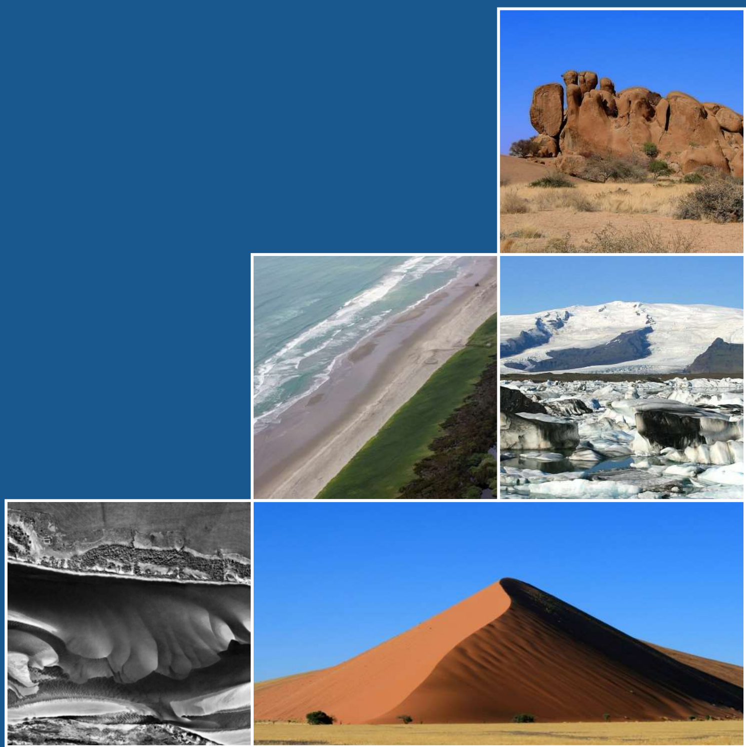
10 reasons why **Geomorphology** is important



BSG
British Society for Geomorphology

10 reasons why **Geomorphology** is important

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www.geomorphology.org.uk
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What is geomorphology?

In today's world, there is much interest in, and concern about, the global environment and how it operates and changes. The threats of climate change and species extinctions are commonly highlighted, but what about the potential changes to physical landscapes? Understanding how landscapes operate and change is a crucial part of gaining a full understanding of the Earth system and enabling better environmental management. There are many questions that remain to be answered about physical landscapes and our interactions with them.

- Why are some parts of the Earth mountainous and other parts much flatter?
- Why are the Himalaya so high?
- Why does part of the Australian continental interior lie close to, or below, sea level?
- Where does all the sand in the Sahara come from?
- How old is the Grand Canyon?
- How fast are Greenland's glaciers retreating?
- How rapidly will Britain's coastline change over the 21st century with predicted rises in sea level?
- Are hazards like landslides getting more serious?
- How can we best conserve and manage landscapes?

Geomorphology is the science that studies the origin and development of landforms (such as hills, valleys, sand dunes, caves), and how those landforms combine to form landscapes. As such, it makes a critical contribution to answering the sorts of aforementioned questions. Geomorphological studies include the quantitative analysis of landform shapes, the monitoring of surface and near-surface processes (e.g. running water, ice, wind) that shape landforms, and the characterisation of landform changes that occur in response to factors such as tectonic and volcanic activity, climate and sea level change, and human activities. Investigations may be directed principally towards reconstructing past processes and landform changes, towards understanding present-day processes and landform changes, or towards anticipating future processes and landform changes.

derived from Greek
geomorphology

ge - 'earth'
morphe - 'form'
logos - 'discourse'

How are geomorphological studies undertaken?

Geomorphology is an eclectic science that has its own heritage and history but also draws on aspects of other sciences, particularly physical geography, geology, and ecology. Traditionally, geomorphological study approaches focused mainly on field observation, description and measurement but also included physical experimentation (e.g. in small field plots or using laboratory flumes). Since the early 1970s, however, high-resolution images of the surface topography of the Earth and other planets have been acquired at rapid pace from a variety of satellites and spacecraft (e.g. Figure 1a). Many of these images are now readily available for free from the internet (e.g. using virtual globes such as Google Earth). In addition, large numbers of computer-based topographic models (e.g. Digital Elevation Models) have become readily available (Figure 1b), and ground-based monitoring, computational modelling, and geochronological (dating) techniques (e.g. luminescence, cosmogenic isotope analysis) have advanced rapidly. Consequently, traditional geomorphological study approaches are now commonly combined with these new images, models and techniques to quantify rates and timescales of landform change. It is now possible to view, measure, age, and model a variety of landforms and landscapes in ways that were unimaginable even a decade ago. These advances are helping to shed light on a variety of long-standing problems in explaining the development of the Earth's surface, as well as informing interpretation of the development of other planetary surfaces (most notably Mars).

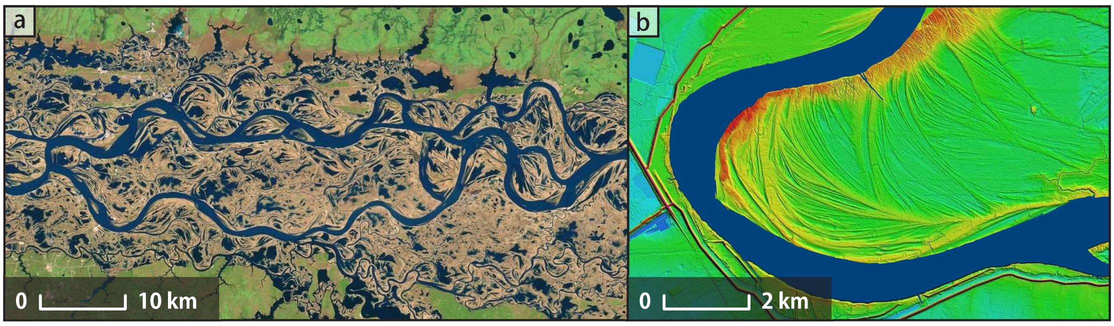

Figure 1. a) Widespread availability of satellite imagery such as this Landsat image of the multiple channels of the Ob River, Russia, enables quantification of river and floodplain characteristics. Comparison of satellite images from different dates enables assessment of rates of riverine and wider landscape change (Source: United States Geological Survey Earth Explorer). b) A high resolution Digital Elevation Model of a meander bend on the Mississippi River, USA, can be used to identify sediment deposition zones and measure movement patterns. In this instance, the curved features on the inside of the bend are former channel deposits and indicate bend migration towards the lower left of the image (Source: Atlas: The Louisiana Statewide GIS).

Why is geomorphology important?

