THE BASICS OF GEOMORPHOLOGY: KEY CONCEPTS

Supporting Website Material

This website provides material to supplement the text and is organized by chapter with the complete reference list given at the end. Diagrams and tables that are essential for understanding the text are contained in the book. For each chapter the synopsis is given together with additional material, which includes figures and tables, compiled to amplify the discussion in the text, relevant articles in *Progress in Physical Geography*, which is an excellent resource to pursue particular themes, and a list of the concepts given in bold from the index (together with the references cited in each chapter). The complete reference list is given at the end.

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INTRODUCTION: CONCEPTS AND GEOMORPHOLOGY

Any discipline has concepts that are key for its progress. For geomorphology these need to be explicitly stated and consistently understood for what they are. We set them within the evolving history of geomorphology and the changing techniques and understanding that have been involved. This demonstrates the fashioning surges that have characterized the discipline and which complicate identification of those concepts which endure and which remain basic to the present and future study of geomorphology.

Figure 1.1 Grand Canyon (from near Powell Memorial)

Table 1.1 Some developments in constructing geomorphology (years in italics refer to use of the word 'geomorphology')

Year	Contribution
1674	Pierre Perrault's (1608–1680) published book on *De l'origine des fontaines*, showing precipitation sufficient to sustain the flow of rivers in the Seine basin: probably a foundation for understanding of the hydrological cycle.
1795	James Hutton's (1726–1797) *Theory of the Earth*, which rejected catastrophism and paved the way for uniformitarianism.
1802	John Playfair's (1747–1819) *Illustrations of the Huttonian Theory of the Earth,* which proselytised Hutton's views and has since been regarded as the first modern statement of the principles of fluvial geomorphology.
1815	William Smith (1769–1839) credited with creating the first nationwide geological map, embracing the principle of superposition so that he became known as 'Strata Smith'.
1830	Charles Lyell's (1795–1875) *Principles of Geology*, with uniformitarianism 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). Described as 'High Priest of Uniformitarianism' by Archibald Geikie (1835–1924).
1840	Louis Agassiz (1807–1873) credited with the idea, revolutionary in 1840, that glaciers erode and that Ice Ages are responsible for many of the features found in areas not now occupied by glaciers.
1858	Word 'geomorphology', which means literally to write about (Greek *logos*) the shape or form (*morphe*) of the Earth (*ge*), first appeared in the German literature.
1859	Charles Darwin's (1809–1882) *On the Origin of Species*, which proposed 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.
1864	George Perkins Marsh's (1801–1882) *Man and Nature* illustrated that man is 'a power of a higher order than any of the other forms of animated life'. Marsh thought of as America's first environmentalist and founder of the conservation movement. Significance for geomorphology long delayed.
1869	Ludwig Rutimeyer (1825–1895), in a book on valley and lake formation, showed that the largest Alpine valleys had been produced by stream erosion over long periods of geologic time and that different sections of a river course can be marked by distinct types of erosional forms including waterfalls, meanders and floodplains.

Year	Contribution
1870	Oscar Peschel (1826–1875) compared the nature of similar landforms throughout the world, involving the classification of surface features and comparison of their morphology.
1875	J.W. Powell (1834–1902), in a study of the Colorado in 1875, identified three types of river valleys (antecedent, consequent, superimposed), referred to landforms, and developed the concept of base level.
1877	T.H. Huxley's (1825–1895) *Physiography* provided a view of Earth's surface processes at a stage when 'physiography' was still preferred to the term 'geomorphology'.
1877	G.K. Gilbert's (1843–1918) *Report on the Geology of the Henry Mountains* provided the first treatment by a geologist of the mechanics of fluvial processes, and later (in 1914) in *The Transportation of Debris by Running Water* included results from laboratory experiments. His approach was largely ignored until the 1960s when more attention was given to stresses acting on materials, aided by mathematical and statistical methods and the development of new models. The book by Leopold et al. (1964) was particularly influential.
1886	Referred to as 'la geomorphologie' by Emmanuel de Margerie (1862–1953).
1886	Baron Ferdinand von Richthofen's (1833–1905) *A Guidebook for Scientific Travellers* was largely descriptive of landforms, including a classification of mountains.
1888	First use of 'geomorphology' in English by W.J. McGee (1853–1912), who compiled a genetic classification of landforms similar to those used in subsequent textbooks. The term came into general use, including by the US Geological Survey, after about 1890.
1889	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. Associated landforms with stages in the cycle of erosion and furnished over 150 terms and phrases, some relating to landforms, with probably at least 100 generated by his students. Published *Geographical Essays* in 1909.
1891	'Geomorphology' used at International Geological Congress by McGee and Powell.
1895	'Geomorphology' used in Mackinder's lecture to the British Association meeting in Ipswich, described as 'the causal description of the Earth's present relief'. International Geographical Congress to London had a section entitled 'Geomorphology', including a paper by A.Penck which used the term 'geomorphology'.

