24 satellites placed into orbit by the US Department of Defense which works anywhere in the world, in all weather conditions, 24 hours a day. Geographical information systems refer to the collection, analysis, storage and display of data which are spatially referenced to the surface of the earth by a set of geographic co-ordinates (Heywood et al., 1998).

2.3 CONCEPTUAL IDEAS

Data about the form of the land surface or the processes operating upon it must be collected according to some a priori hypothesis. Basic theory was not always explicit, so that a well-known quotation opening a chapter on bases for theory in geomorphology (Chorley, 1978: 1) was 'Whenever anyone mentions theory to a geomorphologist, he instinctively reaches for his soil auger' – a comment made because geomorphological studies of the land surface had concentrated upon empirical observations and field investigations. A change

Table 2.3 SOME DATING METHODS FOR QUATERNARY DEPOSITS (ADAPTED FROM SOWERS ET AL., 2000, STOKES AND WALLING, 2003 AND GREGORY AND DOWNS, 2008)

Type of method	Method	Approximate age range	Basis of method
Siderial	Dendrochronology	10–4000	Aging of living tree or correlation to chronologies for other trees
	Varve chronology	10–9000	Counting seasonal sediment layers back from present
	Scierochronology	10–600	Counting annual growth bands in molluscs and corals
Isotopic	Radiocarbon	100–30,000	Radioactive decay of ^{14}C to ^{14}N in organic fissures tissues and carbonates
	Cosmogenic nuclides ^{10}Be, ^{26}Al, ^{36}Cl, ^{3}He, ^{14}C	400–10,000,000	Formation and decay of nuclides in rocks exposed to cosmic rays
	Potassium-argon (K-Ar), argon-argon (Ar-Ar)	10,000–20,000,000	Radioactive decay of ^{40}K in K-bearing silicate minerals
	Uranium series (^{234}U-^{230}Th, ^{235}U-^{231}Pa)	10–400,000	Radioactive decay of uranium and protégés in sedimentary minerals
	Short-lived radionuclides, lead-210 (^{210}Pb)	10–70	Radioactive decay of ^{210}Pb to ^{206}Pb
	Short-lived radionuclides, caesium-137 (^{137}Cs)	10–100	Radioactive decay of ^{137}Cs to ^{137}Ba
	Uranium-lead (U-Pb), thorium-lead (Th-Pb)	10,000–20,000,000	Measurement of Pb enrichment from decay of radiogenic Th and U
Radiogenic	Fission track	2000–20,000,000	Accumulation of damage trails from natural fission decay of ^{238}U
	Luminescence (TL, OSL, IRSL)	10–1,000,000	Accumulation of electrons in crystal defects due to radiation
	Electron-spin resonance	1000–1,000,000	Accumulation of electrons in crystal defects due to radiation

Table 2.3 *(Continued)*

Type of method	Method	Approximate age range	Basis of method
Chemical and biological	Amino-acid racemization (AAR)	200–2,000,000	Racemization of L-amino acid to D-amino acid in organic material
	Obsidian hydration	10–1,000,000	Increase in thickness of hydration rind on obsidian surface
	Lichenometry	10–10,000	Growth of lichens on freshly exposed rock surfaces
Geomorphic	Soil profile development	3000–100,000	Systematic changes in soil properties due to soil processes
	Rock and mineral weathering	10–100,000	Systematic alteration of rocks and minerals due to weathering
	Scarp morphology	2000–30,000	Progressive changes in scarp profiles due to surface processes
Correlation	Palaeomagnetism, secular variation	10–6000	Secular variations in the earth's magnetic field
	Pamaeomagnetism, geomagnetic reversal stratigraphy	400,000–2,000,000	Reversal of the earth's magnetic field recorded in magnetic minerals
	Tephrochronology	10–2,000,000	Recognition and correlation of tephra layers via unique properties
	Palaeontology	50,000–500,000	Progressive evolution
	Climatic correlations	1000–1,000,000	Correlation of landforms and deposits to known global climate changes

occurred, with greater awareness of general philosophical thinking, of a more scientific foundation, together with the advent of statistical and mathematical methods and with recognition of the types of model available to assist understanding.