In addition to explaining how landscapes have developed in the past, how they function at present, and how they might change in future, there is growing recognition of the importance of geomorphology and geomorphologists in contributing to a range of environmental investigations and management issues (Figure 2).

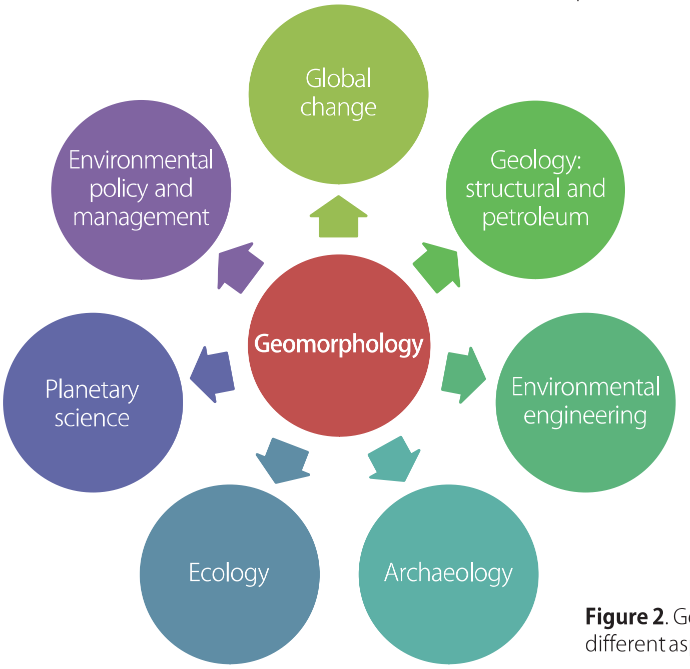

Figure 2. Geomorphology interfaces with, and contributes to, many different aspects of the earth, environmental and social sciences.

For instance, structural geologists want to know how erosion at the Earth's surface influences patterns of rock deformation in developing mountain belts. Petroleum geologists employ an understanding of modern-day depositional processes to improve subsurface exploration efforts for oil and gas reserves hosted in sedimentary rocks. Engineers use knowledge of erosional and depositional processes to improve estimations of the thresholds of stability for hillslopes, or to assess the likelihood of channel changes along rivers where infrastructural developments are planned. Planetary scientists apply insights gained from study of the Earth's landscape processes to help them interpret planetary surfaces. Archaeologists are interested in how erosional and depositional processes influence the preservation of artefacts and other forms of evidence for past human societies. Ecologists acknowledge that geomorphological processes provide the morphological, sedimentary, and hydrological templates upon which key ecological processes such as succession take place; in particular, ecologists concerned with conservation of biodiversity are interested in understanding the complexity of the physical landscape - 'geodiversity' - as this can exert an important control over species diversity. Implicitly or explicitly, geomorphological considerations also underpin many aspects of environmental policy, law, and land management decision making, such as the European Union's Water Framework Directive.

In short, geomorphology and geomorphologists provide data, knowledge and perspectives that are additional and complementary to those provided by other academic disciplines and professions. In many cases, geomorphological considerations are important – indeed essential – for enabling a comprehensive approach to environmental investigations and achieving sustainable environmental management.

What is this document about?

Despite the demonstrable importance of geomorphology, the terms 'geomorphology' and 'geomorphologist' are probably not very well understood. In part, this is because geomorphology does not exist as a stand-alone university discipline, typically having its roots within Geography departments in countries like the UK and Australia and mainly within Geology or Earth Science departments in the USA. Nonetheless, there are a large number of national and international organizations dedicated to the support and promotion of geomorphology, including the British Society for Geomorphology (BSG), the Australian and New Zealand Geomorphology Group (ANZGG), and the International Association of Geomorphologists (IAG). In addition, specialist geomorphology sessions are regularly held within meetings convened by larger organizations such as the European Geosciences Union (EGU) or American Geophysical Union (AGU).

The aim of this document is to introduce the term 'geomorphology' to a non-specialist audience and to illustrate a selection of key principles that underpin the discipline. The popularity of virtual globes such as Google Earth illustrates that public interest in the landforms and landscapes of the Earth and other planetary bodies is high; some of the online discussion threads in Google Earth Blog and Google Earth Community forums even revolve around questions of landform development, but in some cases the accuracy and clarity of discussion could benefit from greater grounding in the principles of modern geomorphology. Drawing inspiration from the US-based Climate Literacy[1] and Earth Science Literacy initiatives[2], we highlight ten key points that any citizen should know about geomorphology. These ten points are not exhaustive but are simply intended to indicate why geomorphology should be viewed as an eclectic but coherent, vibrant, innovative and relevant science. The document concludes by providing sources of additional information.

[1] www.globalchange.gov/resources/educators/climate-literacy
[2] www.earthscienceliteracy.org

Geomorphic literacy: 10 key points that everyone should know about geomorphology

The ten key points that everyone should know about geomorphology - the ten reasons why geomorphology is important - are summarized in Table 1, both in abridged and extended form.

Table 1. Summary of the ten key points

1	**Landscapes are shaped by movements of mass**	Landforms are shaped by geomorphological processes, which essentially involve the movement of mass – rock, sediment, water – across the Earth's surface
2	**Landscape shaping processes are influenced by many different factors**	Various tectonic, geological, climatic and ecological factors provide major influences on geomorphological processes and the movement of mass
3	**Landscape processes operate at many different scales**	The tectonic, geological, climatic and ecological factors that influence geomorphological processes and movement of mass change with different time and space scales
4	**The Earth's landscapes are dynamic**	Landforms and landscapes are not static and unchanging, but are dynamic and develop through time
5	**Landscape dynamics are often complex**	In addition to changing tectonic, geological, climatic or ecological conditions, internal readjustments can also drive landform and landscape development
6	**Landscapes are archives of the past**	Landscapes contain histories of their development that potentially can be deciphered and reconstructed from study of the associated landforms and sediments
7	**Global change is influencing landscape dynamics**	Ongoing global environmental change, which includes atmospheric warming and sea level rise, is currently driving landform development, including desert lake desiccation, ice sheet and glacial retreat, and coastline erosion
8	**Human activities are influencing landscape dynamics**	Increasingly, many geomorphological processes and landform/landscape developments are influenced by human activities
9	**The Earth's landscapes are becoming more hazardous**	Both global environmental change and human activities are increasing the magnitude and frequency of geomorphological hazards, which occur wherever and whenever land surface stability is affected and adverse socio-economic impacts are experienced
10	**Successful environmental management needs geomorphological knowledge**	Geomorphology can provide a key input to environmental management, including landscape conservation, ecosystem conservation and restoration, heritage conservation and carbon landscaping

