

GS32120 – Sedimentary Environments

Lecture 8 Anthropogenic Disruptors and Plastics

Prior tasks

- 1) Watch the pre-recorded Lecture 8a April 2021 that provides a short overview of the arguments for and against humans being the dominant geological agent, and briefly traces the history of the development of the Anthropocene concept.

Active learning exercise 1 (~20 minutes)

- 1) Read the two short articles that brought the embryonic term 'Anthropocene' to wider attention (available on Blackboard), and then answer the associated questions:
Crutzen, P.J. and Stoermer, E.F. 2000. The "Anthropocene". IGBP Newsletter 41: 17-18.
Crutzen, P.J. 2002. Geology of mankind. Nature 415: 23.

The "Anthropocene"
by Paul J. Crutzen and Eugene F. Stoermer

The name Holocene ("Recent World") for the post-glacial geological epoch of the past ten to twelve thousand years seems to have been proposed for the first time by Sir Charles Lyell in 1830, and adopted by the International Geological Congress in Bologna in 1888 (1). During the Holocene mankind's activities gradually grew into a significant geological, morphological force as recognized early on by a number of scientists. Thus, G.P. Marsh already in 1864 published a book with the title "Man and Nature", more recently reprinted as "The Earth as Modified by Human Action" (2). Stoppani in 1879 rated mankind's activities as a "new salient force which in power and universality may be compared to the greater forces of earth" (quoted from Clark (3)). Stoppani already spoke of the anthropogenic era. Mankind has now inhabited or visited almost all places on Earth, he has even set foot on the moon.

The great Russian geologist V.I. Vernadsky (4) in 1926 recognized the increasing power of mankind as part of the biosphere with the following excerpt: "... the direction in which the processes of evolution must proceed, namely towards increasing consciousness and thought, and forms having greater and greater influence on their surroundings". He, the French Jesuit P. Teilhard de Chardin and E. Le Roy in 1924 coined the term "noosphere", the world of thought, to mark the growing role played by mankind in shaping its own future and environment.

The expansion of mankind, both in numbers and per capita exploitation of Earth's resources has been astounding (5). To give a few examples: During the past 3 centuries human population increased tenfold to 6000 million, accom-

panied e.g. by a growth in cattle population to 1400 million (6) (about one cow per average size family). Urbanization has been increasing tenfold in the past century. In a few generations mankind is exhausting the fossil fuels that were generated over several hundred million years. The release of SO₂ globally about 180 Tg/year to the atmosphere by coal and oil burning, is at least two times larger than the sum of all natural emissions, occurring mainly as sulfate dimethyl sulfide from the oceans (7). From Vitousek et al. (8) we learn that 30-50% of the land surface has been transformed by human action; more nitrogen is now fixed synthetically and applied as fertilizer in agriculture than fixed naturally in all terrestrial ecosystems; the escape into the atmosphere of NO_x from fossil fuel and biomass combustion likewise is larger than the natural inputs, giving rise to photochemical ozone ("smog").

The great Russian geologist V.I. Vernadsky (4) in 1926 recognized the increasing power of mankind as part of the biosphere with the following excerpt: "... the direction in which the processes of evolution must proceed, namely towards increasing consciousness and thought, and forms having greater and greater influence on their surroundings". He, the French Jesuit P. Teilhard de Chardin and E. Le Roy in 1924 coined the term "noosphere", the world of thought, to mark the growing role played by mankind in shaping its own future and environment.

The expansion of mankind, both in numbers and per capita exploitation of Earth's resources has been astounding (5). To give a few examples: During the past 3 centuries human population increased tenfold to 6000 million, accom-

Geology of mankind

Paul J. Crutzen

referring to the "anthropogenic era" and in 1926, V. I. Vernadsky acknowledged the increasing impact of mankind: "The direction in which the process of evolution must proceed, namely towards increasing consciousness and thought, and forms having greater and greater influence on their surroundings". Teilhard de Chardin and Vernadsky used the term "noosphere" — the "world of thought" — to mark the growing role of human brain-power in shaping its own future and environment.

