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The biosphere in times of global urbanization

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ABSTRACT

Vladimir Ivanovich Vernadsky introduced the concept of the biosphere into Geochemistry. This sphere comprises the biological processes responsible for the distribution of chemical elements on Earth. Already when Vernadsky developed the concept of the biosphere he was aware of the important impact human beings have on the distribution of chemical elements in the Earth's system. However, since that time the meaning of human beings for the global element fluxes dramatically increased that becomes visible in the enormous urbanization process the Earth currently is facing. In this scientific-philosophical assay contributed to the 150th anniversary of the birthday of Vernadsky, the process of urbanization is discussed from the view point of the biosphere.
Today, more than half of the world's population lives in urban systems, and this portion is growing. Urbanization has become a geological factor since the need for geological resources for urbanization is shaping the Earth's surface and relocating chemical elements on a global scale. Since human beings are part of Vernadsky's biosphere also urban systems are part of the biosphere. This human induced development of the biosphere caused subspheres such as the agrosphere and the astysphere, the first comprises fluxes of chemical elements due to agricultural activities, the second refers to fluxes caused by urban systems. With the progress of the global urbanization the astysphere will expand its influence. This is accompanied by severe consequences for the global environment such as the climate change. According to Vernadsky, the scientific thought of societal man is transforming the biosphere into the noosphere. This noosphere describes the fluxes of chemical elements when human ideas and inventions become realized. Thus, goal-oriented human processes such as urbanization and management of environmental challenges caused by global urbanization and climate change accelerating the extension of the noosphere.

1. Introduction

Vladimir Ivanovich Vernadsky (1926, 1944) developed the concepts of the biosphere and noosphere from the viewpoint of geochemistry (Levit, 2001). It was his merit to realize the enormous meaning of biological processes for the distribution of chemical elements within the Earth in space and time. The influence zone of organisms on chemical element fluxes is called biosphere. Early in his career, he also reckoned the influence of scientific thoughts on the biosphere, finally resulting in the noosphere, when those thoughts become realized. Furthermore, Vernadsky realized at his time that human activity is a geological force when considering the mining activities (Krüger, 1981). These concepts of biosphere and noosphere are of high relevance for handling environmental challenges of today. Industrialization and urbanization dramatically have increased the human caused element and material fluxes on Earth, which led to global environmental problems such as climate change, excessive water and soil pollution or biodiversity loss. These problems endanger the means of livelihood of the whole mankind. Within this context it has to be considered that already more than half of the world's population is now living in cities, and that share is constantly growing. Worldwide the number of cities is increasing, due to the world population growth small settlements become cities and new cities are found. It is estimated that 0.3 to 2.7% of the total land area is already urbanized (Angel et al., 2005; Salvatore et al., 2005). Facing the challenges of global change mankind recently is developing management tools and mitigation measures to overcome the global environmental problems created by industrialization and urbanization. Thus, mankind is reorganizing the biosphere. Consequently, there is an obvious need for the discussion of the role of urbanization within the biosphere, and whether the pursued human control of the biosphere to achieve sustainable development of the environment is a step toward Vernadsky's noosphere. Therefore, this article will span a scientific-philosophical discussion from the fundamentals of geochemistry used for the development of the biosphere concept toward the meaning of urbanization for the biosphere and its further transformation into the noosphere.

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2. Geochemistry, the fundament of the biosphere

"Geochemistry deals with the distribution and migration of the chemical elements within the Earth in space and time" (Mason, 1952). According to Correns (1968), the German chemist Christian Friedrich Schönbein used the word "Geochemie", or in English language "Geochemistry", first in 1838. The meaning of the science of geochemistry was amplified by Victor Moritz Goldschmidt by discovering that chemical elements can be grouped according to their behavior during the cooling down of a melt and the consequent enrichment in certain envelopes or spheres within the global system (Goldschmidt, 1923). Based on the ideas of Eduard Suess (1875) classifying the global geosystem into spheres, on the works of Dimitri Ivanovich Mendelejew (1869) and Lothar Meyer (1864), who developed the periodic table of chemical elements, on Frank Wigglesworth Clarke's (1908) compilation of the abundances of chemical elements in minerals and rocks and the growing availability of data on free energies for chemical reactions, Goldschmidt classified siderophile, chalcophile, lithophile and atmophile chemical elements. Siderophile elements are associated with the iron phase of meteorites or the Earth's iron core (siderosphere) such as Ni, Co and platinum group elements (PGE). Chalcophile elements are concentrated in the sulfidic phase of meteorites or the sulfidic section of the mantle (chalcosphere) and comprise chemical elements like As, Zn, Cd, and Cu. Lithophile elements are associated with silicates composing the lithosphere, e.g. Li, Na, K, Mg and Ca. Volatile elements and compounds are atmophile and form the atmosphere (Goldschmidt, 1923, 1954; Rößler, 1991).