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Table 1.1 (Continued)

Year	Contribution
1909	W. von Lozinski first used periglacial leading to recognition of a periglacial zone.
1915	Alfred Wegener (1880–1930) suggested the concept of continental drift, which later became understood with the advent of plate tectonics (see 1956 below).
1921`	A. Hettner's (1859–1941) *Die oberflachenformen des Festlandes, ihre Untersuchung und Darstellung; Probleme und Methoden der Morphologie,* and a subsequent book in 1928 which did not appear in English until 1972.
1924	Walther Penck's (1888–1923) *Die Morphologische Analyse* proposed a parallel recession of slopes rather than the progressive decline of the Davisian cycle. Published in English in 1953 as *Morphological Analysis of Landforms.*
1928	International Union for Quaternary Research (INQUA) established in 1928 involving a range of earth and environmental scientists including archaeologists, biologists, oceanographers and limnologists. Catalysed by developments in pollen analysis, radiocarbon dating and subsequent dating methods, and by refinement of the Quaternary time scale.
1938	*Journal of Geomorphology* established but discontinued after several years of publication.
1941	Brigadier Ralph Alger Bagnold's (1896–1990) *The Physics of Blown Sand and Desert Dunes* demonstrated how experimentation and physics could be used to understand landscape dynamics.
1945	The American engineer R.E. Horton's (1875–1945) paper provided the foundation for the runoff model and for quantitative approaches in geomorphology.
1946	Swiss Geomorphological Society (SGS) founded, possibly the first Geomorphological Society; subsequently at least 22 others have been established.
1947	Richard Foster Flint's (1901–1976) *Glacial Geology and the Pleistocene Epoch*, followed in 1957 by *Glacial and Pleistocene Geology.*
1949	W.F. Libby (1908–1980) introduced the radiocarbon dating method using naturally occurring radioisotope carbon-14 (^{14}C) to estimate the age of carbon-bearing materials.
1950	*Revue de Geomorphologie Dynamique* edited and inspired by Professor Jean Tricart.
1950	A.N. Strahler's (1918–2002) paper succeeded by school of quantitative geomorphology, and in 1952 a paper provided a dynamic basis for geomorphology, and especially for hillslopes.
1951	The physicist John Frederick Nye (1923–) provided a theoretical approach to glacier flow.

Year	Contribution
1955	Jean Tricart's (1920–2003) and Andre Cailleux's (1907–1986) *Introduction à la Géomorphologie Climatique*.
1956	Harry Hess (1906–1969) introduced plate tectonics at a symposium in Tasmania. Later work on sea floor spreading and magnetic field reversals by Hess and Mason was important in leading to the construction of plate tectonics theory in 1961.
1956	*Zeitschrift für Geomorphologie* published papers from the entire field of geomorphological research, both applied and theoretical.
1960	British Geomorphological Research Group (BGRG) established, later to become the British Society for Geomorphology in 2006.
1962	Lester C. King's (1907–1989) papers culminated in *The Morphology of the Earth* which argued that pediplanation and lower latitudes were the global norm rather than temperate areas, and correlated surfaces from Africa to South America, Australia and other parts of the world's plainlands. Formalised his approach in 50 canons of landscape evolution.
1960	Remote sensing data from satellites complemented previously used air photographs.
1962	R.J. Chorley (1927–2002) introduced a systems approach to the study of the land surface of the Earth in accord with general systems theory as suggested by L. Von Bertalanffy (1901–1972).
1963	Julius Büdel (1903–1983) published a paper on 'Klima-genetischen Geomorphologie', subsequent papers and his book on *Klima-Geomorphologie* in 1977.
1964	L.B. Leopold's (1915–2006), M.G. Wolman's (1924–2010) and J.P. Miller's (1923–1961) *Fluvial Processes in Geomorphology* demonstrated how geomorphology could become more process-based.
1965	S.A. Schumm (1927–2011) and R.W. Lichty recognized steady, graded and cyclic timescales, showing that, whereas the geologic timescale had been developed 1800–1850, it was possible to link different timescales to understand the land surface. Schumm was a major contributor to concepts including thresholds and complex response.
1973	N.J.Shackleton (1937–2006) and N.D. Opdyke used oxygen isotope and palaeomagnetic analysis of deep ocean cores to indicate climate changes, identifying 22 stages, thereby providing a template widely used for correlation and for interpreting the terrestrial record.
1977	*Earth Surface Processes* 1977–1979, then expanded to *Earth Surface Processes and Landforms,* published as an International Journal of Geomorphology.
1981	M.A. Summerfield proposed a more secure basis of geophysical, sedimentological and geochronometric data, and published the first textbook to fully integrate global tectonics into the study of landforms in 1991.

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Table 1.1 (Continued)

Year	Contribution
1989	International Association of Geomorphologists founded at the Second International Conference on Geomorphology in Frankfurt/Main (Germany).
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.
1994	GPS Global Positioning System developed as a navigation system using a constellation of 24 orbiting satellites, speeding up survey and measurement.
2000	LiDAR (light detection and ranging) uses laser pulses with many applications.
2004	Virtual globes, including Google Earth, vastly increase the availability of digital imagery.
2004	Cosmogenic isotope dating involves the measurement of cosmogenic nuclides that have accumulated in the upper few metres of the Earth's surface.

