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Introduction to the Anthropocene and Anthropogeomorphology

1.1 The Anthropocene

This book examines how humans have modified landforms and the processes which formed them during the Anthropocene. It takes a long time perspective and draws on examples from many different environments and countries. It demonstrates how extensive and significant human impacts on geomorphology have been, and how these impacts are likely to increase in future. The Anthropocene is itself a contested concept, both in terms of whether or not it exists and when it began. We argue that geomorphological evidence for the Anthropocene has been underplayed, but may be crucial in assessing the reality and scope of the Anthropocene. This chapter introduces the major debates over the Anthropocene, the field of Anthropogeomorphology, and the framework used in the rest of the book.

There are four key areas of debate surrounding the Anthropocene. First, there is debate surrounding what the Anthropocene actually is – what the concept means. Second, there is debate over whether the Anthropocene is a real entity and something that can be identified in the geological record. Third, if it is real, there is much debate over when the Anthropocene started and whether there can be a clear "golden spike" which marks its beginning. Finally, there is a rich and complex debate over what the Anthropocene means for humans and our relationship with the Earth.

The word "Anthropocene," which has Greek roots, is a new term for an older concept and a great deal of argument concerns how it can be differentiated, if at all, in terms of a boundary with the Holocene. Those who propose that the Anthropocene should become formally established as part of the geological timescale do so on the grounds that human activities now dominate the Earth System, and have led to a marked shift in its state. Those who oppose such a move note the difficulty of establishing a "golden spike" marking the beginning of the Anthropocene, and doubt whether the concept is necessary or desirable. It is agreed, however, that the human impact on the environment and the Earth System has been increasing hugely in the last few centuries and that humans are now a very potent geomorphological force as part of this.

It is also apparent that in coming centuries a combination of population increases, land cover changes, climatic changes, and new technologies will increase this force still further. The burgeoning interest in the topic is reflected in the recent appearance of three new journals – *Anthropocene* (Elsevier), *The Anthropocene Review* (Sage), and *Elementa: The Science of the Anthropocene* (BioOne) and is fully discussed by Castree (2014a, b, and c), and Castree (2015).

The term "Anthropogene" was much used by Russian and some other European scholars in the twentieth century, more or less as a synonym for the Quaternary (see discussion in Gerasimov, 1979), but the word "Anthropocene" is largely a product of the twenty-first century. However, the recognition that humans have had a major suite of impacts on the natural environment has a much longer history (see Goudie, 2013b). Glacken (1967) pointed that out in a scholarly monograph, and others have recently reviewed the history of terminology and concepts surrounding the Anthropocene, such as its use in 1922 by the Russian geologist Aleksei Pavlov (Lewis and Maslin, 2015). An important stimulus to such ideas arose in the seventeenth and eighteenth centuries as Europeans became aware of the ravages inflicted in the tropics by their overseas expansion (Grove and Damodoran, 2006). In the nineteenth century George Perkins Marsh (1864; Figure 1.1) wrote his remarkable *Man and Nature*, the first full-length study in the English language of how humans were transforming the Earth's surface by deforestation and other processes (Lowenthal, 2016). Subsequently, many historical geographers became concerned with such activities as the use of fire, the clearing of woodland, and the drainage of wetlands (see Whitaker, 1940 for a review of early work), and in 1956 many of these issues were considered in a symposium on *Man's Role in Changing the Face of the Earth* edited by William L. Thomas, and in a masterful review by Turner et al. (1990). Ter-Stephanian (1988) sought to float the term "Technogene" for the accumulated significant effects of humans on the Earth System, but this seems to have been largely forgotten.

At the beginning of the twenty-first century, Steffen et al. (2004) reviewed ways in which biogeochemical systems interact at a global scale and the term "Earth System Science" started to be employed widely. It was against this background that the term Anthropocene was introduced by Crutzen (2002) as a name for a new epoch in Earth's history – an epoch when human activities have "become so profound and pervasive that they rival, or exceed the great forces of Nature in influencing the functioning of the Earth System" (Steffen, 2010, p. 443). In the last 300 years, Steffen et al. (2007) suggest, we have moved from the Holocene into the

Figure 1.1 George Perkins Marsh (1801–1882), from the Library of Congress Prints and Photographs Division, Washington, DC (http://loc.gov/pictures/resource/cwpbh.02223/; accessed November 17, 2015).