1 Landscapes are shaped by movements of mass

Landforms are shaped by geomorphological processes, which essentially involve the movement of mass – rock, sediment, water – across the Earth's surface. Movement of mass commonly involves the weathering, erosion, transportation and deposition of surface materials by gravity, ice, wind, or water, but can also involve near-surface tectonic, volcanic or groundwater activity. The movement of mass most commonly is predominantly downwards (ie. from higher to lower elevations, such as by gravity-induced landsliding or downhill sediment movement by running water) but can also be predominantly upwards (i.e. from lower to higher elevations, such as through tectonic uplift, volcanic eruptions, or the action of the wind). The balance between the two types of movement determines whether landforms/landscapes tend to decrease in relief (i.e. flatten and/or lower) through time, or increase in relief (i.e. steepen and/or elevate) through time (Figure 3). Within landscapes, individual landforms can be classified as primarily erosional/ degradational (i.e. mass is removed to create features such as valleys) or depositional/ constructional (i.e. mass accumulates to create features such as hillslope deposits and volcanic cones).

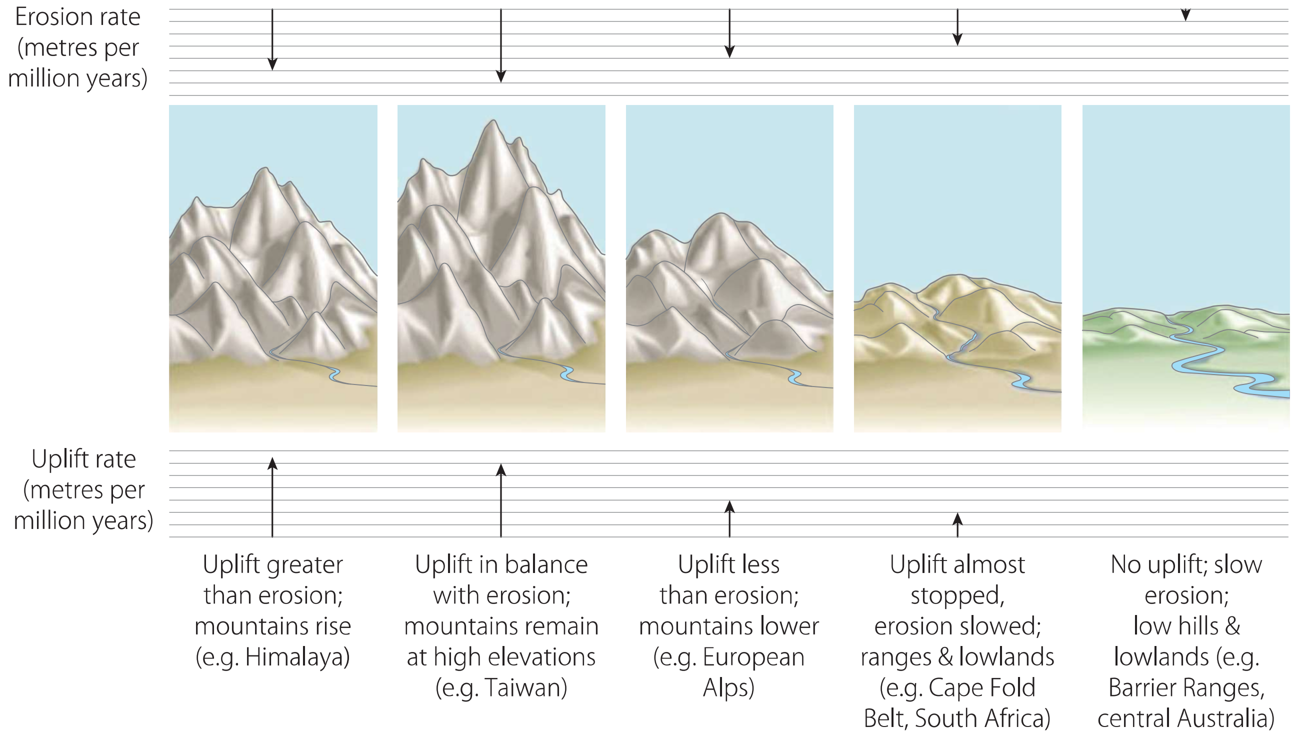

Figure 3. The elevation and relief of large-scale landforms like mountains is determined by a competition between upward movement of mass (e.g. through tectonic uplift) and downward movement of mass (e.g. through weathering and erosion) (Source: redrawn and adapted from Press, F. and Siever, R., 1997. Understanding Earth (2nd edition), W.H. Freeman and Company, New York).

Did you know?

The highest point on the Earth's surface as measured from sea level is the summit of Mt Everest, on the border between Nepal and China. The summit's elevation is commonly given as approximately 8848 m, and results from ongoing tectonic uplift in the Himalaya that is outpacing weathering and erosion. The lowest point on dry land is on the shore of the Dead Sea, shared by Jordan and Israel. The elevation of approximately 418 m below sea level is a result of tectonic rifting and downfaulting of this part of the Earth's crust (Source: Wikipedia[3]).

[3] http://en.wikipedia.org/wiki/Extreme_points_of_Earth

2 Landscape shaping processes are influenced by many different factors

Various tectonic, geological, climatic and ecological factors provide major influences on geomorphological processes and the movement of mass. Different tectonic settings can influence whether the potential for movement of mass is predominantly up (e.g. through uplift where continental landmasses collide) or down (e.g. through downfaulting where the Earth's crust is fracturing). Different lithologies (rock types) have different susceptibilities to weathering and erosion. Climatic setting influences temperature and moisture availability – key influences on the potential for weathering and the availability of water in liquid or frozen form – and this affects erosion, transportation and deposition. Ecological influences – plant and animal (including human) – may also play a role, in some cases limiting the potential for movement of mass (e.g. tree roots stabilizing hillsides against erosion – Figure 4a) but in others enhancing the potential for movement of mass (e.g. the digging activities of insects and mammals – Figure 4b). In essence, geomorphology is the science that studies the integrated effect of all these different factors in the shaping of the Earth's land surface. As the integrated effect varies from region to region, many landforms have semi-predictable spatial distributions. For instance, rugged mountain ranges tend to be found mainly in areas undergoing active tectonic uplift, with lithologies that are susceptible to weathering and erosion under climates characterized by heavy rainfall or snowfall (e.g. the New Zealand Alps, or in Taiwan) (Figure 3). Less rugged uplands or plains tend to be found in less tectonically active or tectonically inactive areas, particularly where lithologies are more resistant and/or climate is drier (e.g. in southern Africa or central Australia) (Figure 3). Ice sheets and glaciers are located mainly in the higher latitudes and/or at higher elevations where water remains frozen for all or a substantial part of the year. Hillslopes with thick soils tend to be best developed in wetter regions where a stabilizing vegetation cover is well developed, while active wind-blown sand dunes tend to occur mainly in dry, sandy regions largely devoid of vegetation cover.