Table 1.4 Some dating methods now available (adapted from Sowers et al., 2000, in Stokes and Walling, 2003; Gregory and Downs, 2008) showing the dramatic contrast with fifty years ago

Method	Basis of Method	Approximate Age Range
Dendrochronology	Aging of a living tree or correlation to chronologies for other trees	10–4,000
Varve chronology	Counting seasonal sediment layers back from the present	10–9,000
Scierochronology	Counting annual growth bands in molluscs and corals	10–600
Radiocarbon	Radioactive decay of ^{14}C to ^{14}N in organic fissures, tissues and carbonates	100–30,000
Cosmogenic nuclides ^{10}Be, ^{26}Al, ^{36}Cl, ^{3}He, ^{14}C	Formation and decay of nuclides in rocks exposed to cosmic rays	400–10,000,000
Potassium-argon (K-Ar), argon-argon (Ar-Ar)	Radioactive decay of ^{40}K in K-bearing silicate minerals	10,000–20,000,000

Method	Basis of Method	Approximate Age Range
Uranium series (^{234}U-^{230}Th, ^{235}U-^{231}Pa)	Radioactive decay of uranium and protégés in sedimentary minerals	10–400,000
Short-lived radionuclides, lead-210 (^{210}Pb)	Radioactive decay of ^{210}Pb to ^{206}Pb	10–70
Short-lived radionuclides, caesium-137 (^{137}Cs)	Radioactive decay of ^{137}Cs to ^{137}Ba	10–100
Uranium-lead (U-Pb), thorium-lead (Th-Pb)	Measurement of Pb enrichment from decay of radiogenic Th & U	10,000–20,000,000
Fission track	Accumulation of damage trails from natural fission decay of ^{238}U	2,000–20,000,000
Luminescence (TL, OSL, IRSL)	Accumulation of electrons in crystal defects due to radiation	10–1,000,000
Electron-spin resonance	Accumulation of electrons in crystal defects due to radiation	1,000–1,000,000
Amino-acid racemization (AAR)	Racemization of L-amino acid to D-amino acid in organic material	200–2,000,000
Obsidian hydration	Increase in thickness of hydration rind on obsidian surface	10–1,000,000
Lichenometry	Growth of lichens on freshly exposed rock surfaces	10–10,000
Soil profile development	Systematic changes in soil properties due to soil processes	3,000–100,000
Rock and mineral weathering	Systematic alteration of rocks and minerals due to weathering	10–100,000
Scarp morphology	Progressive changes in scarp profiles due to surface processes	2,000–30,000
Palaeomagnetism, secular variation	Secular variations in the Earth's magnetic field	10–6,000
Pamaeomagnetism, geomagnetic reversal stratigraphy	Reversal of the Earth's magnetic field recorded in magnetic minerals	400,000–2,000,000
Tephrochronology	Recognition and correlation of tephra layers via unique properties	10–2,000,000
Palaeontology	Progressive evolution	50,000–500,000
Climatic correlations	Correlation of landforms and deposits to known global climate changes	1,000–1,000,000+

Table 1.5 Some geomorphological publications which have specified concepts

Source	Concepts Enumerated
King, L.C. (1953) *Bulletin Geological Society of America,* 64: 721–52	Introduced 50 canons of landscape evolution; these subsequently reviewed by Twidale, 2003 (BGSA)
Thornbury, W.D. (**1954)** *Principles of Geomorphology.* New York:Wiley.	1. The same physical processes and laws that operate today operated throughout geological time, although not always with the same intensity as now 2. Geological structure is a dominant control factor in the evolution of landforms and is reflected in them 3. To a large degree the Earth's surface possesses relief because the geomorphic processes operate at different rates 4. Geomorphic processes leave their distinctive imprint upon landforms, and each geomorphic process develops its own characteristic assemblage of landforms 5. As the different erosional agents act upon the Earth's surface there is produced an orderly sequence of land forms 6. Complexity of geomorphic evolution is more common than simplicity 7. Little of the Earth's topography is older than Tertiary and most of it no older than Pleistocene 8. Proper interpretation of present-day landscapes is impossible without a full appreciation of the manifold influences of the geologic and climatic changes during the Pleistocene 9. An appreciation of world climates is necessary for a proper understanding of the varying importance of the different geomorphic processes 10. Geomorphology, although concerned primarily with present-day landscapes, attains its maximum usefulness by historical extension
Pitty, A.F. (1971) *The Nature of Geomorphology.* London: Methuen.	Section 3 refers to Basic Postulates and these include: catastrophism and uniformitarianism; the cycle of erosion; climatic geomorphology; stillstands and the mobility of earth structures; structure process and stage; the necessity for simplification of geomorphological complexity

Source	Concepts Enumerated
Schumm, S.A. (1977) *The Fluvial System.* New York: Wiley.	Refers to Thornbury's 10 concepts and collapses them to three: 1. Uniformity: the permanency of natural laws, thresholds, intrinsic and extrinsic 2. Land form evolution: a determinable sequence of landscape evolution through time within the constraints of geology (structure) – steady, graded and cyclic time 3. Landscape history and earth history are complex: complex response – multicyclic and compound landscapes result from different rates of processes or different processes operating on landscape at different times 4. Could also have a fourth concept of thresholds
McCullagh, P. (1978) *Modern Concepts in Geomorphology.* Oxford: OUP.	Does not define concepts explicitly and aims 'to present in one volume the more important recent advances in geomorphology'.
Coates, D.R. (1981) *Environmental Geology.* New York:Wiley.	Sees geomorphology within environmental geology and, like Thornbury, identifies 10 concepts: 1. Complexity is the norm in physical systems: includes equifinality, uniformitarianism, environmental unity (everything related to everything else) 2. Human-induced changes of the land and water invariably produce environmental feedback systems 3. Geologic thresholds are an ever-present danger in coping with the environment: intrinsic and extrinsic thresholds 4. The geologic environment contains both open and closed systems: includes exogenic and endogenic processes, law of aphasy (e.g. climatic environment changes faster than organic adaptation to meet the change) 5. Resources can be categorized as to whether they are renewable or non-renewable 6. Environmental problems are universal 7. There is an exponential rate of increase in environmental deterioration

