# Erosion

The term erosion covers the various processes contributing to the breakdown of the terrestrial "relief". It is a disputable term in that its very etymology (Latin erodere, to gnaw away) focuses on only one aspect of a complex chain combining the attack of rock (or weathering), the removal of matter (synonymous with erosion in the strict sense), and transport and sedimentation, a set of actions that would be better described by the less ambiguous term of morphogenesis.

The word is readily used as a sort of deus ex machina both in everyday language and by specialists. Indeed its polysemy is very marked. What is there in common between micro-channel erosion, sheet erosion, glacial abrasion and wind entrainment? Even greater confusion is reached if we consider differential erosion phenomena acting on differences in rock composition, and the erosion surface that removes these contrasts. Thus erosion needs to be envisaged in a synthetic manner, extending beyond its different modes of action, and considering the two sets of factors that combine to diversify removal processes: tectonic forces and the effects of anthropisation.

Measures of present day erosion worldwide are based on measures of the load transported by the large river systems, responsible for 90% of transfers of material today from the continents towards the oceans. The principle is simple: if we know the flow rate of a water course, the salinity of its waters, the suspended load, and the bedload, it is possible to calculate the total mass of sediments removed in the part of the river basin situated upstream from the measurement station considered, and if the station is near the river mouth to calculate the total tonnage reaching the ocean. Thus a specific erosion rate can be calculated by multiplying the concentration of dissolved or suspended elements (expressed in mg/l) in a water course by the total flow over the year, dividing the product, i.e. the total tonnages transported, by the surface area of the drainage basin. Erosion (or material removed) is generally expressed in tonnes per square kilometre per year, or better in cubic metres per square kilometre per year which provides an equivalent Bubnoff unit measure, this obviously being a generalisation. In relation to the total erosion surface areas worldwide, i.e. 105.106 km2, material transported can thus be estimated at 169 t.km2.year-1, or 60mm.ka-1, for a mean density of 2 800 g.cm3 and 60 m.Ma-1. This figure, which should be compared to the speed of weathering (around 10 to 20 mm.ka-1), masks considerable disparities: while amounts eroded do not much exceed 2 mm.ka-1 in the Oubangui basin in central Africa, or 4 mm.ka-1 in the Kolyma basin in eastern Siberia, it can reach 271 mm.ka-1 in the Ganges basin, and as much as 688 mm.ka-1 in the Brahmaputra basin.

As one might think, the erosion of materials depends on the resistance of the materials exposed on the surface, and the efficacy of the weathering by atmospheric agents. It however depends more fundamentally on the height and scale of the relief, governing the "erosion potential" in the meaning of J. Blache (1928), the magnitude of which determines in particular the energy deployed by water courses and runoff. It is in fact estimated that around 70% of sedimentary flows worldwide are supplied by recent orogens where tectonic activity is accompanied by marked incisions of orographic volumes taking the form of ridges and steep slopes. The formation of river valleys, which may be accentuated by glacial attrition, leads to the development of steep slopes, generating massive amounts of solid debris which contributes to the potential for attrition of the rock in the river beds.

The increased energy resulting from the relief is accompanied by a marked increase in erosive power, leading to the downcutting of the whole profile. Even in non-orogenic zones, there are remarkable examples of linear concentrations of flow waters, such as the monumental downcutting of the Colorado valley, or the widespread dissection of the coastal relief of the Mediterranean in the Upper Miocene following the drying-out of the Messinian salinity crisis.

Continental morphology at a given moment is the expression of present and past relationships between internal and external forces governing the shaping of emergent land masses. P. Birot considers that "climatic changes merely introduce variants in this fundamental system" which he terms the "antagonistic combination of tectonics and erosion ".

What can be said of erosion resulting from human presence? Can present-day erosion rates be reasonably extrapolated to the long spans of geological time? A calculation of the erosive periods based on the estimation of correlative sediment volumes in different sub-Himalayan sedimentary basins in the Quaternary (F. Mativier, Y. Gaudemer, 1999) shows great long-term stability of the loads transported through the drainage basins "" of more the 105 km2 in southern and south-eastern Asia: the Ganges-Brahmaputra basin (1285 versus present-day load of 1402 x 106 t year-1), the Irrawaddy basin (250 versus 260) and the Indus basin (475 versus 385), etc. One notable exception is however the Huang He basin, since the above authors found themselves obliged to correct contemporary figures to align them on the trend observed throughout the Quaternary. It is well-established, indeed, that from the appearance of the Qin empire, the load carried by the Yellow River across the Loess plateau (317.103 km2), across which it cuts twice, increased from 16.106 before 200 BC to 100.106 t.yr-1 in the course of the Maoist period.