Anthropocene. They identify three stages in the Anthropocene. Stage 1, which lasted from c. 1800 to 1945, they call "The Industrial Era." Stage 2, extending from 1945 to c. 2015, they call "The Great Acceleration," and Stage 3, which may perhaps now be starting, is a stage when people have become aware of the extent of the human impact and may thus start stewardship of the Earth System (see Chapter 11).

However, many scientists argue that the Anthropocene has a much longer history than this scheme suggests, with early humans causing major environmental changes through such processes as the use of fire and the hunting of wild animals (e.g. Ruddiman, 2003). Indeed, one of the great debates surrounding the Anthropocene is when it started and whether it should be regarded as a formal stratigraphic unit with the same rank as the Holocene (Zalasiewicz et al., 2011a; Rull, 2013; Bostock et al., 2015; Edgeworth et al., 2015; Zalasiewicz et al., 2015). Walker et al. (2015), for example, consider the possibility that the Anthropocene might be designated a unit of lesser rank, that is, of stage, age, or even sub-stage/sub-age status, and hence could become a subdivision of the Holocene rather than an epoch in its own right. On the other hand, some even think that the Anthropocene should replace the Holocene, which would become downgraded and reclassified as the final stage of the Pleistocene (Lewis and Maslin, 2015). Conversely, there are those who think the Anthropocene started with the Industrial Revolution and that 1800 AD is a logical start date for the new epoch (Steffen et al, 2011; Zalasiewicz et al., 2011b). At the other extreme, there are those, including archaeologists (Balter, 2010, 2013), who believe that substantial human impacts go back considerably further (see examples in Chapter 11) and have drawn attention to the deep history of widespread human impacts (Ellis et al. 2013a, b; Braje and Erlandson, 2014; Braje et al., 2014; Albert, 2015; Braje, 2015; Piperno et al., 2015). This case was made powerfully by Ruddiman et al. (2015, p. 38) who argued,

> Does it really make sense to define the start of a human-dominated era millennia after most forests in arable regions had been cut for agriculture, most rice paddies had been irrigated, and CO_2 and CH_4 concentrations had been rising because of agricultural and industrial emissions? And does it make sense to choose a time almost a century after most of Earth's prairie and steppe grasslands had been plowed and planted? Together, forest cutting and grassland conversion are by far the two largest spatial transformations of Earth's surface in human history. From this viewpoint, the "stratigraphically optimal" choice of 1945 as the start of the Anthropocene does not qualify as "environmentally optimal."

Foley et al. (2013) have proposed the term "Palaeoanthropocene" for the period between the first signs of human impact and the start of the Industrial Revolution, whereas Glikson (2013) suggested a sub-division of the Anthropocene into three phases. He regarded the discovery of ignition of fire as a turning point in biological evolution and termed it the Early Anthropocene. The onset of the Neolithic he referred to as the Middle Anthropocene, while the onset of the industrial age since about 1750 AD he referred to as the Late Anthropocene. Smith and Zeder (2013) argued that the Anthropocene started around 10,000 years ago at the Holocene/Pleistocene boundary, with the initial domestication of plants and animals and the development of agricultural economies. Ruddiman (2013, 2014), on the other hand, argued that early deforestation and agriculture caused large greenhouse gas emissions slightly later, but nevertheless quite early in the Holocene. In China, Zhuang and Kidder (2014) have identified the importance and extent of gully erosion on slopes and sedimentation in valleys that developed in the Neolithic, when, they argue, Ancient China saw its own version of the Great Acceleration. Certini and Scalenghe (2011) preferred to put the lower boundary at around 2,000 years ago when major civilizations flourished, but Gale and Hoare (2012) have argued that the worldwide diachroneity of human impact makes it impossible to establish a single chronological datum for the start of the Anthropocene. It is certainly dangerous to think that in all places the human impact has shown a continually increasing trajectory, for there are many examples of ravages in one era being followed by phases of restoration, recovery, and stability in another. Trimble (2013) demonstrates this in the context of land use and land degradation history in the American Midwest.