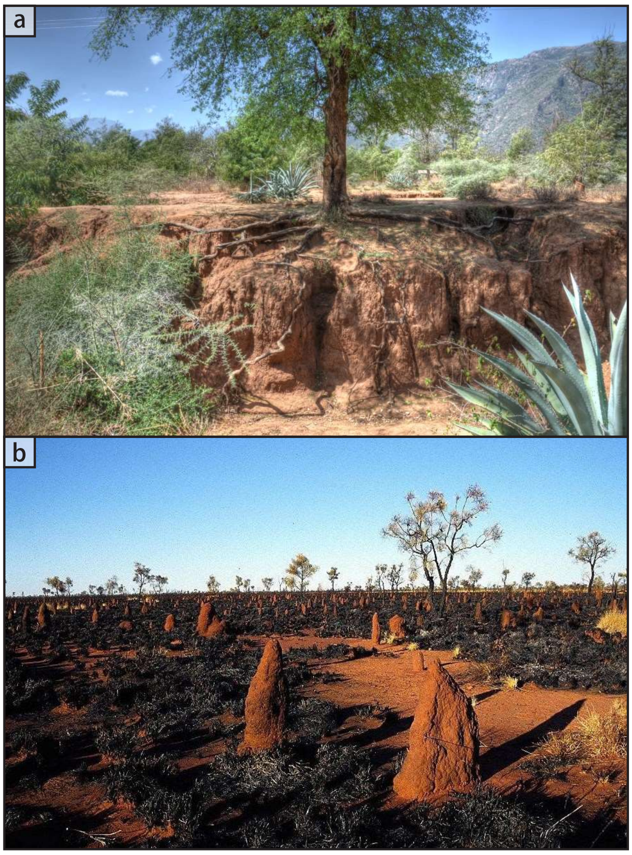

Figure 4. a) The roots of trees, shrubs and grasses commonly help to bind loose sediments and soils, minimizing the potential for erosion during rainfall and runoff events. In this example from Kenya, the extent of a tree root network is revealed by erosion that started on an adjacent, unprotected part of the land surface (Photo: Daniel Green); b) Termite mounds are landforms that result from the movement of mass by insects. In this example from the Tanami Desert, central Australia, multiple mounds up to 1.5 m tall provide stark contrast with the burnt vegetation (Photo: Stephen Tooth).

Did you know?

Around the Alpine Fault in the Southern Alps of New Zealand, land is rising vertically at up to around 10 mm per year and moving horizontally at around 30 mm per year. These rates are roughly the rates at which healthy adult nails grow (Source: Little, T.A. et al., 2005. Variations in exhumation level and uplift rate along the oblique-slip Alpine fault, central Southern Alps, New Zealand. Geological Society of America Bulletin, 117, 707-723; Yaemsiri, S. et al. 2010. Growth rate of human fingernails and toenails in healthy American young adults. Journal of the European Academy of Dermatology and Venereology, 24, 420-423).

3 Landscape processes operate at many different scales

The tectonic, geological, climatic and ecological factors that influence geomorphological processes and movement of mass change with different time and space scales. Some factors can be characterized as low frequency/high magnitude, as they act relatively irregularly through time but can move large amounts of mass (e.g. regional tectonic uplift that involves faulting) and result in large-scale landforms (e.g. mountain belts). Other factors are high frequency/low magnitude as they act relatively regularly but move only small amounts of mass (e.g. soil creep under gravity, or localized weather events that lead to rainfall and shallow flow on hillslopes) and result in only small-scale landforms (e.g. small gullies). Between these two extremes, tectonic, geological, climatic and ecological factors can combine in various ways to influence geomorphological processes and movement of mass. By distinguishing between geomorphological processes that occur along this spectrum from low frequency/high magnitude to high frequency/low magnitude, we can conceptualize how movement of mass occurs at different rates (Figure 5), and how different landforms develop across a spectrum of time and space scales (Figure 6).

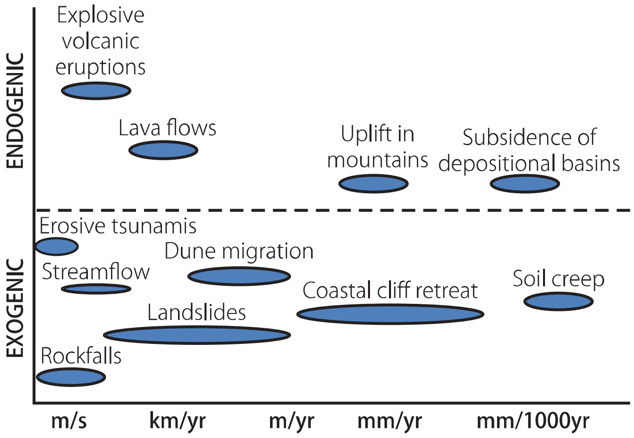

Figure 5. Geomorphological processes are driven by endogenic factors (powered from within the Earth such as volcanoes and earthquakes) and exogenic factors (powered by the sun's energy and working through the climate system, such as rain, wind and waves). Different processes result in different rates for the movement of mass, from very slow (e.g. basin subsidence, soil creep) to extremely rapid (e.g. volcanic eruptions, rock falls) (Source: adapted from Goudie, A.S. and Viles, H.A., 2010. Landscapes and Geomorphology: A Very Short Introduction. Oxford University Press, Oxford).

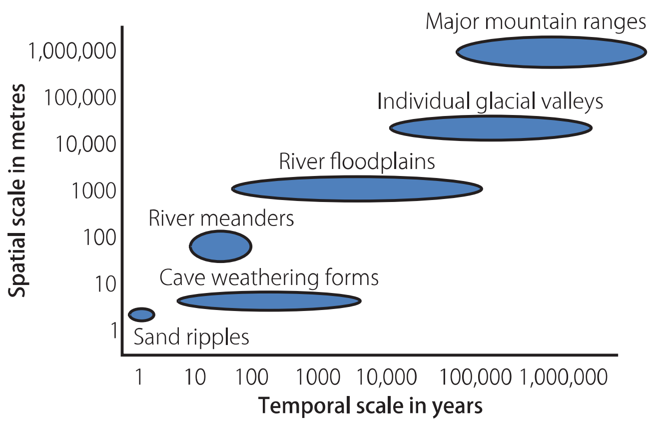

Figure 6. Landforms vary widely in spatial scale (size), and their development occurs across a wide range of temporal scales. Small scale landforms such as sand ripples form, erode and re-form on rapid temporal scales, while large scale landforms such as mountain ranges develop over far longer temporal scales (Source: adapted from Goudie, A.S. and Viles, H.A., 2010. Landscapes and Geomorphology: A Very Short Introduction. Oxford University Press, Oxford).