The rapid expansion of mankind in numbers and per capita exploitation of Earth's resources has continued apace. During the past three centuries, the human population has increased tenfold to more than 6 billion and is expected to reach 10 billion in this century. The methane-producing cattle population has risen to 1.4 billion. About 30–50% of the planet's land surface is exploited by humans. Tropical rainforests disappear at a fast pace, releasing carbon dioxide and strongly increasing species extinction. Dam building and river diversion have become commonplace. More than half of all accessible fresh water is used by mankind. Fisheries remove more than 25% of the primary production in upwelling ocean regions and 35% in the temperate continental shelf. Energy use has grown 16-fold during the twentieth century, causing 160 million tonnes of atmospheric sulphur dioxide emissions per year, more than twice the sum of its natural emissions. More nitrogen fertilizer is applied in agriculture than is fixed naturally in all terrestrial ecosystems; nitric oxide production by the burning of fossil fuel and biomass also overrides natural emissions. Fossil-fuel burning and agriculture have caused substantial increases in the concentrations of greenhouse gases — carbon dioxide by 30% and methane by more than 100% — reaching their highest levels over the past 400 millennia, with more to follow.

So far, these effects have largely been caused by only 25% of the world population. The consequences are, among others, acid precipitation, photochemical smog and climate warming. Hence, according to the latest estimates by the Intergovernmental Panel on Climate Change (IPCC), the Earth will warm by 1.4–5.8 °C during this century.

Many toxic substances are released into the environment, even some that are not toxic at all but nevertheless have severely damaging effects, for example the chlorofluorocarbons that caused the Antarctic "ozone hole" (and which are now regulated). Things could have become much worse: the

concepts
The Anthropocene


The Anthropocene could be said to have started in the late eighteenth century, when analysis of air trapped in polar ice showed the beginning of growing global concentrations of carbon dioxide and methane.

ozone-destroying properties of the halogens have been studied since the mid-1970s. If it had turned out that chlorine behaved chemically like bromine, the ozone hole would by then have been a global, year-round phenomenon, not just an event of the Antarctic spring. More by luck than by wisdom, this catastrophic situation did not develop.

Unless there is a global catastrophe — a meteoric impact, a world war or a pandemic — mankind will remain a major environmental force for many millennia. A daunting task lies ahead for scientists and engineers to guide society towards environmentally sustainable management during the era of the Anthropocene. This will require appropriate human behaviour at all scales, and may well involve internationally accepted, large-scale geo-engineering projects, for instance to "optimize" climate. At this stage, however, we are still largely treading on terra incognita.

Paul J. Crutzen is at the Max Planck Institute for Chemistry, PO Box 3060, D-55020 Mainz, Germany, and the Scripps Institution of Oceanography, University of California, San Diego, 9500 Gilman Drive, La Jolla, California 92093-7482, USA.

FURTHER READING
Marsh, G. P. *Man and Nature* (1864) (Reprinted as *The Earth as Modified by Human Action* (Belknap Press, Cambridge, Massachusetts, 1965)).
Crutzen, P. J. & Stoermer, E. F. *IGBP Newsletter* 41 (Royal Swedish Academy of Sciences, Stockholm, 2000).
Clark, W. C. & Munn, R. E. (eds) *Sustainable Development of the Biosphere*, Ch. 1 (Cambridge Univ. Press, Cambridge, 1986).
Vernadsky, V. I. *The Biosphere* (translated and annotated version from the original) (Springer, New York, 1986).
Turner, B. L. et al. *The Earth as Transformed by Human Action* (Cambridge Univ. Press, Cambridge, 1990).
McNeill, J. R. *Something New Under the Sun: An Environmental History of the Twentieth-Century World* (W. W. Norton, New York, 2000).
Houghton, J. T. et al. (eds) *Climate Change 2007: The Scientific Basis* (Cambridge Univ. Press, Cambridge, 2007).
Bergey, A. & Loomis, M. F. C. *Acad. Sci. Paris* 323 (196), 1–16 (1996).
Schubert, A. J. *Nature* 402, C19–C23 (1999).



IGBP NEWSLETTER 41

engine in 1784. About at that time, biotic assemblages in most basins began to show large changes (11–13).

Without major catastrophes like an enormous volcanic eruption, an unexpected epidemic, a large-scale nuclear war, an asteroid impact, a new ice age or continued plundering of Earth's resources by partially still primitive technology (the last four dangers can, however, be prevented in a real functioning noosphere) mankind will remain a major geological force for many millennia, maybe billions of years, to come. To develop a world-wide accepted strategy leading to sustainability of ecosystems

against human induced stresses will be one of the great future tasks of mankind, requiring intensive research efforts and wide application of the knowledge thus acquired in the noosphere, better known as knowledge on information society. An exciting, but also difficult and daunting task lies ahead of the global research and engineering community to guide mankind towards global, sustainable environmental management (15).

We thank the many colleagues especially the members of the IGBP Scientific Committee, for encouraging correspondence and advice.