Lewis and Maslin (2015) review the evidence for a "golden spike" which might provide an incontrovertible, globally relevant mark in the sedimentary record of the start of the Anthropocene. They find two candidates: a dip in atmospheric CO_2 levels around 1610 as recorded in high-resolution Antarctic ice cores, and a spike in ^{14}C concentrations in 1964 as recorded within tree-rings of a dated pine tree in Poland. According to Lewis and Maslin (2015), the evidence is most convincing for the 1610 date, which they prefer but do not go so far as to recommend. Rose (2015) argued that a stratigraphic marker for the start of the Anthropocene was provided by spheroidal carbonaceous fly ash particles (SCPs) – by-products of industrial fossil-fuel combustion. He found that data from over 75 lake sediment records showed a global, synchronous, and dramatic increase in particle accumulation starting in c. 1950 and driven by the increased demand for electricity and the introduction of fuel-oil combustion, in addition to coal, as a means to produce it. He argued that SCPs are morphologically distinct and solely anthropogenic in origin, providing an unambiguous marker. However, the validity of a search for these sorts of golden spike has been rejected by Hamilton (2015) and the controversy rumbles on.

Geomorphological change is an important component of the Anthropocene, though its effects will have varied greatly in space and time, and it is often neglected in accounts of human impacts on the Earth System (Brown et al., 2013). For example, in Central Europe the initial deforestation of a slope in the Neolithic may have been the most important geomorphological event since the end of the Pleistocene, while in Dubai it is the alteration of the coastline in just the last few decades (see Chapter 3). In this context, Fuller et al. (2015, pp. 266–7) provide an interesting analysis of Anthropocene changes in the rivers of New Zealand. They found that the nature and timing of human impact in New Zealand's river catchments are highly variable between regions and catchments, and this makes any attempt at formally defining the Anthropocene problematic at best because there is no ubiquitous, synchronous marker in New Zealand river catchments that marks the start of the Anthropocene:

> In catchments draining the Southern Alps, natural processes are far more significant in determining erosion, sedimentation, and river activity. The clearest evidence for Polynesian impact is found in Northland's catchments in the form of increased floodplain sedimentation. Here, the start of the Anthropocene could be considered to equate with Māori occupation c. 1280 AD, with further augmentation associated with European settlement in the 1800s and 1900s. Farther east, in the East Coast Region of the

North Island, the start of the Anthropocene could be taken as c. 1920 when European clearance of indigenous vegetation in the Waipaoa and Waiapu catchments exposed a highly erodible terrain to a range of erosion processes, which resulted in erosion rates exceeding by an order of magnitude those estimated at the end of the Last Glacial Maximum. Each catchment and region must be recognised as unique in its response to human disturbance. New Zealand challenges the notion that the Anthropocene can be defined simply by a critical regime change in which human impact becomes the dominant controlling factor in the environment and overwhelms the forces of nature. New Zealand's highly active tectonic and climatic regime largely mitigates against Mankind becoming the dominant factor controlling river activity and alluvial sedimentation in most of its naturally dynamic catchments. The exception is Northland and the East Coast Region, where a regime change has been identified by these systems having been overwhelmed by sediment generated as a result of human impact resulting in rapid valley-floor sedimentation.

Whenever key anthropogenic changes may have taken place, however, their overall impact on the Earth System at a global scale is now immense. Hooke et al. (2012) provide estimates of the land area modified by human action in 2007 and suggest that more than 50 percent of Earth's ice-free land area has now been directly modified by human action. As Phillips (1997) perceptively pointed out, however, the significance of human actions depends on how big they are in comparison with natural changes, how they relate to the relaxation times of systems, how long in duration they are, and how frequent they are.