Greater awareness of philosophical thinking meant that paradigms were recognized and thought was given to ways in which data was collected and analysed and how conclusions were reached. Distinction between inductive and deductive methods coincided with investigations seeking general models rather than those based exclusively upon detailed field investigations of specific areas. Positivists dominated until the late 1950s (Brown, 1996) maintaining that scientific theories should be evaluated solely on the basis of observational data in accordance with a set of formal rules, but this approach was flawed because of the absence of sound principles of verification or induction and because observations are actually theory-dependent (Haines-Young and Petch, 1986). A move towards a critical rationalist view, whereby a rational basis for scientific knowledge is provided by deducing the consequences of theories and then attempting to expose their falsity by critical testing, appreciated that facts are not objective because they are observations perceived in a particular way, according to the technology available for measurement and observation. The variables perceived to be important, and selected for measurement, are chosen in the light of some preconceived theory. In this post-positivist state it is possible to have a multi-paradigm state; it takes years to develop a new paradigm, heretical thinking must go on for a long time before paradigm change, so that pluralism is required (Slaymaker, 1997).

One of the prevailing approaches is described as scientific realism, deriving from the contributions of C.S. Peirce at the end of the nineteenth century and of Karl Popper since the 1930s. Critical realism adopts the perspective that the aim of science is *to seek the truth* not merely to solve problems, readily acknowledging that all aspects of scientific enquiry are theory laden, that current theories are approximately true and are the foundation for scientific progress (Baker, 1996).

Greater awareness of the philosophy of science paralleled a greater scientific foundation. Yatsu (1966: 13) expressed the idea that 'Geomorphologists have been trying to answer the *what, where* and *when* of things, but they have seldom tried to ask *how*. And they have never asked *why*. It is a great mystery why they have never asked *why*'. Asking the why question required awareness of basic scientific principles. As geomorphology has been characterized as a mesoscale science, then, as in other earth sciences, the extent to which it is realistic to extend geomorphological processes to the micro scale is debatable. Geomorphology needs to identify the physical principles underlying landscape processes because this will not necessarily prejudice a mesoscale approach and has been achieved by sedimentology (for example, Allen, 1970) and by soil science.

A model is any abstraction or simplification of reality providing a major tool in addressing the limitations of laboratory experimentation and environmental records in extending the bounds of space and time in environmental understanding (Lane, 2003). Several stages of modelling can be employed as a basis for investigations of the land surface of the earth in a problem-solving context including (Huggett, 1980):

- *a lexical phase* identifying the components investigated in a particular problem
- the *parsing phase* establishing relationships between the components

- the *modelling phase* expressing relationships in a type of model (conceptual, mathematical empirical or mathematical deterministic) followed by calibration of the model
- the *analysis phase* attempting to solve the system model

If not successful the procedure is repeated with a modified model.

The enormous growth in design, creation and use of databases, together with the rapid decrease in the cost of computing power with micro computers, means that separate categories of statistical, mathematical and databased modelling are already becoming redundant (Macmillan, 1989: 310).

2.4 Debates and paradigm shifts

Communication of ideas requires societies, journals and books as well as the internet. Although geomorphology research was originally published as part of geographical (earliest founded in 1821 in Paris) or geological societies (London founded in 1810), geomorphological societies were established later, including the British Geomorphological Research Group (now the British Geomorphological Society) founded in 1959/60. Many societies publish journals but others were independently created, some developed for subfields (see Table 2.4). Most journals have expanded enormously so that *Earth Surface Processes* which began in 1976 with 4 issues (totalling 395 pages) had 14 issues (2306 pages) in 2008.