Did you know?

The volcano of Kilauea on the Big Island of Hawaii is perhaps the world's most active volcano. Various estimates suggest that Kilauea began to form 300 000-600 000 years ago on the sea floor and has likely been active ever since, with no prolonged periods of quiescence. Kilauea emerged from the sea as an island perhaps 50 000-100 000 years ago and now stands nearly 1280 m above sea level, and has an estimated volume of 25 000-35 000 km^3 (1 km^3 is equivalent to 1 billion m^3). The island is made mostly of lava flows, locally interbedded with deposits of explosive eruptions, illustrating how endogenic processes originating more than 60 km deep in the earth have driven vast volumes of magma to the surface (Source: United States Geological Survey, Hawaiian Volcano Observatory[4]).

[4] http://hvo.wr.usgs.gov/kilauea/

4 The Earth's landscapes are dynamic

Landforms and landscapes are not static and unchanging, but are dynamic and develop through time. Although the dynamic nature of landforms and landscapes is well known to geomorphologists, it is not always appreciated by the wider public, and there can be a tendency to view landforms/ landscapes as largely fixed in form, size and position. Given that tectonic, geological, and especially climatic and ecological factors change through time and over space (see key point 3), however, all landforms and landscapes are subject to change. For example, with a change to drier climates, decreases in stabilizing vegetation covers can lead to greater soil loss through wind or water erosion, whereas with a change to wetter climates, formerly active wind-blown dunes can become stabilized by renewed vegetation growth. Nonetheless, as illustrated in Figures 5 and 6, the rate of landform/landscape development can vary widely, depending on the processes operating and the amount of mass that needs to be moved for change to be recognisable. Large-scale landforms/landscapes (e.g. mountain belts) typically develop only slowly over time because of the vast amounts of mass that need to be moved to effect change, and thus can be relatively persistent features of the Earth's surface. Small-scale landforms (e.g. hillslope gullies) can change rapidly over time because only relatively small amounts of mass need to be moved to effect change. Other landforms may develop slowly for a while, then suddenly and rapidly develop as a threshold is crossed. For example, some river channels can remain in largely stable positions between levees that slowly increase in height over time, and that effectively raise the channel above the level of the surrounding floodplain (Figure 7). Eventually, the levees fail during floods, and a new channel is eroded in a lower position on the floodplain while the old channel is gradually abandoned.

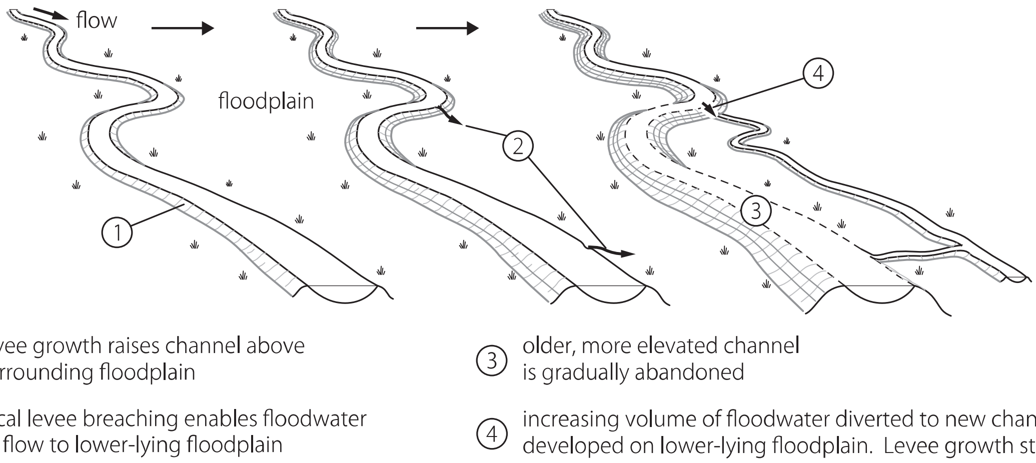

Figure 7. Deposition of sand, silt and clay along and adjacent to river channels can lead to the growth of levees and the raising of flow above the level of the surrounding floodplain. During floods, levee breaching can divert increasing amounts of flow to parts of the lower-lying floodplain. Eventually, a threshold is crossed whereby a newly-formed channel carries an increasing proportion of the flow, and the old, higher-elevation channel is gradually abandoned.

Did you know?

Over the last two centuries, the Kosi River, India, moved more than 113 km westward in its passage across the Himalayan foreland. In August 2008, however, the Kosi River changed course dramatically, moving 60 km eastwards in one event and diverting most of the river flow into a new channel (Source: Chakraborty, T. et al., 2010, Kosi megafan: historical records, geomorphology and the recent avulsion of the Kosi River, Quaternary International, 227, 143–160).

5

Landscape dynamics are often complex

In addition to changing tectonic, geological, climatic or ecological conditions, internal readjustments can also drive landform and landscape development. The main drivers of landform and landscape development are commonly external factors, including those related to tectonic, volcanic, climatic, sea level or anthropogenic perturbations, but landform/landscape developments can also result from internal readjustments that occur independently of changes to these external factors. For example, even under conditions of steady flow and sediment transport, lateral migration (sideways movement) of river meander bends ultimately can result in bend cutoff and oxbow lake formation (Figure 8). In some situations, both internal and external factors can combine to drive landform/landscape changes. For example, hillslope deposits may steadily accumulate mass over time, with the slope angle gradually increasing (Figure 9). Eventually, the critical angle for slope stability may be crossed but these internal readjustments may be insufficient to trigger change by themselves; the landform may remain stable until slope failure (Figure 9) is triggered by a change in external factors, such as tectonic activity (e.g. an earthquake) or a heavy rainfall event.