Smil (2015, p. 28) has cautioned against both exaggerating the power of humans and of rushing into accepting the creation of the Anthropocene as a new division of geological time. As he asked:

> But is our control of the planet's fate really so complete? There is plenty of counter evidence. Fundamental variables that make life on Earth possible – the thermonuclear reactions that power the sun, suffusing the planet with radiation; the planet's shape, rotation, tilt, the eccentricity of its orbital path (the "pacemaker" of the ice ages), and the circulation of its atmosphere – are all beyond any human interference. Nor can we ever hope to control the enormous terraforming processes, the Earth's plate tectonics driven by internal heat and resulting in slow but constant creation of new ocean floor, forming, reshaping, and elevating landmasses whose distributions and altitudes are key determinants of climate variability and habitability. Similarly, we are mere bystanders watching volcanic eruptions, earthquakes, and tsunamis, the three most violent consequences of plate tectonics . . . let us wait before we determine that our mark on the planet is anything more than a modest microlayer in the geologic record.

Humans will continue to modify the Earth System in coming decades. New technologies will be developed and applied in areas like agriculture and mining, and increasing population levels will lead to further changes in land cover and in the exploitation of natural resources. The effects of land cover changes, as Slaymaker et al. (2009) point out, may be at least as important as the changes that will be caused by future climatic change. However, as the various reports of the

Intergovernmental Panel on Climate Change (IPCC) have shown (e.g. IPCC, 2013), global warming will greatly modify biomes, lead to massive changes in the cryosphere, and cause sea levels to rise. One major current concern is that certain key boundaries, thresholds, or tipping points may be crossed (Rockstrom et al., 2009).

There are signs that we are progressing into the era of environmental stewardship (see Chapter 11). Wohl (2013) argues that there are many ways in which geomorphologists can contribute to the management of what is now being called “the critical zone.” This is Earth’s near surface layer from the tops of the trees down to the deepest groundwater, where most human interactions with the Earth’s surface take place and the locus of most geomorphological activity. Some examples of such management are discussed in Chapter 11. Harden et al. (2013) indicate some of the issues and focal points that the geomorphological community need to address for understanding human–landscape interactions in the Anthropocene, and these include the study of boundaries, thresholds, and feedbacks. Chin et al. (2014) have also argued that there needs to be a greater concern with feedbacks between society and the geomorphological environment, while Hamilton et al. (2015) explore the implication of the Anthropocene concept for the social sciences and the humanities. The whole way in which human geographers consider human/nature relationships may need to be reevaluated (Lorimer, 2012).

1.2 Anthropogeomorphology: Its History

Anthropogeomorphology, a term invented by Golomb and Eder (1964), is the study of the human role in creating landforms and modifying the operation of geomorphological processes. It thus focuses on many key aspects of geomorphological processes within the Anthropocene. Most of the classic textbooks of geomorphology, including those from the last few decades, however, ignore it totally.

Some Milestones in Anthropogeomorphology

Marsh, G. P. (1864) *Man and Nature*. New York: Scribner. The pioneer work on the human impact on the environment.

Woeikof, A. (1901). De l’influence de 1’homme sur la terre. *Annales de Geographie*, 10, 97–114; 193–215. An influential Russian work on the multitude of ways in which humans modify the surface of the Earth.

Shaler, N. S. (1912). *Man and the Earth*. New York: Duffield. One of a number of works by an author who was keenly aware of soil erosion and other human impacts on the landscape of the United States.

Gilbert, G. K. (1917). Hydraulic-mining debris in the Sierra Nevada. *USGS Professional Paper* 105. A detailed study by one of America's greatest geomorphologists on the consequences of gold mining inland from San Francisco.

Bennett, H. H. (1938). *Soil Conservation*. New York: McGraw Hill. A massive survey by the head of the Soil Conservation Service, which contains a great deal of quantitative data on the effects of land use change on erosion rates.

Jacks, G. V. and Whyte, O. (1939). *The Rape of the Earth: A World Survey of Soil Erosion.* London: Faber and Faber. A popular global survey and polemic on the global menace of soil erosion.

Happ, S. C., Rittenhouse, G., and Dobson, G. C. (1940). Some principles of accelerated stream and valley sedimentation.*US Department of Agriculture Technical Bulletin*, 695. An impressive example that studies the links between erosion on slopes and alluviation in valleys.