Table 1.5 (Continued)

Source	Concepts Enumerated
	8. Environmental decisions invariably involve and produce internal conflicts, including tragedy of the commons, utilitarian ethic, conservation ethic, preservation ethic 9. The majority of environmental decisions should be based on cost-benefit analysis 10. Environmental stewardship is a prerequisite to the long-range compatibility of man and nature
Chorley, R.J., Schumm, S.A. and Sugden, D.E. (1984) *Geomorphology.* London and New York: Methuen.	Two major conceptual bases: 1. Historical studies which aim to deduce from the erosional and depositional features of the landscape the sequence of historical events through which it has passed: include palimpsest, retrodiction, linked to functional studies by uniformitarianism, evolution towards increasing entropy, timescales 2. Functional studies of reasonably contemporary processes and the behaviour of earth materials which help understand the maintenance and change of landforms: include prediction, systems, landforms considered in different ways, complex response and thresholds, geomorphic scales
Selby, M.J. (1985) *Earth's Changing Surface: An Introduction to Geomorphology.* Oxford: Clarendon.	Chapter 1 on Basic Concepts for Geomorphology includes: 1. Energy for landform change: endogenetic, exogenetic, hydrological cycle 2. Inheritance from the past: climate change 3. Timescales: dating methods 4. Objectives and history of geomorphology: Hutton and Playfair onwards 5. Climatic geomorphology: processes and climatic zones, structural influences 6. Climatogenetic geomorphology 7. Equilibrium 8. Geomorphic systems 9. People as geomorphic agents
Graf, W.L. (1988) *Fluvial Processes in Drylands*. Berlin: Springer-Verlag.	1. General systems theory: 2. Temporal: uniformitarianism, evolution, equilibrium, rate laws 3. Spatial: regions, networks, distance 4. Integrative: thresholds, complex response, scale, magnitude-frequency, allometric changes, catastrophe theory

Source	Concepts Enumerated
Brunsden, D. (**1984)** Tablets of stone: Toward the ten commandments of geomorphology, *Zeitschrift für Geomorphologie Supplementband*, 79: 1–37.	1. Style and location of landform change are determined by the type, location and rate of tectonic movements and their associated stress fields over the relevant time and space framework of the landform assemblage 2. Landforms are shaped by tectonic and denudational processes proceeding concurrently and directly reflect the ratio between the rates of operation of these processes 3. The lower boundary conditions for landform development are set by the varying sea levels experienced during the lifetime of the landscape 4. For any given set of environmental conditions, through a constant set of processes, there will be a tendency over time to produce a set of characteristic landforms 5. Landforms are continually subject to perturbations that arise from form changes in the environmental conditions of the system: these impulses are episodic and complex in nature at all scales and therefore the changes to landforms will be episodic and complex 6. Within each tectono-climatic regime landforms are produced by specific process events: such events are called formative events 7. New landforms are produced when an event is reached on the frequency-magnitude scale of the tectono-climatic regime, at which the normal behaviour is overturned and a new system is created: such events are called geocatastrophies 8. When a perturbing displacement exceeds the resistance of the system, the system will react and relax toward a new stable state that will be expressed by a new characteristic form 9. There is in landscape a wide spatial variation in the ability of landforms to change: this is known as the sensitivity of change, and thus landscape stability is a function of the temporal and spatial distributions of the resisting and disturbing forces and is therefore diverse and complex 10. The ability of a landscape to resist impulses of change tends to increase with time
Thorn, C.E. (1988) *An Introduction to Theoretical Geomorphology.* Boston, MA: Unwin Hyman.	Concepts not in index but does include uniformitarianism, ergodicity, magnitude and frequency, equilibria, spatial concepts, equifinality and convergence

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Table 1.5 (Continued)