Increased knowledge about the surface of the earth, with consequent increases in societies, journals, books and students, inevitably encouraged major debates – or paradigm shifts. Many occurred during the history of geomorphology, impressively dealt with by R.J. Chorley (see Box 2.1) in three scholarly volumes (Chorley et al., 1964, 1973; Beckinsale and Chorley, 1991) now complemented by a fourth (Burt et al., 2008). A major debate concerned the contributions by W.M. Davis – with most of one 874-page volume devoted to his contribution (Chorley et al., 1973) and more than 20% in Part II of the subsequent volume (Beckinsale and Chorley, 1991). His contributions are noted in Table 2.5 with a selection of other paradigms. Other topics that might have been included: whether **uniformitarianism/catastrophism** is necessary for our understanding of the land surface; is there certainty in explanations or are they ruled by chaos; and should we examine cultural differences and ethical considerations. However Table 2.5 demonstrates how study of the land surface has to be undertaken in the context of a prevailing idea or conceptual hypothesis, with any investigation subject to ideas prevailing at the time. As suggested above, pluralism is necessary and Slaymaker (1997) argued that there is no recognizable central concept in geomorphology and no problem focus. That could be a good thing – we should approach the land surface of the earth with an open mind but with a range of ideas to test. A recent debate concerns present global change – are those who study the land surface of the earth doing enough to explore the possible impact of present trends in global climate change?

Table 2.4 EXAMPLES OF JOURNALS PUBLISHING PAPERS ON THE LAND SURFACE OF THE EARTH

Geomorphological journals are given in bold, followed by examples of other categories. Many geographical and geological journals such as *Geographical Journal* (1831–), *Bulletin Geological Society of America* (1890–), also contain important geomorphological papers.

Year initiated	Journal	Comments
	Zeitschrift fur Geomorphologie	Publishes papers from the entire field of geomorphological research, both applied and theoretical. Since 1960 has published 153 Supplementbände (Supplementary volumes) for specific topics.
1950	***Revue are Geomorphologie Dynamique***	Edited and inspired by Professor John Tricart.
1960	***Geomorphological Abstracts***	At first published abstracts of papers in geomorphology but later expanded to Geo Abstracts covering many related disciplines.
1977	***Earth Surface Processes and Landforms***	From 1977–1979 was *Earth Surface Processes* but then expanded its name. Described as an International Journal of Geomorphology publishing on all aspects of Earth Surface Science.
1989	***Geomorphology***	Publishes peer-reviewed works across the full spectrum of the discipline from fundamental theory and science to applied research of relevance to sustainable management of the environment.
Hydrological	*1963 Journal of Hydrology* *1970 Nordic Hydrology* *1971 Water, Air and Soil Pollution* *1984 Regulated Rivers* *1987 Hydrological Processes*	
Glacial	*1947 Journal of Glaciology* *1977 Polar Geography and Geology* *1980 Annals of Glaciology* *1990 Permafrost and Periglacial Processes* *1990 Polar and Glaciological Abstracts*	
Coastal	*1973 Coastal Zone Management* *1984 Journal of Coastal Research*	
Arid	*1981 Journal of Arid Environments* *2009 Aeolian Research*	
Quaternary	*1970 Quaternary Research, Quaternary Newsletter* *1972 Boreas* *1982 Quaternary Science Reviews* *1985 Journal of Quaternary Science* *1990 Quaternary Perspectives, Quaternary International* *1991 The Holocene*	
Physical geology	*1973 Geology* *1975 Environmental Geology*	

Table 2.4 *(Continued)*

Year initiated	Journal	Comments
Physical geography	*1977 Progress in Physical Geography*	
	1980 Physical Geography	
Environment	*1972 Science of the Total Environment*	
	1973 Catena	
	1976 Geo Journal, Environmental Management	
	1990 Global Environmental Change	
	1997 Global Environmental Outlook	

Table 2.5 SOME DEBATES OR PARADIGM SHIFTS

Subject/issue	Established position	Alternative view
Davisian cycle of erosion	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 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 – an approach termed denudation chronology (see Gregory, 2000: 38–42).	Approach was essentially qualitative and did not have a sound scientific foundation, it appealed to persons with little training in basic physical sciences but who like scenery and outdoor life, and focused on parts of the land surface and ignored others. It was partial in that it focused exclusively upon the historical development of the land surface of the earth without giving sufficient attention to the formative processes operating (see Chorley et al., 1973).
Developments of cycle	Debates about origin of planation surfaces as of subaerial or marine in origin.	Attracted similar objections to those to the cycle approach.
Alternative models: slope-based	Walther Penck in 1924 proposed parallel recession of slopes rather than progressive decline as suggested in the Davisian cycle.	Subject to similar limitations as Davisian cycle and some slopes shown to decline (see Tinkler, 1985: 166–69).
Alternative models: pediplanation	Series of papers culminated in book (King, 1962) which argued that pediplanation	Subject to some of the criticisms levelled at the Davisian approach, overtaken