Thomas, W. F. (ed.) (1956). *Man's Role in Changing the Face of the Earth*. Chicago: University of Chicago Press. A multi-author report of a ground-breaking symposium on the human impact.

Brown, E. H. (1970). Man makes the Earth. *Geographical Journal* 136, 74–85. A thoughtful and largely neglected study of anthropogeomorphology.

Trimble, S. W. (1974). *Man-Induced Soil Erosion on the Southern Piedmont*. Ankeny, IA: Soil Conservation Society of America. A masterful historical survey of the effects of land use change on erosion.

Nir, D. (1983). *Man, a Geomorphological Agent: An Introduction to Anthropic Geomorphology.* Jerusalem: Keter. A thorough review of knowledge by an Israeli geographer.

Slaymaker, O., Spencer, T. and Embleton Hamann, C. (eds.) (2009). *Geomorphology and Global Environmental Change*. Cambridge: Cambridge University Press. An edited work that places anthropogeomorphology in the context of global change.

Szabó, J., David, L., and Lóczy, D. (eds.) (2010). *Anthropogenic Geomorphology*. Dordrecht: Springer. A largely Hungarian review that is especially strong on constructed and excavated landforms.

Nevertheless, anthropogeomorphology has a long history of study (Goudie, 2013b). Research on torrents in the European Alps, undertaken in the late eighteenth and early nineteenth centuries, deepened immeasurably the realization of human capacity to change the environment (Surell, 1841). Similarly, de Saussure (1796) showed that Alpine lakes had suffered a lowering of water levels in recent times because of deforestation. In Venezuela, von Humboldt, with his partner Bonpland (see Humboldt and Bonpland, 1815), concluded that the level of Lake Valencia in

