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Galitskaya I.V., Yanin E.P.
Geochemistry // Encyclopedia of Engineering
Geology. Encyclopedia of Earth Sciences Series. –
Cham: Springer, 2018, p. 378–380.
DOI 10.1007/978-3-319-73568-9_133

Geochemistry

I.V. Galitskaya[1] and E.P. Yanin[2]
[1]Sergeev Institute of Environmental Geoscience Russian Academy of Sciences (IEG RAS), Moscow, Russia
[2]Vernadsky Institute of Geochemistry and Analytical Chemistry of the RAS (GEOKHI RAS), Moscow, Russia

Definition

The science of the chemical composition, chemical processes, and chemical evolution of the Earth.

The Earth consists of chemical elements that mainly formed before the existence of the Earth. During the formation and evolution of the planet and subsequent geological history, these have become redistributed and, in the case of radioactive elements, have transmuted into other elements. Initially, redistribution depended wholly on inorganic processes, but once living organisms appeared, they played an increasing part in geochemical processes on land and in surface- and groundwater. In recent times, human activities have increasingly affected processes in the shallow Earth's Crust, water, and the atmosphere. Therefore, geochemistry was initially focused on the geological past but has become increasingly important in respect of geological resources and environment protection. The theoretical basis of geochemistry is physical and chemical laws governing the behavior of matter in the ranges of thermodynamic conditions that occur in the geosphere.

Development of Geochemistry

The term "Geochemistry" was first used in 1838 by C.F. Schönbein (Switzerland) for the science of the chemical processes in the Earth's crust, and was widely recognized after the work by V.I. Vernadsky (Russia) (Vernadsky 1954–1960). Other key founders of the discipline were V.M. Goldschmidt (Norway) (Goldschmidt, 1954), F.W. Clarke (USA), who presented the first major summary of the subject, and A.E. Fersman (Russia). It was Fersman who introduced the first high-level University course in the discipline (see Fersman 1934 and 1952–1962). These pioneers focused on the relative abundances of chemical elements and their isotopes, the patterns of distribution of chemical elements in the geosphere, and laws of the behavior of chemical elements in natural processes. To some extent, a parallel development of this science within the former Soviet Union and in Western Europe/USA and some other countries led to some differences in terminology. More recently, these traditions have converged.

Main Aspects of the Discipline

Modern geochemistry is a combination of scientific disciplines, united by common approaches and specific research methods, applied to the Earth's main accessible layers – the lithosphere, atmosphere, hydrosphere, and biosphere – and also, from indirect evidence, to deeper levels. However, organic geochemistry focuses on conditions of accumulation and the geochemical role of once living organic matter. Natural geochemical processes can be divided into endogenous (magmatic, hydrothermal, metamorphic) and exogenous (supergene) processes.

The main aspects of the discipline are the distribution, history, and behavior of the chemical elements and their isotopes in our planet, including migration, transport, and concentration (accumulation) of chemical elements and transitions from one state to another. The main theoretical problem is to ascertain the behavior of chemical elements in the geosphere. Any geological process is accompanied by accumulation of some elements and isotopes and migration and

P. T. Bobrowsky, B. Marker (eds.), *Encyclopedia of Engineering Geology*,
https://doi.org/10.1007/978-3-319-12127-7_133-1

dispersal of others. From that point of view, geochemistry reflects processes of separation due to differences in physical and chemical properties and the nature of the environments in which they are migrating or accumulate. This is reflected in the geochemical classification of elements – the Law of Matter Differentiation of the Earth – which states that the distributions, laterally and vertically of chemical elements, define the distinctive chemical compositions of geological structural units (Goldschmidt 1954).

Geochemistry is based on the concept of chemical elements dispersion in the earth's space, which is reflected in Vernadsky's Law about the abundances of chemical elements in any volume of terrestrial matter. The current geochemical field is a transitional stage in the long process of redistribution of elements by continuous migration in time and space. F W Clarke (1924) developed the concept of identifying the average percentages of elements in the Earth's crust (estimates known as "clarkes").