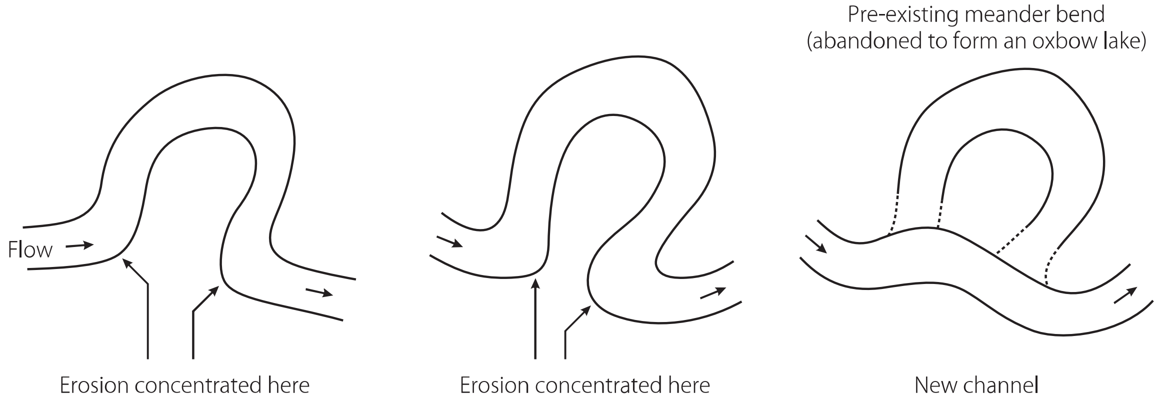

Figure 8. Along river meanders, erosion tends to be enhanced on the outer parts of the bends. This can lead to the meeting of adjacent bends, which ultimately straightens the channel and abandons the former bend.

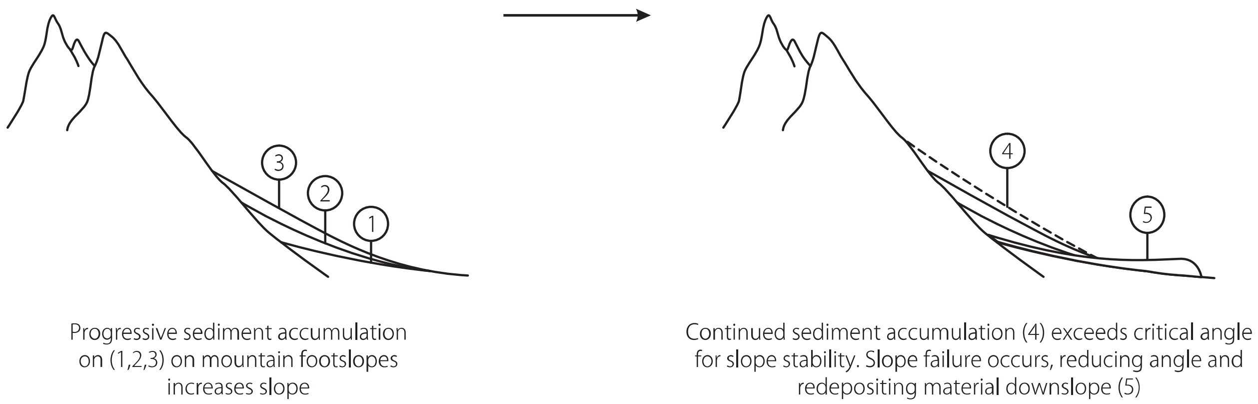

Figure 9. Erosion of mountain summits commonly results in sediment deposition on adjacent footslopes. Progressive sediment accumulation leads to steepening of the slope. If the critical angle for slope stability is exceeded, the deposits become unstable, and failure (e.g. a landslide) may be triggered by an earthquake or heavy rainfall. In the event of failure, slope is reduced below the critical angle and sediments are redeposited downslope.

Did you know?

Landslides can move very slowly; for example, even the most rapidly moving parts of the Slumgullion Landslide, Colorado, move at less than 0.020 m per day (Source: Colorado Geological Survey[5]). Other landslides, however, can move extremely rapidly; for instance, some landslides in the European Alps move at tens of km per hour (Source: European Commission, Joint Research Centre[6]).

[5] http://coloradogeologicalsurvey.org/wp-content/uploads/2013/08/41.pdf
[6] http://eusoils.jrc.ec.europa.eu/library/themes/landslides/

6 Landscapes are archives of the past

Landscapes contain histories of their development that potentially can be deciphered and reconstructed from study of the associated landforms and sediments. In many mid- and high-latitude parts of the northern hemisphere, landscapes host landforms and sediments that bear the distinctive signatures of processes operating under significantly colder conditions in the past, including those related to ice sheets and glaciers (e.g. parabolic valleys, scoured and striated bedrock surfaces, and poorly-sorted deposits ranging from mud through to boulders) (Figure 10a). In regions that have largely escaped glaciation, such as the interior of some southern hemisphere continents, landscapes host landforms and sediments that bear the distinctive signatures of processes operating under significantly warmer and wetter past conditions (e.g. soils enriched in certain chemical compounds, or former channels with larger dimensions than at present) and/or processes operating under significantly cooler and drier past conditions (e.g. soils enriched in certain salts, or wind-blown dunes now stabilized by vegetation) (Figure 10b). Other landscapes may host landforms and sediments testifying to enhanced tectonic or volcanic activity in the past (e.g. inactive, degraded fault lines or volcanoes). The response of landforms and landscapes to these changing conditions may be complicated by internal readjustments (see key point 5), while evidence for the nature of past processes and landscape changes is commonly partially erased by later geomorphic processes operating under different conditions. Nevertheless, if enough evidence remains – albeit fragmentary – a coherent landscape developmental history can be deciphered and reconstructed, including establishment of rates of change and assessment of the likely internal and external factors driving change. Reconstructing landscape development histories provides essential context for assessing the nature of recent and present-day changes, and also helps to constrain or project possible trajectories of future landscape changes under global climate change scenarios (see key point 7) and evaluate the importance of human impacts (see key point 8).

Figure 10. a) Parallel grooves ('striations') etched into fractured bedrock, indicating past ice movement on the Isle of Skye, northwest Scotland (Photo: Stephen Tooth); b) view along the crest of a wind-blown sand dune in the northern Simpson Desert, central Australia. This and other neighbouring dunes are now largely stabilized by vegetation, but at intervals in the past, enhanced dune activity has occurred under conditions of reduced vegetation cover and/or increased wind strength (Photo: Stephen Tooth).

Did you know?

Today, about 10 per cent of the world is covered by ice, but in the past that figure has been as high as 30 per cent. In the UK, the extent and thickness of past ice sheets are a topic of ongoing research but certainly have reached as far south as London, and in places the ice arguably has been 4-5 km thick (Source: after British Geological Survey[7]).