It was Vernadsky (1926, 1997), who added the biosphere to this geochemical system, when he reckoned the enormous meaning of biological processes for the distribution of chemical elements at the Earth's surface. Vernadsky was e.g. inspired by interpreting the movement of locust swarms as mass movement of chemical elements and compared it to the annual mining of Zn and Cu (Smil, 1997; Vernadsky, 1930). Since then, more and more "spheres" were introduced and used in natural sciences, such as hydrosphere, pedosphere, detritus sphere and rhizosphere, defining spaces of matter fluxes or chemical, physical or biological processes. According to the geochemical definition of the biosphere, even rocks like limestone or minerals such as goethite are part of the biosphere, since they only could be formed due to e.g. carbonate shell producing organisms and free oxygen in the atmosphere from photosynthesis. In this sense, also human beings are products and part of the biosphere, and thus chemical element fluxes induced by humans are part of the biosphere as well. The biosphere is overlapping other spheres e.g. in case of soil formation between atmosphere and lithosphere (Fig. 1a). Similar, human beings are able to expand the extension of the biosphere and to create new overlapping zones with other spheres e.g. by mining in juvenile rocks.

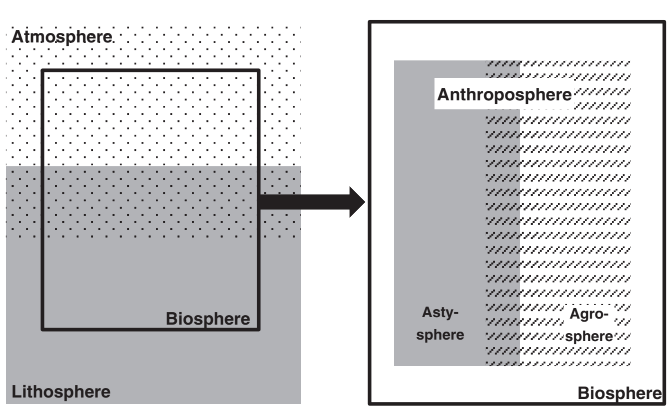

Fig. 1. The concept of spheres. (a) The biosphere between atmosphere and lithosphere. (b) The composition of the anthroposphere as part of the biosphere. The proportions of the respective fields of the sketch are not proportional to their significance in reality.

3. The anthroposphere as part of the biosphere

The rise of mankind toward one of the most important exogenic factors of shaping Earth started with the end of the last ice age almost 15,000 years ago. Since then, the Earth saw the Neolithic revolution with the upcoming agricultural systems substituting the untouched natural ecosystems roughly 12,000 years ago followed by the establishment of the first towns about 11,000 ago, such as Jericho. Since the end of the last ice age it is estimated that the global population has grown from about 4 million inhabitants via 1 billion inhabitants in the beginning of the 19th century toward more than 7 billion inhabitants today (Kremer, 1993; United Nations, 2013). A comparison between the prehistoric hunter-gatherer and the modern human being shows that the consumption of goods has increased by more than an order of magnitude (Baccini and Brunner, 2012; Brunner et al., 1994). Now, more than half of this world's population is living in cities and for the mid of the 21st century it is expected that 7 out of 10 people will be urban inhabitants (UN-Habitat, 2013).

Together with this enormous growth of urban population also fluxes of materials and energy are directed toward urban systems. Globally, geogenic and anthropogenic material fluxes already occur in comparable scales even if considering the annual uplift of mountains (Heinloth, 2003). For example, the worldwide extraction of black coal grew between 1870 and 2005 from 203.5×10^6 to 4.55×10^9 t by three orders of magnitude (Fischer Weltalmanach, 2005). The global anthropogenic Cd flow exceeds twice the rate of the non-man-made flows (Baccini and Brunner, 2012). Steel production increased from 1950 to 2012 from about 190 Mio t to as more as 1500 Mio t (Wirtschaftsvereinigung Stahl, 2006; World Steel Association, 2013). In 2012, 3.6 billion t of cement were produced (IMF, 2013), and about 100,000 chemical substances are registered in the EU market (Commission of the European Communities, 2001). Half of the annual global N fixation is actually caused by anthropogenic activities (Fowler et al., 2013). Combustion activities in urban systems are one main driver of the recent release of the climate-active gas CO_2. At present 80% of material consumption and up to 75% of carbon emissions are caused by urban systems (UNEP, 2012). Furthermore, land use change for agricultural purposes leads to CH_4 emissions due to cattle and rice cultures and to CO_2 release caused by deforestation. This process already has started with the Neolithic revolution and is being discussed to be responsible of global warming (Ruddiman, 2003, 2013). This impact of mankind on material and energy fluxes has been considered to create a new sphere within the geochemical concept of the distribution of elements: the anthroposphere (Baccini and Brunner, 1991). One characteristic of the anthoposphere is the large number of new chemical compounds produced in various kinds of technical facilities outside of the human body. This is a very meaningful criterion to describe the difference between human beings and other species. In contrast to other species, humans purposeful are able to externalize the production of chemical compositions useful for their life outside of their specific bodies.

Considering this enormous impact of mankind's activities on global substances and energy fluxes since the last glaciation, Crutzen (2002) proposed to rename the Holocene into Anthropocene. Seto et al. (2010) alluded to the considerable role of urban systems for this geological period and introduced the expression Astycene instead of Anthropocene. Thus, recently, fluxes of both, chemical elements and energy caused by urban systems became relevant for geochemical research. This field of geochemistry was first specified as urban geochemistry (Thornton, 1991), then as urban environmental geochemistry (Wong et al., 2006).

4. Anthroposphere = agrosphere + astysphere

As already indicated in the previous chapter, anthropogenic matter and energy fluxes can be allocated to two subsystems of the anthroposphere, the agricultural subsystem and the urban subsystem, which are intensively interlinked. Agricultural systems are subsumed