(Continued)

Table 2.5 *(Continued)*

Subject/issue	Established position	Alternative view
	was the norm, that lower latitudes were the norm rather than temperate areas and correlated surfaces from Africa to South America, Australia and other parts of the world's plainlands. Embraced earth movements in terms of cymatogenic arching (see Gregory, 2000: 142–43). Formalized approach in 50 canons of landscape evolution (King, 1953: 747–50).	by the advent of plate tectonics, and overshadowed by other approaches including climatic geomorphology in Europe including interpretation of landscape in terms of double surface of levelling (see Ollier, 1995).
Emphasis on earth surface processes	Lead given by Gilbert (1914) was largely ignored until 1960s when more attention given to stresses acting on materials, aided by mathematical and statistical methods and by development of new models. The book by Leopold et al. (1964) was particularly influential (see Box 4.1).	Towards the end of the twentieth century some geomorphologists felt that the study of the energetics of the land surface had 'perhaps robbed the subject of some of its scope and depth' (Thomas, 1980), that the original intention of process research, to explain landforms, had been forgotten (Conacher, 1988: 161), and that evolutionary geomorphology (Ollier, 1979, 1981) is more appropriate to some areas of the world such as Australia.
Quaternary science and interdisciplinary research	International Union for Quaternary Research (INQUA) established in 1928 and one example of need to involve range of earth and environmental scientists including archaeologists, biologists, oceanographers, limnologists. Catalysed by developments in pollen analysis, radiocarbon dating and subsequent dating methods, and by refinement of the Quaternary time scale.	Quaternary science community focused on chronology and stages of development tended to become separate from that concerned with earth surface processes and with landforms. At the end of the twentieth century the two communities have interacted much more profitably.
Landscape reenchantment of geomorphology	Baker and Twidale (1991) perceived disenchantment to have arisen from denigration of the study of landform, the infatuation with theory, the dominance of models, and the emphasis upon applications, so that they proposed	That studies of process continued to be necessary together with theory and modelling to provide the necessary foundation for understanding how the land surface works. Some of the process studies necessarily began at small detailed scales

Table 2.5 *(Continued)*

Subject/issue	Established position	Alternative view
	reenchantment where 'the landscape must be viewed with awe and wonder, that is, as something far superior to the idealizations that we seek to impose upon it'.	but could later be extended to regional or continental scales.
Macro geomorphology	Proposed to have a more secure basis of geophysical, sedimentological and geochronometric data (Summerfield, 1981) and led to the first textbook to fully integrate global tectonics into the study of landforms (Summerfield, 1991).	Distinction drawn by Church (2005) between the diminishing role of 'geographical geomorphologists' and the growing role of geophysicists whereas Summerfield (2005) counters that there is enormous scope to advance geomorphology as a whole, probably at its most exciting time since it emerged as a discipline.
Human activity and applications	Influence of human activity had been ignored in research until mid-twentieth century and potentially very influential on processes.	Alternative group tended to ignore human activity and focus upon land systems relatively little affected by human impact.

Box 2.1

PROFESSOR DICK CHORLEY

Professor Dick Chorley (1927–2002) was inspirational in evolving geomorphology from the first to the second half of the twentieth century. 'A reformer with a cause' the very apt title of the first chapter (Beckinsale, 1997) of a book compiled in his honour (Stoddart, 1997) was so appropriate for someone so extremely pleasant, unassuming yet ebullient, with such warm good humour and gentle self-effacement, but responsible for bringing many ideas critical to the development of geomorphology – including general systems theory and quantification. After his school career in Somerset, including Minehead Grammar, he was a lieutenant in the Royal Engineers (1946–48), studied at the University of Oxford and graduated with a BA in Geography in 1951. Subsequently he spent several years in the USA in Geology departments where he interacted with A.N. Strahler and his students including Stanley Schumm and Mark Melton, and was inspired by the contributions of Luna Leopold (see Box 4.1, pp. 00). In 1958 he was appointed to