Source	Concepts Enumerated
Summerfield, M.A. (1991) *Global Geomorphology.* Harlow: Prentice Hall.	Section 1.3 on some key concepts includes: 1. Endogenic and exogenic processes: denudation 2. Geomorphic systems: feedback, homeostasis, threshold 3. Magnitude and frequency: return period, recurrence interval 4. Equilibrium and evolution: functional and evolutionary/historical approaches 5. Scale in geomorphology: temporal scale, relaxation time, spatial scale and causality 6. Explanation in geomorphology: immanent (aspects of reality to do with inherent properties of the Universe) and configurational (arising from operation of physical laws), neocatastrophism, uniformitarianism (methodological and substantive), actualism
Bishop, P. (ed.), **2004** *Geomorphology: Critical Concepts in Geography. Volume 7: Landscape Evolution.* London: Routledge. ISBN 9780415276085	
Huggett, R. (**2010**) *Physical Geography: The Key Concepts*. London, Routledge.	53 of 99 concepts for which explanation is provided might be regarded as geomorphological. These 53 include some general ones, others that are overall approaches, some imported from other disciplines, and many that describe states or trends.
Bierman, P.R. and **Montgomery, D.R. (2013)** *Key Concepts in Geomorphology.* New York: W.H. Freeman and Co.	An integrative, applications-centred approach to the study of the Earth's dynamic surface. Each chapter focused specifically on key concepts and underlying principles rather than regional or local examples. The book's philosophy emerged from a National Academy of Sciences workshop on the future of the textbook, and the table of contents was determined at a National Science Foundation-sponsored retreat where over 60 geomorphologists gathered to identify core concepts and areas of common interest that future geomorphologists would need to know. Each chapter focuses on a consistent structure of themes, including mass transport, energy transfer, and explicit linkages between the processes that shape the Earth's surface and the landforms and deposits those processes leave behind.

Table 1.6 Sources of information on concepts in geomorphology

Subject of Book	Examples
Nature of discipline	Haines-Young, R. and Petch, J. (1986) *Physical Geography: Its Nature and Methods* Gregory, K.J. (2000) *The Changing Nature of Physical Geography* Inkpen, R. (2005) *Science, Philosophy and Physical Geography*
Textbooks	Chorley, R.J., Schumm, S.A. and Sugden, D.A. (1984) *Geomorphology* Summerfield, M.A. (1991) *Global Geomorphology* Huggett, R.J. (2003) *Fundamentals of Geomorphology* Gregory, K.J. (2010) *The Earth's Land Surface* Bierman, P.R. and Montgomery, D.R. (2013) *Key Concepts in Geomorphology*
Dictionaries	Thomas, D.S.G. and Goudie, A.S. (2000) *The Dictionary of Physical Geography* Gregory, K.J., Simmons, I.G., Brazel, A.J., Day, J.W., Keller, E.A., Sylvester, A.G. and Yanez-Arancibia, Y. (2009) *Environmental Sciences: A Student's Companion*
Handbooks	Gregory, K.J. and Goudie, A.S. (2011) *The SAGE Handbook of Geomorphology*
Encyclopaedias	Alexander, D.E. and Fairbridge, R.W. (eds) (1999) *Encyclopedia of Environmental Science* Mathews, J.A. (ed.) (2001) *The Encyclopaedic Dictionary of Environmental Change* Goudie, A.S. (ed.) (2004) *Encyclopedia of Geomorphology,* 2 vols
History of the discipline	Chorley, R.J., Dunn, A.J. and Beckinsale, R.P. (1964) *The History of the Study of Landforms, Vol. I, Geomorphology before Davis* Chorley, R.J., Beckinsale, R.P and Dunn, A.J. (1973) *The History of the Study of Landforms, Vol. II, The Life and Work of William Morris Davis* 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* Burt, T.P., Chorley, R.J., Brunsden, D., Cox, N.J. and Goudie, A.S. (2008) *The History of the Study of Landforms or The Development of Geomorphology Vol. 4: Quaternary and Recent Processes and Forms (1890–1965) and the Mid-Century Revolutions* Kennedy, B.A. (2006) *Inventing the Earth: Ideas on Landscape Development since 1740*
Review journals	*Progress in Physical Geography:* many relevant papers but dependent upon the contents list from year to year

BOX 1.1

The development of geomorphology

Although geomorphology became defined in the late 19th century, its subject matter was recognizable much earlier (Tinkler, 1985) when it was significantly influenced by concepts including stratigraphical succession and uniformitarianism in Geology, and evolution in Biology. Despite antecedents in Geology, it became more geographically based with the contribution by W.M. Davis of the ‘normal’ cycle of erosion. Although alternative approaches, such as that of G.K.Gilbert, clearly introduced the physical process studies that the Davisian approach lacked, the influence of Davisian concepts themselves prevailed for the first half of the 20th century, ensuring emphasis upon the historical development of landforms. The cycle as introduced by Davis was appealing in its simplicity: from initial uplift via recognisable erosion stages to a landscape of low relief, it was presented logically and graphically, although at the time there was little in the way of dating techniques or other detailed evidence with which to test its field applicability. However, by the mid 20th century outstanding contributions provided by Bagnold, Strahler, Nye, and Leopold, Wolman and Miller (Table 1.1) were stimuli instigating the quantitative analysis of processes (largely physical but also chemical) shaping the land surface – and hence ‘process geomorphology’. Strahler (1952) identified two quite different viewpoints for geomorphology: dynamic (analytical, particularly involving physical forces) and historical (regional, with sequences in time); these were associated respectively with what came to be known as timeless and time bound perspectives. Quaternary investigations also became more prominent in the second half of the 20th century, particularly given advances in dating techniques and in the biological analysis of palaeoenvironments. Plate tectonics was a major transforming advance for the earth sciences and this has been reinforced by geochronological techniques including cosmogenic dating methods. This also reinvigorated geomorphology such that Summerfield (2005a) saw two scales to geomorphology: small scale process geomorphology contrasting with a macroscale geomorphology reflecting geophysical advances made by researchers outside the traditional geomorphological community. Summerfield (2005b) avowed that ‘there is enormous scope to advance geomorphology as a whole probably at its most exciting time since it emerged as a discipline’. In a sense both became process-driven: the one large-scale and dominantly tectonic, the other by smaller-scale surface landforming systems operating in rivers, in glaciated landscapes, at coastlines and in deserts. However, the bonus provided by new dating techniques allowed timescales to be placed on both.