Geochemical provinces from planetary to regional scales can be distinguished. These provinces have fairly homogeneous geochemical characteristics that reflect the types of mineralization and other geochemical associations that have developed, in irregular stages, through geological time (Tan and Chi-Lung, 2009). Migration for most elements is cyclical, including the passage of elements from one part of the geosphere to another during geologic time. Migration in the biosphere is carried out partly or wholly with the participation of living organisms. Certain elements are absorbed by living matter during the biological cycle but, on leaving the living matter, the atoms give up stored energy to the environment. Many chemical reactions reflect this biogenic energy, for instance, reduction-oxidation (redox) zoning systems.

The study of the nature of, and changes to patterns of lithogenesis of sedimentary rocks, describes the composition of the past and present atmosphere, hydrosphere, and lithosphere and geochemical factors in the origin and development of life, environments, and habitats. It involves the chemical composition and physicochemical conditions of sedimentary rocks; their evolution in the geological history; the abundance of elements in sedimentary rocks, patterns of behavior, distribution, and migration of elements; and their associations in the processes of sedimentation, diagenesis of sediments, and epigenesis. Lithogenesis of igneous rocks involves the partitioning of elements during cooling of magmas and extends into the hydrothermal processes that lead to the formation and zoning of ore bodies. The genesis of metamorphic rocks is described in terms of the migration and accumulation of elements under ambient temperature and pressure conditions.

Principal Research Tasks

Key tasks have been and are:

- Determining the abundances of chemical elements and average composition of the Earth's crust
- Determining patterns of distribution in the Earth as a whole, and in its main layers, including rocks, minerals, soils, water, living organisms, and man-made systems including natural and anthropogenic concentrations of potentially harmful elements
- Establishing migration behaviors of chemical elements leading to their concentration or dispersal that determine the formation of rocks and mineral deposits
- Understanding geochemical and biogeochemical cycles
- Identifying characteristics of geochemical provinces and landscape zones, including mineral deposits associated with them
- Determining chemical composition changes in the biosphere due to both natural processes and human impacts
- Identifying deficiencies of mineral nutrients that affect both agriculture and people
- Using chemical compositions to identify the sources of transported materials such as dust
- Geochemical mapping and zoning
- Improving methods of physical and chemical analysis of the paragenesis of chemical elements
- Securing quantitative data on the content, distribution, and forms of chemical elements and isotopes and their behavior in all relevant systems
- Developing better mathematical methods of data processing and analysis

Subdisciplines

Names have appeared for subdisciplines, notably:

- Physical geochemistry – physicochemical processes of formation of minerals, rocks, and ores in the Earth's crust, mantle, atmosphere, and hydrosphere
- Thermobarogeochemistry – heat- and pressure-related physicochemical processes
- Geochemical ecology – interactions of organisms and their communities with the geochemical environment
- Agro-geochemistry – natural and anthropogenic patterns of change in the geochemical properties of pedological soils and the impacts on quality and quantity of agricultural production

- Isotope geochemistry – behavior of isotopes under the influence of various geological, geochemical, and cosmochemical processes and development of criteria for the use of these data for solving theoretical and applied problems including the reconstruction of the most important events in the history of the elements and, therefore, in the history of the earth's crust and the Earth as a whole, as well as meteorites and the solar system
- Environmental geochemistry – behavior of chemical elements in the environment including consideration of contamination and pollution and impacts on people and ecosystems
- Landscape geochemistry – concentrations and behavior of chemical elements in landscape zone (terrain units)
- Regional geochemistry – characteristics of specific areas from the large to small scales including geochemical terrain units (geochemical zoning) that can be used in forecasting the existence of, and prospecting for, mineral deposits and also for agricultural and medical assessments
- Radiogeochemistry – types and concentrations of radioactive elements and isotopes in geological processes and is the basis for: exploration for radioactive ores; understanding the energy processes crust associated with radioactivity; determination of the absolute age of rocks, fossils, and minerals and archaeological remains from the accumulation of decay products of radioactive isotopes at known rates of decay; and assessment hazards from radioactive elements deposited from the air (e.g., from plumes emitted during nuclear accidents) or emissions from the ground (e.g., radon)

Relevance to Engineering Geologists

Aspects of geochemistry that are relevant to the work of engineering geologists relate to an understanding of the compositions and diagenesis of soils and rocks; processes of mineral resource formation; contaminants and pollutants; and behavior of construction and building materials. Some aspects are direct but an understanding of others is required when working alongside hydrologists and environmental scientists.

