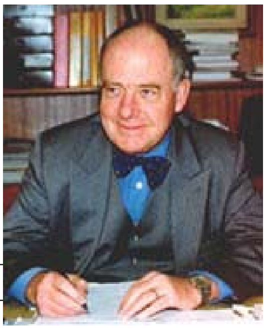
Editorials

Forms of Energy Involved in Soil and Sediment Processes



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Introduction

All processes in soils and sediments as open and complex biotic and non-biotic systems are driven by energy. Therefore knowledge about the forms of this energy is basic for understanding the genesis and functions of these substrates, and the processes involved.

Forms of energy in soils and sediments

In soils and sediments, four main forms of energy can be distinguished: gravity, orogenic energy, solar energy and anthropogenic energy.

Gravity dominates the entire system and therefore, all solid, liquid and gaseous materials. Gravity is inherently influencing the vector and the velocity of fluxes within soils and sediments (e.g. solute movement) and at their surface (e.g. erosion and transport by water and wind), with some exceptions, caused by specific physical, physico-chemical and biological conditions. For example, biota living in these substrates can act against gravity, based on foodstuff deriving from solar energy. Also, certain physical conditions, such as specific pore sizes (e.g. medium pores, 0.2–10µm Ø) can counterbalance gravity through capillary rise of water and solutes.

Gravity is not only important for processes within sediments and soils, but is also the main factor of morphogenesis.

Orogenic energy is the second form of energy and is inherited from the rock parent material, which was formed through orogenesis, an endogenic process which created very diverse types of rocks and minerals, under high temperature and pressure. This endogenic energy, which can also be called orogenic energy, is contained in the rocks and in the rock-forming minerals, and is normally not renewed for a very long time interval, except in cases such as volcanic activities or earthquakes.

This orogenic energy pool is constantly decreased by exogenic forces, derived from solar sources, e.g. through processes of weathering and transport (e.g. erosion). Primary minerals, such as micas and feldspars contain more energy, derived from orogenesis, than their weathering products: clay minerals and oxides. Further examples are the resistance of different minerals against weathering or the buffer capacity of sediments and soils against acidification, see e.g. Winiwarter and Blum, in press. All buffer pools, derived from orogenic energy, such as carbonates, exchangeable alkaline and earth alkaline cations, silicates and finally Fe- and Al-oxides are limited, which means that buffering against acidification is a finite process and only possible as long as these compounds exist. Through weathering and transport, the total energy pool in the soil-sediment systems is constantly lowered, thus increasing the entropy of these systems.

The orogenic (endogenic) energy can be further subdivided into:

- the crystallography of minerals and its resistance to exogenic forces, which can be explained to a great extent by the form and density of element package in the crystal structure, which is different between primary minerals, e.g. micas and feldspars, and newly formed secondary minerals, such as clay minerals and oxides.
- the chemical composition of minerals, which plays an important role, e.g. through the content of alkaline or earth-alkaline cations in relation to silica, aluminium and metals, such as iron, manganese, copper, zinc and others.

Crystallography and chemical composition are important for all bio-geochemical processes in sediments and soils, especially biomass production, filtering, buffering and transformation processes (e.g. 'natural attenuation') and living conditions for biota (biodiversity).

Solar energy is the third form of energy, deriving from solar radiation, which can be subdivided into direct radiation (including diffuse radiation through reflection, etc.) and forms of solar energy contained in organic matter and biomass, which is nothing else but a secondary form of solar energy with a different dimension of time.

Both, direct and indirect forms of solar energy are the basis of exogenic forces, driving important biochemical and physico-chemical processes in soils and sediments. Their forms and intensities can be defined on the basis of climatic systems and sub-systems (compare also Krinner et al. 2005).

Solar energy is not only the cause of bio-physico-chemical reactions, but also influences their velocity (see rule of van t'Hoff). Energy derived from solar radiation can also act against gravity, especially under arid and semi-arid conditions, where water movement in sediments and soils occurs against gravity, through evaporation (evapo-transpiration) at the surface of these substrates, leading partly to the formation of new components, e.g. water soluble salts, such as carbonates, chlorides, sulphates, nitrates and others. Therefore, solar energy may have very diverse impacts, according to the prevailing climatic and soil and sediment conditions.

In contrast to the energy derived from orogenesis (rocks, primary minerals), this form is renewable and is acting constantly at the surface of sediments and soils and within these substrates.

In the past, sediments and soils developed under different climatic conditions (paleoclimates), especially in the tropics and sub-tropics, which makes it doubtful to use current climatic data, such as temperature and/or precipitation for their analysis and classification.

Anthropogenic energy is the fourth form of energy, deriving from anthropogenic activities. It is a mixture of different energy forms, including human labour, mainly based on fossil energy and non-renewable resources such as oil, coal, rocks, minerals, elements, influencing the genesis and functions of sediments and soils through physical, chemical and biological impacts, e.g. through hydrological engineering, navigation, agriculture and forestry, landscape architecture, urbanisation, industrialisation, and others.

Since the end of the 18th century, anthropogenic impacts on terrestrial and aquatic ecosystems have been exceeding the natural impacts. Therefore, PJ Crutzen (2002) named the last two centuries the 'Anthropocene', in contrast to the 'Holocene' and the 'Pleistocene', using, as its starting point, the invention of the steam engine by James Watt in 1784, which developed the physical forces of about 200 humans, even at a degree of efficiency of less than 1%.

According to Crutzen (2002), the Anthropocene is a human-dominated geological epoch, with characteristics different from the rest of the Holocene: a tenfold increase of world population to 6.5 millions within the last three centuries; more than 1.4 billion of methane-producing cattle; about 40–50% of the earth surface exploited by humans releasing CO_2, and increasing species in extinction; more than 50% of accessible fresh water used; twentyfold growth of energy use within this time interval; more nitrogen fertiliser applied in agriculture than fixed naturally; and all these effects caused by only about 25% of the world's population (see also Blum and Eswaran 2004).

Outlook and Conclusions

According to these four different forms of energy, the definition of steady-state equilibria in sediments and soils is not possible, because the orogenic energy pools derived from rocks and minerals are constantly decreasing through external, mainly solar and anthropogenic energies, thus increasing the entropy of the system. Further forms of energy in soil and sediment processes such as energy transfer from the inner part of the earth, can be neglected, see, for example, the permafrost conditions in the extreme northern and southern hemisphere.

It seems possible to use this energy concept for understanding most of the processes in sediments and soils and answering the question, why specific forms of energy have been preserved irreversibly, e.g. in the form of secondary minerals (clay minerals, oxides and others), thus testifying historical environmental conditions with different energy impacts, which can be described as the 'memory of soils and sediments'.

Moreover, a survey of the ecological impacts of these energy forms on aquatic and terrestrial ecosystems reveals that the resilience[1] of sediments and soils is higher than that of the biosphere, because the latter is mainly based on solar energy, including possible anthropogenic impacts, and less on orogenic energy (Blum 2000) – even when considering that the physico-chemistry of substrates supporting life is inherited from orogenesis. For example, the pH in terrestrial and aquatic ecosystems mainly depends on the existence of carbonates and/or the presence of alkaline or earth alkaline cations.

Summarising, it can be said that the forms of energy in soils and sediments are the basis of all processes at the cross-road between the lithosphere, the hydrosphere, the biosphere, the atmosphere and the anthroposphere. Any attempt to quantify these functions economically and socially, e.g. as goods and services for mankind, has to be based on an energy concept (Warr and Ayres 2004).

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[1] resilience = capacity of a system to return to a (new) equilibrium after disturbance

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