Progress in the 20th century was aided by the foundation of geomorphological societies, as in the case of the Swiss Geomorphological

Society (SGS) established in 1946, and by the inauguration of key journals enabling the volume of published research to increase considerably. Although many important geomorphological papers were published in geological and geographical journals in the first half of the 20th century, growth in research activity and publication led to the establishment of dedicated geomorphological journals, including *Revue de Géomorphologie Dynamique* (1950–), *Zeitschrift für Geomorphologie* (1956–), *Earth Surface Processes* (1977–), and *Geomorphology* (1989–) (Table 1.1). Also included in Table 1.1 are key years in which particular techniques affected geomorphology: dating advances, the analysis of ocean cores, the advent of satellite remote sensing, LiDAR, virtual globes, Global Positioning Systems, and more advanced modelling capability – just some of the ways in which technical developments enabled geomorphology to be revolutionized in the latter years of the 20th century.

During this revolutionary growth it was inevitable that the discipline would fragment into separate branches, each interfacing with other disciplines, thereby strengthening multidisciplinary research communities. Not only were there more geomorphologists, they also came equipped with different skills and objectives. Such developments have encouraged formative debates recognized (Gregory and Goudie, 2011a) to be concerned with such things as the spatial limits of the discipline, temporal limits for geomorphology, relating space and time, gradualism and catastrophism, human impact, holistic views, and practical applications. At least four alternative foci can now be perceived: process-based, interpreting morphology and morphology-process relationships; morphometric, especially using computational analysis of newly available remote sensing data; geophysical macro-geomorphology, concentrating upon broad structural and continental outlines, and chronological/historical (mostly Quaternary but also the last few centuries) focused on the history of change (see Church, 2005; Summerfield, 2005a; Walker and Lowe, 2007; Bishop et al., 2012; Macklin et al. 2012; Phillips, 2012a). It might be said that the discipline of geomorphology has remained attractively un-disciplined.

RELEVANT ARTICLES IN *PROGRESS IN PHYSICAL GEOGRAPHY:*

Chorley, R.J. (1971) The role and relations of physical geography, *Progress in Geography,* 3: 87–109.

Chorley, R.J. (1995) Classics in physical geography revisited: Horton 1945, *Progress in Physical Geography,* 19: 533–54.

Cockburn, H.A.P. and Summerfield, M.A. (2004) Geomorphological applications of cosmogenic isotope analysis, *Progress in Physical Geography,* 28: 1–42.

Curran, P.J. (1994) Imaging spectrometry, *Progress in Physical Geography,* 18: 247–66.

Duller, G.A.T. (1996) Recent developments in luminescence dating of Quaternary sediments, *Progress in Physical Geography,* 20: 127–45.

Fisher, P. F., Mackaness, W.A., Peacegood, G. and Wilkinson, G.G. (1988) Artificial intelligence and expert systems in geodata processing, *Progress in Physical Geography,* 12: 371–88.

Gardiner, V. and Gregory, K.J. (1977) Progress in portraying the physical landscape, *Progress in Physical Geography,* 1: 1–22.

Goudie, A.S. (1994) R.J. Chorley Commemorative Issue, *Progress in Physical Geography,* 18: 317–18.

Mosley, M.P. and Zimpfer, G.L. (1978) Hardware models in geomorphology, *Progress in Physical Geography,* 2: 438–61.

Phillips, J.D. (1995) Self-organization and landscape evolution, *Progress in Physical Geography,* 19: 309–21.

Raper, J. (1991) Geographical information systems, *Progress in Physical Geography,* 15: 438–44.

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UPDATES

An article in *Progress in Physical Geography* 2015 (Gregory, K.J. and Lewin, J. (2015)) Making concepts more explicit for geomorphology, *Progress in Physical Geography*, 39: 711–27 reviews the nature, prevalence and function of concepts in geomorphology, and was written after the experience gained in writing this book. Table 4 in that paper provides a classification of concept types, grouped into 6 categories (see overleaf).