[7] www.bgs.ac.uk/discoveringGeology/geologyOfBritain/iceAge/

7 Global change is influencing landscape dynamics

Ongoing global environmental change, which includes atmospheric warming and sea level rise, is currently driving landform development, including desert lake desiccation, ice sheet and glacial retreat, and coastline erosion. Although landform and landscape response to external factors may be complicated by internal readjustments (see key point 5), geomorphological 'hot spots' can be identified as those landforms/landscapes that are particularly prone to dramatic and irreversible changes as a consequence of global environmental change. These include ice sheets and glaciers, desert dunes and lakes, and deltas and coral reefs (Figure 11). In turn, some of these landscape/landform developments can then influence environmental change, particularly because many landforms are directly and indirectly linked with climate 'tipping points' (i.e. regional phenomena that may exert a positive feedback on global warming) and ecological 'hot spots' (i.e. regions with a significant reservoir of biodiversity that is under threat). Accelerated Antarctic and Greenland ice sheet retreat, for instance, will contribute directly to sea level rise but will also reduce the Earth's albedo (reflectivity) and influence ocean salinity, which in turn will affect ocean temperatures, currents, and global heat redistribution, with the likely ramifications being further atmospheric warming. Sea level rise, ocean warming and changing currents may lead to accelerated coastline erosion, possibly with negative consequences for biodiverse mangrove and coral reef ecosystems. The regional or global influence of some other landform changes is less well understood but may also be significant; for instance, desert lake desiccation and wind action can lead to the generation of increased quantities of dust in the atmosphere, with implications for climate and ecosystems, including complex but poorly understood effects on hurricane generation, ocean fertilization, and terrestrial nutrient supply.

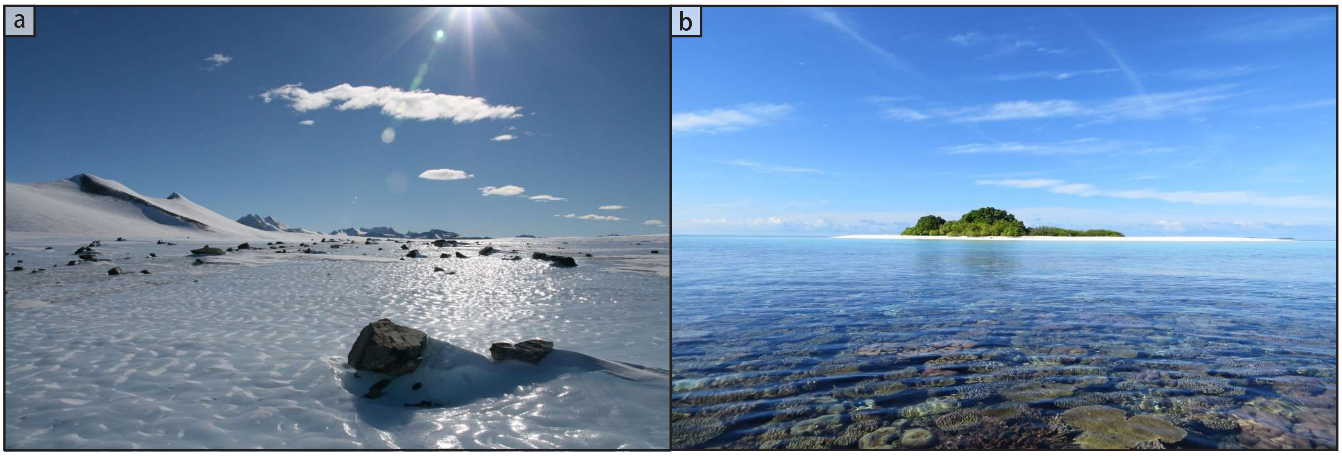

Figure 11. a) Horseshoe glacier, Antarctica (Photo: Stuart Dunning); b) low elevation sandy island (cay) rising above fringing coral reef, Maldives Archipelago (Photo: Holly East). Such landforms are vulnerable to the impacts of various global environmental changes including rising air and sea temperatures, increased sea levels, and enhanced wave erosion.

Did you know?

If all the ice in Antarctica was converted to liquid water, it would be sufficient to raise the height of the world's oceans by 60 m (Source: National Snow and Ice Data Center[8]). Nevertheless, although there is currently much concern over the role of ice sheet melting in sea level rise, such an extreme scenario is not considered likely in the near future.

[8] www.nsidc.org/cryosphere/quickfacts/icesheets.html

8 Human activities are influencing landscape dynamics

Increasingly, many geomorphological processes and landform/ landscape developments are influenced by human activities. Human activities may have a direct influence on geomorphological processes, either enhancing natural rates of change (e.g. encouraging river meander cutoffs as part of channel straightening projects) or suppressing natural rates of change (e.g. through river bank or coastal protection works) (Figure 12). Human activities may also have an indirect influence on natural processes, such as through forest clearance and conversion to agricultural land and its influence on hillslope runoff and sediment transfer, or through translocations of plants and animals that have a geomorphological influence, such as willow trees and rabbits. In addition, many human activities involve the movement of mass (rock, sediment and water) across the Earth's surface. This is most obvious in the case of mining activities but also occurs as a result of the dredging of rivers and estuaries, dam and reservoir construction, inter-basin water transfer schemes, and many other activities. 'The Anthropocene' has been proposed as demarcating a recent time interval in which human activities have become the dominant influence on the shaping of the Earth's surface, but vigorous debate still surrounds the relative roles of natural external drivers (e.g. tectonic/volcanic activity and climatic change), internal readjustments, and human activities as influences on the development of landforms/ landscapes and sediments.

Figure 12. Oblique aerial view of a typical sinuous river within a wide, cultivated and settled floodplain in western Europe. Although the sinuous planform gives the impression of active meanders, the river is now constrained by bank protection works and no meandering now takes place (Photo: Stephen Tooth).

Did you know?

Estimates suggest that current annual amounts of rock and soil moved over Earth's surface in response to construction and agricultural practices would fill the Grand Canyon of Arizona (see Figure 13) in about 50 years (Source: Wilkinson, B.H. 2005. Humans as geologic agents: a deep-time perspective. Geology, 33, 161-164).

9 The Earth's landscapes are becoming more hazardous

Both global environmental change and human activities are increasing the magnitude and frequency of geomorphological hazards, which occur wherever and whenever land surface stability is affected and adverse socio-economic impacts are experienced. Many geomorphological hazards are driven by low frequency/high magnitude and fast-acting geomorphological processes (see key point 3), with examples including floods, landslides, earthquakes and volcanic eruptions. Other hazards may result from high frequency/low magnitude and slow-acting processes, such as soil salinization resulting from gradual groundwater rise (Figure 13a). Hazards have been an ever-present threat throughout human history, but mounting evidence suggests that atmospheric warming and sea level rise may be associated with increases in the magnitude and frequency of weather extremes and associated hazards, including flooding, drought, and possibly cyclone/hurricane and storm surge activity. In some mountainous regions, glacial retreat is leading to an increase in the number and size of moraine-dammed meltwater lakes (Figure 13b), which presents a hazard because the dams are vulnerable to overtopping or failure during earthquakes or landslides. Owing to the burgeoning human population, increasing amounts of human activities are taking place in areas that are increasingly vulnerable to one or more of these types of weather extremes or failure events (e.g. mountain valleys, river floodplains and low-lying coastal areas), also contributing to a rise in the magnitude and frequency of geomorphological hazards.