For this reason, the Huang He basin is an exception among the river systems that are the most loaded with suspended matter. Apart from this particular example, the constancy of solids exported by the Himalayan rivers over long time spans confirms the prevalence of river downcutting over soil erosion, even if its manifestations can be catastrophic: the Orange river as it leaves the Lesotho lowlands (104 km2), cut into by 25000 dongas, carries away 5.2. 106 tonnes yearly, and the Mississippi transfers daily 1.106 tonnes to the Gulf of Mexico, despite the scale of fluvial and alluvial storage across its vast basin (3.2. 106 km2).

As the action of runoff is confounded by (and linked to) rainfall erosion, one condition for its calculation is the discontinuity of vegetative cover, particularly the lower herbaceous vegetation. Obviously human presence has extended the phenomenon over cleared and cultivated land. This is the most emblematic form of human impact on erosion, since the agro-system "breaks off the organic solidarity between the soil and the vegetation" (R. Neboit, 2010). This can be seen from the deforestation of French mountain areas through history, which A Surell (1841) or the economist A.J. Blanqui (1843) attributed to damage by mountain streams; it can likewise be seen from the preponderant role of vegetative cover and agricultural practices on the soil losses, collected downstream from experimental plots in Africa (E. Roose and F. Lelong, 1976).

Itinerant crop farming, which favours surface runoff, also extends the action of wind deflation. Vast areas become exposed, in particular in marginal bioclimatic environments such as the temperate steppes of central Asia (Kazakhstan and Uzbekistan, the Argentinian pampa or the middle-west prairies in the USA, where in the 1930s a prolonged period of severe drought particularly impacted certain sectors, which came to be known as "dust-bowls", leading to a massive exodus to California by Oklahoma farmers, the subject of John Steinbeck's *The grapes of Wrath* (1939)).

Observation focused on the plurality and discontinuity of geomorphological time provides insight into forms. It is high time we closed the debate on the advantages of the classic approach based on the logic of relief forms, and those of a newer approach based on better knowledge of the processes involved. The classic approach has not had much support over the last half century, while the second has enjoyed excessive credit. There are today two conceptual approaches to erosion: that of a "geological" erosion, and that of an "anthropological" erosion. According to estimations put forward by B. Wilkinson and B. McElroy (2007), 83% of sedimentary flows imputable to the first form are derived from the highest 10% of the continental surface areas, while 65% of the most low-lying areas provide 83% of soil erosion products.

As clearly underlined by C. Klein (1993), "the two ways to gain understanding of forms are in fact complementary. Thus it is not possible to retain the concept of "accelerated" erosion processes, because a ravine in the course of formation will not generate a valley. There is no need to hierarchise scientific focus on this or that spatio-temporal form, since they are not reducible one to the other, and all are legitimate.

see also: Morphogenetic "system"

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The first reflections on geomorphology in the century of Enlightenment were a breakaway from the Biblical narrative of the book of Genesis, although creationism still has its proponents. Unlike Buffon, Hutton or Playfair, the name of H. Gauthier (1660-1737), an inspector of roads and infrastructures in the Languedoc region of France, has not reached posterity. He was however the author of a work entitled Nouvelles Conjectures sur le Globe de la Terre (1721) in which he estimated, from measures of turbidity of the Rhone, that the wearing down of relief to sea level could be complete in 35 000 years, inviting the reader to make the calculation himself, and to envisage the evolution of emergent land masses in millions of years. Because of the ubiquity of rivers, the main part of the evolution of megaforms on continental scale can be attributed to water courses, so that the concept of "normal erosion" was formed by the American geologist W.M. Davis at the end of the19th century to account for the necessary impact of volumes wherever they are "above the general basic level", represented by the level of the oceans, and hence exposed to sub-aerial attrition. This concept is less open to criticism than some have maintained, because water courses shape the drainage basin slopes, which, depending on steepness, undergo a wide range of transportation phenomena carrying debris from the weathering of rock, from landslides involving large amounts of coarse material, and diffuse runoff which only transports the finer elements. Davis can be criticised for introducing the notion of a "cycle" which postulates an irreversible succession of evolutionary stages, in the absence of tectonic deformations, until a peneplain is formed, i.e. a mature form that a later upthrust will reshape. Far from following a linear pattern, the evolution of forms is fundamentally discontinuous, but it would be a mistake to consider lithosphere mobility, climatic fluctuations or human interventions on the same footing. Their effects do not occur on the same spatio-temporal scale. Although important on account of its consequences on human life, anthropological erosion "only leaves traces, in a sort of overprint (R. Coque, 1993) compared to the forms arising from natural dynamics, among which geological structure governs the backbone of the relief, while present-day climates and paleoclimates diversify "the livery".

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