Table 4 A classification of concept types

Category	**Glossary** (Gregory and Lewin, 2014)	**Huggett** (2010)
1. **General scientific terms**	Accuracy, Atomic energy or chemical energy, Boundary conditions, Capacity, Competence, Complexity, Cycles, Cycling, Disaster, Effective force, Efficiency, Enthalpy, Entropy, Geothermal energy, Gravity, Hydrological cycle, Idiographic/interpretive, Immanent processes, Life cycles, Modelling, Nomothetic, Power, Precision, Prediction, Risk, Rock cycle, System, Thresholds, Timescales, Vulnerability	cyclicity/periodicity, time, topography,energy/energy flow, environment, feedback, geological cycle, hydrological cycle, sustainability, systems, thresholds, time, topography, transport processes
2. **Utilized by several disciplines, mainly sciences**	Anthropic Force, Anthropocene, Biogeochemical cycling, Catastrophism, Cellular automaton model, Complexity theory, Covering Law model, Denudation rate, Dissipative structure, Ecological footprint, Endogenetic processes, *Environmental flows,* Environmental Impact Assessment, Exogenetic processes, Factor of safety, Fractals, Gaia theory, Geohazards, GM processes, Holism, Holistic approach, Homosphere, Hysteresis, Kinds, Land systems, Landscape fluidity, Least Action Principle, Milanković cycles, Neo's, Neocatastrophism, Nonlinear dynamical systems, Noosphere, Open systems, Panarchy, Rate law concept, Reaction time, Recovery times, Relaxation time, Resilience, Sediment cycle, Sensitivity, Space-time substitution, Steady statism, Systems of complex disorder, Undersensitivity	active and passive margins, biogeochemical cycles, bombardment, catastrophism, catena, drainage basin, ecosystem, endogenic forces, ergodicity, eustasy, exogenic forces, Gaia hypothesis, continental drift, geochronology, isostasy, resilience, soil landscapes, zonality

(Continued)

Table 4 (Continued)

Category	**Glossary** (Gregory and Lewin, 2014)	**Huggett** (2010)
3. Describing states, processes or conditions	Actualism, Balance of nature, Disturbance regimes, Dynamic equilibrium, Dynamic metastable equilibrium, Emergence, Environmental forcing, Episodism, Equilibrium, Exhaustion effects, Forcing functions or drivers, Gradualism, Hazardousness of a place, Historical contingency, Hypersensitivity, Indeterminacy, Metastable equilibrium, Non-equilibrium, Quasi equilibrium, Regime, Steady state, Uniformitarianism	actualism/ non-actualism, complexity, equilibrium, equifinality, gradualism, uniformitarianism
4. Describing trends	Desertification, Global warming, Historical memory or persistence, Metamorphosis	aridity, climate change, desertification, environmental change, evolution, global warming, land degradation, sea level change
5. Describing geomorphological approaches	Adaptive management, Anthropogeomorphology, Earth system science, Engineering geomorphology, Environmental geomorphology, Environmental hazards, Geomorphic engineering, Geomorphometry, Hard engineering, Land evaluation, Landscape ecology, Resilience theory, Restoration, Self-organizing systems, Simple systems, Soft engineering	evolutionary geomorphology, geographical cycle, landscape ecology,plate tectonics, plume tectonics, systems, sustainability, tectonics and neotectonics
6. Developed in specific form within geomorphology	Anthropogenic alluvium, Autogenic or intrinsic processes, Characteristic form, Characteristic slope angles, Complex response, Configurational factors, Cyclic or geologic time, Duration time, Earthcasts, Effectiveness, Formation time, Formative events, Geomorphic	chronosequence, etchplanation, magnitude and frequency

Category	Glossary (Gregory and Lewin, 2014)	**Huggett** (2010)
	effectiveness, Geomorphic hazards, Geomorphic transport laws, Geomorphic work, Geomorphon, Glacier power, Grade, Graded time, Historical range of variability (HRV), Hysteretic loops, Inheritance, Landforms, Legacy sediment, Magnitude-frequency concepts, Neogeomorphology, Palimpsest, Paraglacial, Patchy, Process controls, Sediment budget, Sediment cascade, Sediment delivery, Steady state time	

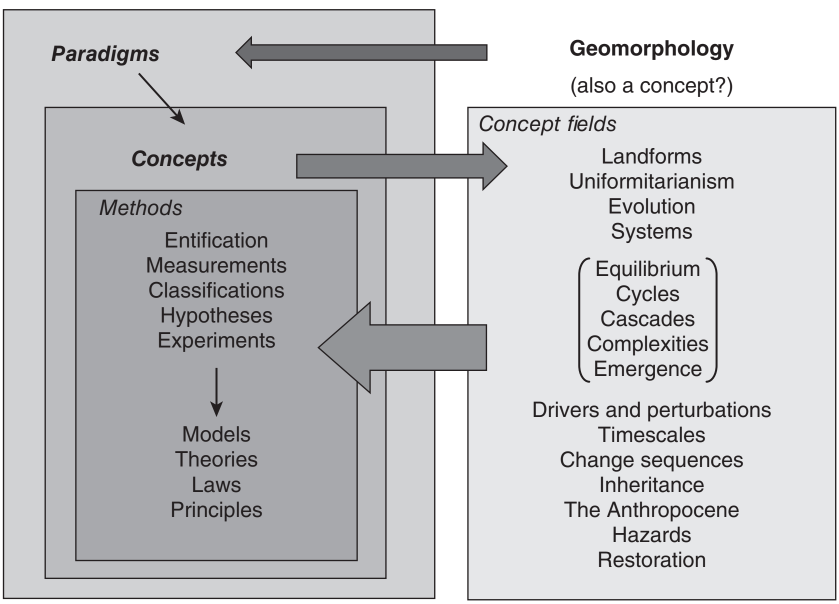

Figure 1 A system structure for geomorphological understanding

The paper also includes a diagram (Figure 1) suggesting a system structure for geomorphological understanding which can be used in relation to the content of the book to reinforce appreciation of the importance of concepts in geomorphology.