Figure 13. a) White crust indicating salt build up on the side of an irrigation ditch, Orange River valley, western South Africa (Photo: Stephen Tooth); b) small moraine-dammed lake (Lago del Miage) in the Italian Alps (Photo: Mark Allan).

Did you know?

Floods are one of the most significant and widespread natural hazards, accounting for some of the greatest losses of life annually and the greatest economic losses. Following severe flooding (autumn 2013/winter 2014) in the Somerset Levels, southwest England, the UK government has backed a 20-year flood action plan for the area with £20 million, although the total cost is expected to reach £100 million (Source: The Guardian[9])

[9] www.theguardian.com/environment/2014/mar/06/uk-government-somerset-levels-20m-flood-plan

10 Successful environmental management needs geomorphological knowledge

Geomorphology can provide a key input to environmental management, including landscape conservation, ecosystem conservation and restoration, heritage conservation, and carbon landscaping. Landforms and landscapes may be conserved for their own intrinsic beauty or rarity, including as part of the UNESCO World Heritage List. Examples include the Grand Canyon National Park, USA (Figure 14), the Maloti-Drakensberg Park, South Africa, and Los Glaciares National Park, Argentina; these are all places where the landforms and landscapes are key to their inclusion on the List, and commonly form the main drawcard for tourists. More broadly, it is now widely recognized that geomorphological processes and landforms provide the template upon which many ecological processes and patterns are developed. For instance, rivers and floodplains typically exhibit a zonation of plants and animals that reflect differences in the frequency, depth and duration of flooding (Figure 15). Consequently, an understanding of the nature of river and floodplain geomorphology, including the drivers and rates of development, can help with the design of conservation strategies for near-pristine systems, and with restoration planning for degraded systems. Other applications of geomorphology include using an understanding of weathering processes and rates to help with the design of conservation strategies for protected buildings (Figure 16). In decades to come, geomorphology is also likely to play an increasingly important role in the active management of terrestrial carbon stocks, either through conservation and restoration of landscapes naturally rich in carbon (e.g. peatlands) but also through more active landscaping to maximize carbon capture and storage (e.g. creation of artificial wetlands or forested landscapes).

Figure 14. View of the Eastern Grand Canyon, Arizona, USA, looking northwest from near Grand Canyon village, North Rim. The inner canyon of the Colorado River is visible in the lower right. The spectacular geomorphology forms the centerpiece of this and many other popular tourist attractions worldwide (Photo: Stephen Tooth).

Figure 15. Aerial view of an ephemeral river in arid central Australia, illustrating a typical vegetation zonation that has developed across the normally-dry channel and floodplain. Irregular small floods supply moisture to the sands and gravels on the channel bed, while rarer larger floods inundate both the channel and floodplain. Large trees (principally River red gums) grow on the channel bed and banks to exploit the more abundant moisture supply. The levee backslopes support some trees, shrubs and grasses, while the floodplain typically only has a sparse cover of shrubs and grasses. The vegetation distribution affects the patterns and rates of water and sediment movement, which in turn influences channel-floodplain forms and processes. Geomorphologists are engaged with research into the nature of these delicate hydroecological interactions, many of which have implications for sustainable land management (Photo: Stephen Tooth).

Figure 16. Degraded limestone figure on the exterior of a church in Axbridge, Somerset, England. Geomorphologists can provide insights into the characteristic weathering processes and rates on such buildings, thereby helping with the design of conservation strategies (Photo: Stephen Tooth).

Did you know?

Soils constitute by far the largest carbon store on land. Northern hemisphere peatlands contain 20-30% of world soil carbon, despite only covering 1-1.5% of the ice-free land surface globally. Erosion, desiccation and burning of peat can thus lead to rapid loss of carbon from terrestrial ecosystems and contribute to increased atmospheric carbon dioxide concentrations (Source: Evans, M. and Warburton, J. 2010. Geomorphology of Upland Peat, Wiley-Blackwell, Chichester).

Are there any 'real-life' case studies where knowledge of geomorphology has proven topical or useful?

Although the terms are not often used explicitly, geomorphology and geomorphologists regularly feature in online media articles that cover pressing issues in science and society, as well as in some more quirky examples. A selection from the BBC includes:

2013

Alpine glaciers 'protect mountain peaks from erosion'
www.bbc.com/news/science-environment-23553094

Cornwall Council warn over coastline landslips
www.bbc.co.uk/news/uk-england-cornwall-21341342

Pakistan quake island off Gwadar 'emits flammable gas'
www.bbc.co.uk/news/world-asia-24272552

Antarctic ice volume measured
www.bbc.co.uk/news/science-environment-21692423

Mexico storms: Village landslide missing 'probably dead'
www.bbc.co.uk/news/world-latin-america-24191716

Star Wars home of Anakin Skywalker threatened by dune
www.bbc.co.uk/news/science-environment-23375344

2014

Communities 'could be abandoned' as seas rise
www.bbc.com/news/uk-wales-26132493

Taiwan's 'vanishing canyon' erasing quake record
www.bbc.com/news/science-environment-28810357

Where can I go for further information?

The British Society for Geomorphology (BSG) is a professional organisation for geomorphologists and provides a community and services for those involved in teaching or research in geomorphology, both in the UK and overseas.

www.geomorphology.org.uk

The Society's flagship international journal, Earth Surface Processes and Landforms, is published by Wiley and online access is available free to members.

www.geomorphology.org.uk/publications/espl

What would you recommend as further introductory reading?

Goudie, A.S. and Viles, H.A. (2010) *Landscapes and Geomorphology: A Very Short Introduction.* Oxford University Press, 144 pp.

Gregory, K.J. (2010) *The Earth's Land Surface: Landforms and Processes in Geomorphology.* SAGE Publications Ltd, 359 pp.

Harvey, A. (2012) *Introducing Geomorphology. A Guide to Landforms and Processes.* Dunedin Academic Press, 124 pp.

And what about online resources?

Vignettes: Key Concepts in Geomorphology
http://serc.carleton.edu/vignettes/index.html
[Last access date: 14th April 2014]

These Vignettes are stand-alone, illustrated electronic case studies that teach about geomorphology and related topics.

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