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the School of Geography, University of Cambridge where he was subsequently Lecturer (1962), Reader (1970) and Professor (1974). Interaction with US geomorphologists early in his career was a fundamental influence conditioning his approach to geomorphology as the study of landforms, and his conviction that the discipline should be scientific, quantitative, process-based and rational. He sought to replace the prevailing paradigm of the Davisian cycles of erosion with a quantitative model-based paradigm which emphasized General Systems Theory and numerical modelling. Robert Beckinsale (1997: 5) reveals that in his first degree examinations Chorley obtained two of his lowest marks in the landform papers, thus instigating his move to the US, so vital for the development of his influential ideas – and for the way in which geomorphology was to develop.

In addition to authoring many extremely influential papers, his book with Barbara Kennedy in 1971 on *Physical Geography: A Systems Approach* provided a breath of fresh air. Other strands to his bow were the magisterial *History of the Study of Landforms* (3 volumes totalling 2048 pages published 1964 1973 and Beckinsale and Chorley 1991), and *Geomorphology* with S.A. Schumm and D.E. Sugden in 1984. His contributions on models and other key developments were influential not only in geomorphology but throughout geography, including his 1978 book with R.J. Bennett on *Environmental Systems*, and his 1968 text co-authored with Roger Barry on *Atmosphere, Weather and Climate* which continued for 8 editions. Many of his written and edited contributions involved collaboration with others, including the influential *Water Earth and Man* (1969) with its subtitle *A Synthesis of Hydrology, Geomorphology and Socio-economic geography*. His many awards include the Patron's medal of the Royal Geographical Society (1987), his many contributions include originating *Progress in Geography* which evolved to become *Progress in Physical Geography* and *Progress in Human Geography,* and many of his fruitful collaborations were with Professor Peter Haggett.

This range of contributions shows what is needed to fundamentally change the direction of landform studies, which Professor Dick Chorley achieved, but to fully appreciate the 'climate' of those times, the transforming changes to which he contributed, and some of the anecdotal context read:

Beckinsale, R.P. (1997) Richard J. Chorley: A reformer with a cause. In D.R. Stoddart (ed.), *Process and Form in Geomorphology.* Routledge, London and New York, pp. 3–12.

Stoddart, D.R. (1997) Richard J. Chorley and modern geomorphology. In D.R. Stoddart (ed.), *Process and Form in Geomorphology*. Routledge, London and New York, pp. 383–399.

FURTHER READING

Further details on the development of geomorphology are included in:

Gregory, K.J. (2000) *The Nature of Physical Geography.* Arnold, London, esp. pp. 63–66, 118–124.

An indication of how a range of disciplines contribute to our cumulative understanding is:

Rhodes, F.H.T., Stone, R.O. and Malamud, B.D. (2008) *Language of the Earth.* Blackwell, Oxford.

A stimulating read is provided by:

Richards, K.S. and Clifford, N. (2008) Science, systems and geomorphologies: why LESS may be more. *Earth Surface Processes and Landforms* 33: 1323–1340.

A comprehensive coverage of geomorphology is provided in:

Summerfield, M.A. (1991) *Global Geomorphology.* Longman, Harlow.

TOPICS

1. Access a model on the internet and explore the limitations and applications (see Brooks, 2003 in Rogers and Viles, 2003 for website addresses).
2. What disciplines are involved in research investigations of the surface of the earth?
3. Should geomorphology be thought of as the science of the study of landforms or as the study of the processes and form of the land surface of the earth? Should it include other planets? (See Baker, 2008b.)
4. For an area/landscape that you know well, envisage how an investigation could employ different geomorphological approaches.
5. Could you conceive of a geomorphology without contributions from W.M. Davis? Do you agree that without Davisian geomorphology the discipline would have not been as coherent as it is?