Other articles can usefully show how concepts have been categorised in the past and in addition to Baker (1986) which we included in the reference list, Vic Baker has communicated that Ollier (1981) and Twidale (1977) produced concept lists from 'down under' and Schumm (Schumm, S.A. (1991) *To Interpret the Earth: Ten Ways to Be Wrong*. Cambridge: Cambridge University Press) also showed that both concepts and their opposites are important. Huggett (Huggett, R. (2010) *Physical Geography: The Key Concepts*. London: Routledge) considers concepts in physical geography as a whole.

A new book by Pauline Couper explores the relevance of broad philosophical schools of thought to geography as a science. She examines such topics as positivism, critical rationalism, phenomenology, and social constructionism:

Couper, P. (2015) *A Student's Introduction to Geographical Thought*. London: Sage.

In a paper on the lexicon of geomorphology John Lewin elaborates how the terms that geomorphology uses reveal much about its identity, history, perceptions, external inspirations and methods. (Lewin, J. (2015) The lexicon of geomorphology, *Earth Surface Processes and Landforms*, available online, Doi: 10.1002/esp.3733). This discussion of the names we use, and the concepts that lie behind them is germane to all the chapters in the book.

Woodward, J. (2015) Is geomorphology sleepwalking into oblivion? *Earth Surface Processes and Landforms* 40: 706–9 gives a commentary using Google Books Ngrams. Explores the changing use of the word geomorphology, shows a very sharp rise and fall in the use of term geomorphology in books published since 1980 and indicates that we should monitor such changes to gain a better understanding of where we need to be most visible to ensure the long-term health of our discipline.

A number of new techniques and approaches are being described including:

- **Fuzzy Cognitive Map (FCM) knowledge-based artificial intelligence** (AI) technique that merges fuzzy logic and neural computing in which knowledge or concepts are structured as a web of relationships that is similar to both human reasoning and the human decision-making process used by Houser, C., Bishop, M.P. and Barrineau, P. (2015) Characterizing instability of aeolian environments using analytical reasoning, *Earth Surface Processes and Landforms*, 40: 696–705 to describe the development and application of analytical reasoning to quantify instability of an aeolian environment using scale-dependent information coupled with conceptual knowledge of process and feedback mechanisms.

- Bocco, G. and Winklerprins, A. (2015) General principles behind traditional environmental knowledge: The local dimension in land management, *Geographical Journal* (in press) focuses on soils and geomorphology to explore some potential general principles that undergird the local component of TEK (**Traditional environmental knowledge**) which has become a widely used concept in theory and practice, and which encompasses environmental knowledge acquired by people native to, or long-term inhabitants of, specific places, over long periods of time; knowledge which is then assumed to apply only to those local areas.
- Slama, T. and Turki, M.M. (2015) 3D cartography and geovisualization based on gis and geovrml for an open access landform investigation and analysis within an open web platform (OWP), *International Multidisciplinary Scientific GeoConference Surveying Geology and Mining Ecology Management, SGEM* 2 (2): 619–26. This shows how **interactive geovisualization** provides theory, methods and tools for the visual exploration, synthesis and presentation of data that contains geographic information, showing the potential of spatial data visualization including GeoVRML (Geographic Virtual Reality Modelling Language).
- Geoff P. Whitman, Rachel Pain and David G. Milledge. (2015) Going with the flow? Using participatory action research in physical geography, *Progress in Physical Geography*, 39: 622–39 propose **participatory action research (PAR)**, which offers an alternative mode of science, involving collaboration and co-production of research from question definition through to outcomes.

It is important to remember how individuals have shaped the way in which geomorphologists conduct research and in a special issue Rhoads, B.L. (2016) The natural and human structuring of rivers and other geomorphological systems: A tribute to William L. Graf, *Geomorphology*, 252: 1–4 describes the contributions of William L. Graf including how to pursue policy-relevant science and to participate in science-based policy formulation.

The discipline continues to change and a review of the content of 1717 papers published in five journals between 1987–2009 shows significant change in methods used in fluvial geomorphology: Piegay H., Kondolf, G.M., Minear, J.T. and Vaudor, L. (2015) Trends in publications in fluvial geomorphology over two decades: A truly new era in the discipline owing to recent technological revolution?, *Geomorphology*, 248: 489–50.

A review of relationships between science, technology and the development of geomorphological tools and techniques is the basis for consideration of five areas of important technological development which are opening the doors to better cross-scalar investigations, blurring the boundaries between laboratory, field and computer model, and facilitating cross-disciplinary and democratized research:

Viles, H. (2016) Technology and geomorphology: Are improvements in data collection techniques transforming geomorphic science?, *Geomorphology*, 270: 121–33.

An interesting paper arising from a BSG working group is given by:

Tooth, S., Viles, H.A., Dickinson, A., Dixon, S.J., Falcini, A., Griffiths, H.W., Hawkins, H., Lloyd-Jones, J., Ruddock, J., Thorndycraft, V.R. and Whalley, B.W. (2016) Visualizing geomorphology: improving communication of data and concepts through engagement with the arts, *Earth Surface Processes and Landforms*, 41: 1793–96.