Paul J. Crutzen
Max-Planck-Institute for Chemistry
Division of Atmospheric Chemistry
P.O. Box 3050
D-55020 Mainz
GERMANY
Email: air@mpch-mainz.mpg.de

Eugene F. Stoermer
Center for Great Lakes and Aquatic Sciences
University of Michigan
Ann Arbor, Michigan 48106-1000
USA

- To what extent does consideration of human impacts on sedimentary environments, landforms/landscapes, and the geological record feature in these articles?;
- Why is consideration of these aspects a key part of any debate over a putative Anthropocene time interval?

GS32120 – Sedimentary Environments

Prior tasks

- 1) Watch the pre-recorded Lecture 8b April 2021 that provides an overview of abiotic and biotic geological agents, and compares landscape shaping by natural and human agents.

Active learning exercise 2 (~20 minutes)

- 1) The oblique aerial view below (from Google Earth, centred on 25.045464°N, 55.317330°E) illustrates some of the distinctive urban developments in Dubai, United Arab Emirates, that are altering the Persian Gulf coastline. From this image and from your own browsing of the wider region, attempt to answer the following questions:



- i) How do you think these developments are impacting on sedimentary environments, landforms/landscapes, and the geological record?;
- ii) Do you think that humans are the dominant geological agent in this setting, at least in the present day? If so, why? If not, why not?;
- iii) What do you think are the key factors that will determine the longevity of the impact of these developments on sedimentary environments, landforms/landscapes, and the geological record?

GS32120 – Sedimentary Environments

Prior tasks

- 1) Watch the pre-recorded Lecture 8c April 2021 that puts human agency in perspective alongside other disruptors to sedimentary environments, outlines relevant space and time considerations, and also considers the distinctiveness of human sedimentary signatures.

Active learning exercise 3 (~15 minutes)

- 1) Read the following short article (available on Blackboard) that makes the case for managing and deliberately shaping landscapes to sequester carbon, and then answer the associated questions:
Kelly, R. 2007. Carbon geomorphology. *Geophemera*, 101: 24-25.

ARTICLE: Carbon Geomorphology – Robert Kelly

Ever heard of 'carbon geomorphology'? Probably not: it's a new area, only now emerging from cross-disciplinary roots to form a coherent subject in its own right. But, in a few years' time, be assured that carbon mapping will be as commonplace as geological, landform and soil mapping are today, and that we'll be casually discussing the finer points of 'carbon landscapes'.

The driving force behind this nascent discipline has been the rapid development of the carbon market over the past few years. In an attempt to mitigate greenhouse gas emissions, and to sequester those that have already been released into the atmosphere, a number of market mechanisms have been established to generate and trade carbon credits. The best-known are the Clean Development Mechanism (CDM) and Joint Implementation (JI) mechanism of the Kyoto Protocol, but these are by no means alone.

Together, the various carbon markets are conservatively worth \$30 billion and are growing rapidly – they tripled in value between 2005 and 2006. Over 700 carbon projects have been registered under the CDM, with a further 1,500 queuing up to join them. Over the next five years, the CDM is expected to generate 4 billion carbon credits, at an average market price of \$10 per credit.

Geomorphology enters the picture because the carbon market is not restricted to industry, commerce and transport. Indeed, over one-third of the carbon credits generated in the so-called 'voluntary' (non-compliance) carbon market stem from forestry and land-use projects. The CDM is less kind to 'LULUCF' (Land Use, Land Use Change & Forestry), restricting it to afforestation and reforestation. But, together, the various carbon markets currently support a wide range of landscape-transforming projects, from soil rehabilitation projects in sub-Saharan Africa, anti-desertification shelterbelts in China, fire management programmes in Australia, peatland preservation in Indonesia and wetland restoration in Eastern Europe.

All of these projects owe their existence to the revenues they can claim for reducing greenhouse gas emissions – as in the case of restored wetlands, for instance, where re-wetting serves to reverse the carbon oxidation process associated with drainage – or for sequestering atmospheric carbon (as in the case of forestry and soil rehabilitation). In Ethiopia, where I am working, there is currently strong interest in rehabilitating highly degraded lands (the picture shows one site that is to be planted in the next month) with the oil-bearing tree, *Jatropha curcas*. This offers the (monetisable) carbon 'double hit' of sequestering atmospheric carbon through photosynthesis and also

24

Geophemera 101

producing bio-diesel that displaces consumption of climate-unfriendly mineral diesel.

Right now, 'carbon landscaping' is a niche activity. Placed in a global context, the number of projects is a drop in the ocean; most are relatively small, occupying sites thousands of hectares in size and generating only localised geomorphological effects. Indeed, until recently geomorphologists have barely been involved: foresters, ecologists and soil scientists have done – literally and metaphorically – most of the groundwork.