The established patterns of distribution and concentrations of chemical elements in geological processes form the theoretical basis of identification of prospects for, and commercial exploration of, mineral deposits. Understanding the principles and mechanisms of formation of primary and secondary halos and dispersion trains in and around ore bodies and chemical indications in soils are the basis of geochemical prospecting.

Since the late eighteenth century, increasing industrial activity has significantly affected the shallow geosphere and biosphere in many parts of the World and effects continue to increase. This has caused a sharp change in the scale of geochemical cycling of substances and increased entry of toxic components into the biosphere. Fersman pointed out the inevitability of destabilization of the Earth's biosphere by creating manufactured chemical compounds that generate reactions that are unusual in nature and change the flow rate in many geological and geochemical processes.

Extraction of minerals and civil engineering operations has become comparable in scale to natural processes. Pollution and contamination of soils and water by solid and liquid industrial and municipal wastes, fertilizers, and pesticides has become widespread. The problems of anthropogenic (technogenic) changes were first identified by A.E. Fersman who stated (Fersman 1912) that by developing industry during a historically short period mankind has become a major geochemical agent that is beginning to change chemical elements in nature and subdue the substance of nature to his will.

Geochemistry is important to elucidating the role of these processes in the current and future chemical evolution of the biosphere, essentially geoecological research. Regaining a geochemical equilibrium will require rational development of land and mineral resources and protection of the environment from human activities. That requires field observations, field and laboratory experiments, modeling, and analytical calculations. In recent decades, geochemistry and biogeochemistry have been increasingly important in environmental protection by establishing baseline data for assessment of levels of anthropogenic pollution and contamination and assessing rates and extent. Work has also extended to the study of elements and compounds in the biosphere in support of studies of health impacts, levels of organic nutrients, and has become important in respect of biosphere evolution forecasts and rational measures of environmental protection from pollution. It is also important in forensic geology.

Conclusion

Three main research directions are distinguished in geochemistry, consistently prevailed over three major periods of modern geochemistry development (Jaroshevsky 2012). The first direction (mainly in the first half of the twentieth century) consists in the formulation and solution of fundamental problems of geochemistry, namely, the assessment of the abundance and establishing the main regularities in chemical element partitioning in the natural objects. The second direction (in the second half of the twentieth century) is connected with the development of the physicochemical principles for interpreting the behavior of chemical elements in natural processes. The main result in this research was the substantiation of the fruitfulness of thermodynamic and dynamic modeling of natural systems and processes. The third direction (in the second half of the twentieth century – the beginning of the twenty-first century) is the creation of physicochemical models for the behavior of chemical elements in geological processes and, on this basis, the development of geochemical criteria for solving geological problems. Making further progress in geochemistry requires the perfection of mineral matter analysis methods and widespread computer technology use in the geochemical studies.

Cross-References

- ► Contamination
- ► Diagenesis
- ► Igneous rocks
- ► Metamorphic rocks
- ► Mineralization
- ► Pollution
- ► Sedimentary rocks
- ► Site investigation

References

Clarke FW (1924) The data of geochemistry. U.S. Geol. Survey Bull. 770

Fersman AE (1934) Geochemistry, vol. 2. Leningrad. ONTI-Himteoret. (in Russian)

Fersman AE (1952–1962) Selected works, vol. 1–7. Moscow. Publishing house USSR Academy of Sciences. (in Russian)

Goldschmidt VM (1954) Geochemistry. Clarendon Press, Oxford

Jaroshevsky AA (2012) Geochemistry and its problems. The turn of XX-XXI centuries. Moscow University press, Moscow, (in Russian).

Mason B, Moore CB (1982) Principle of geochemistry. Wiley, New York

Shcherbina VV (1972) Basics of geochemistry. Nedra, Moscow. (in Russian)

Tan L, Chi-Lung Y (2009) Abundance of chemical elements in the Earth's crust and its major tectonic units. Int Geol Rev 12(7):778–787

Vernadsky VI (1954–1960) Selected works, vol. 1–5. Moscow. Publishing house of the USSR Academy of Sciences. (in Russian)