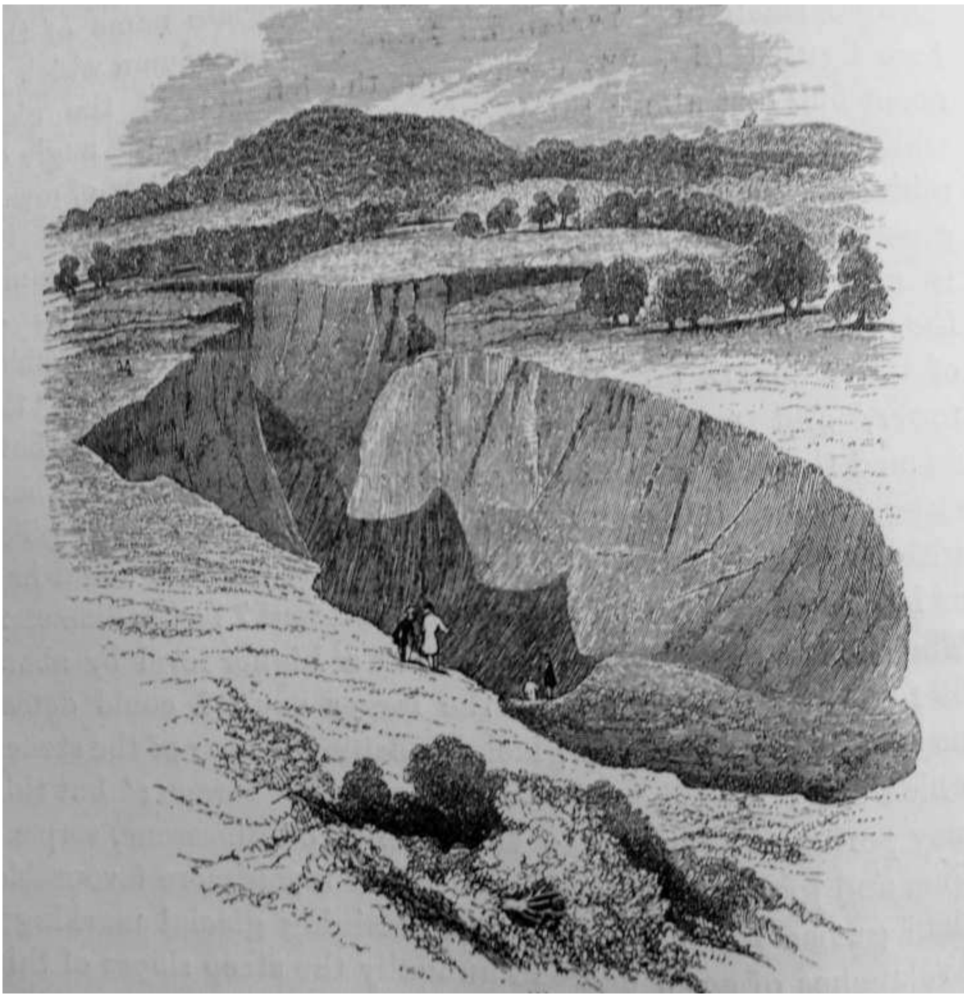

Figure 1.2 A newly-formed ravine that developed at Milledgeville, Georgia, following deforestation (from Lyell, 1875, p. 338).

1800 was lower than it had been in previous times, and that deforestation, the clearing of plains, irrigation, and the cultivation of indigo, were among the causes of the gradual drying up of the basin (Boussingault, 1845; Cushman, 2011).

Lyell, in later editions of the *Principles of Geology* (Lyell, 1875, p. 338), noted the effects of recent deforestation in Georgia and Alabama in the United States. This had produced numerous ravines with considerable rapidity (Figure 1.2). The extent of human influence on the environment was explored in detail by Marsh (1864), who dealt at length with human influence on the woods, the waters, and the sands, and discussed such issues as accelerated erosion, flooding, and coastal dune movement.

A major phase of anthropogeomorphological research, based on the study of the threat posed by soil erosion, took place in the 1930s and 1940s. Notable here was the advocacy of people like Bennett (1938) and Lowdermilk (1934, 1935), who were associated with the early days of the Soil Conservation Service in the United States but who toured the world advocating the importance of soil conservation. Their work was a stimulus to Dale and Carter's (1955) *Topsoil and Civilisation*, which was a global discussion of soil erosion over the last 6,000 years. Also, at the same time, there was a concern about soil erosion and the means of soil conservation in the British colonies (Tempany et al., 1944), and in particular in Africa (Anderson, 1984; Beinart, 1984).

Wind erosion was seen as a big threat, and of particular note in this respect was the work conducted by W. S. Chepil and his collaborators at the Wind Erosion Research Center at Kansas State University, established in 1947 (e.g. Chepil and Woodruff, 1963). They were concerned with establishing the fundamentals of soil movement by wind, the properties of soils which influenced their susceptibility to wind erosion, the sedimentary characteristics of dust storms, and the effects of various land cover treatments (mulches, field size, maintenance of crop residues, type of ploughing). They also developed technology for advancing aeolian research, including dust samplers and portable wind tunnels.

1.3 Direct and Indirect Anthropogeomorphological Influences

Some geomorphological features are produced by direct anthropogenic processes. These tend to be relatively obvious in form and are frequently created deliberately. They include landforms produced by construction (e.g. spoil tips, embankments, sea walls), excavation (e.g. mines), hydrological interference (e.g. reservoirs and canals), and farming (e.g. terraces); see Table 1.1.

By contrast, landforms produced by indirect and inadvertent anthropogenic processes are often more difficult to recognize because they involve the acceleration of natural processes rather than the operation of new ones. It is the indirect and inadvertent modification of process and form that is the most crucial aspect of anthropogeomorphology. Rates of weathering may be modified because of the acidification of precipitation caused by accelerated nitrate and sulfate emissions or because of accelerated salinization in areas of irrigation (Goudie and Viles, 1997; see Chapter 5). By modifying land cover, humans have accelerated erosion and sedimentation (Jones and Marcus, 2006; Wilkinson and McElroy, 2007); caused sedimentation on floodplains and estuaries, and in lakes and elsewhere (see Chapters 6 and 7); triggered landslides and debris flows (see Chapter 6); changed river channel forms (Chapter 7); and created ground subsidence and had an influence on the operation of earthquakes through the impoundment of reservoirs (Meade, 1991; see Chapter 4).