Above and right: Site of proposed *Jatropha* plantation, Ethiopia (© Robert Kelly)

But as the carbon markets grow and the price of carbon increases (which seems inevitable given the greenhouse mitigation challenge facing us over the coming century), so carbon land-use projects will multiply and spread. The expected entry of the United States into the market, and the anticipated relaxation of CDM LULUCF restrictions in the second phase of the Kyoto Protocol (after 2012), will only enhance the landscape-transforming potential of carbon finance.

Very quickly, the geomorphological effects will scale up. 'Carbon landscapes' will span the whole range of geographical scales, from individual hillslopes and river valleys to entire mountain ranges and continental plains: the use of remote sensing and sophisticated statistical sampling offer the potential to monitor inaccessible carbon landscapes thousands of kilometres across at relatively little cost. The landscapes of the Sahel, the South American pampas and the Arctic tundra, to name but three, could be utterly transformed.

Geomorphological change per se is not the objective of carbon landscaping: it's merely the means employed to achieve carbon ends. But the geomorphological implications of carbon landscaping are inescapable, both in its effects (on denudation processes, on fluvial systems, on landforms and so on) and also in its implementa-

tion: there is likely to be growing demand for the services of geomorphologists who can 'geo-engineer' landscapes to maximise environmental carbon storage and minimise carbon translocation and loss. Of course, environmental carbon fluxes aren't divorced from geomorphology's traditional concerns: erosion acts to reduce terrestrial carbon sequestration just as it sculpts landforms; mass transport exports carbon just as it exports other minerals; biotic activity sequesters carbon just as it contributes to regolith weathering and physical stabilisation.

But carbon landscaping has the potential to fundamentally re-orient the study and practice of geomorphology. First, the sheer volume of the financial investments flowing into carbon mitigation/sequestration projects cannot but divert our research and consulting activities – a trend that will be reinforced by the growing emphasis in government research funding on climate change issues. And, second, carbon landscaping is very much a surface-based activity: while geologists may monopolise the study and extraction of minerals and fossil fuels, so geomorphologists should come to dominate the task of capturing, storing and monitoring environmental carbon.

So, take note: a lot more of us may be describing ourselves as 'carbon geomorphologists' in the not-too-distant future!



Robert Kelly works on carbon landscaping issues in sub-Saharan Africa.

robert.kelly@carbopoiesis.com

If you would like to comment on or debate this issue please send your emails and letters to the Editor and the best will be published in the next issue of *Geophemera* – Editor.

25

- i) Nearly 15 years on, to what extent have the predictions made by Kelly come true?;
- ii) Do you think increased landsurface shaping (for carbon sequestration or other environmental management purposes) is a good development, a bad development, or something in between? Why do you think this?

GS32120 – Sedimentary Environments

Prior tasks

- 1) Watch the pre-recorded Lecture 8d April 2021 that provides an overview of human-made ('novel') materials in sedimentary environments, with a particular focus on the transport of plastics from source to sink.

Active learning exercise 4 (~20 minutes)

Read the following short articles (available on Blackboard or online) that address different aspects of plastics in sedimentary environments, and then attempt to answer the associated questions:

- 1) Corcoran, P.L. and Jazvac, K. 2020. The consequence that is plastiglomerate. *Nature Reviews* 1: 6-7.



Note the statement that: “plastiglomerate represents a powerful icon of human impacts no longer only a scientific find, but also an object of power that involves an emotional reaction”.

- i) Do you agree that plastiglomerate is a powerful icon of human impacts?;
 - ii) Can you think of other sedimentary environment-related icons of human impacts?;
 - iii) Do you think emotional reaction to plastic pollution and other forms of environmental degradation is helpful or unhelpful for addressing environmental management challenges?
- 2) The following online, non-specialist article considers the fate of disposable face masks and gloves – plastics-based, durable materials – that are now working their way into the geological cycle, particularly during the COVID-19 pandemic:
Holmes, R., Fugagnoli, A. and Zalasiewicz, J. 2020. What will COVID-19 look like to geologists in the far future? *The Conversation*, July 28th 2020. Available at: <https://theconversation.com/what-will-covid-19-look-like-to-geologists-in-the-far-future-143085>
- i) One of the reader's comments asked: “And what exactly is the problem with countless billions of microplastic fragments ending up in deep sea muds? It sounds like effective carbon sequestration, however inadvertent.”

What would you say in response to this question?