GEOPHYSICS AND GEOCHEMISTRY

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Summary

Geophysics and geochemistry are two closely intertwined and collaborating branches of Earth's sciences. They have roots in ancient times, particularly geophysics. Geophysics is concerned with physical phenomena. Classical geophysics studied the solid Earth body by various methods, like seismic, gravimetric, geodynamic, geomagnetic, geolectric and geothermal methods. Modern geophysics does not exclusively treat the solid Earth; it also includes investigations of the upper atmosphere (aeronomy and magnetospheric physics), solar wind and planetology. The separation of geophysics into different disciplines is based partly on different methods used to study the same physical body, and partly on investigating different media and processes. However, within the natural environment, various disciplines of geophysics are interrelated and interact each other.

Geochemistry deals with the distribution and cycling of the chemical elements, and their isotopes, throughout nature. It is of great importance to understanding the Earth and

planets, and their origin and nature. Geochemistry is an interdisciplinary subject which touches geophysics, geology, astronomy, planetary sciences, atmospheric science, physics, chemistry, biology, material sciences, and others. The subject has evolved from a substantially descriptive to a highly quantitative and predictive discipline.

There are two principal reasons for developing geophysical and geochemical investigations: (i) to understand the broad global environment we are living in, i.e. planet Earth; (ii) to predict and possibly prevent risks and damages associated with certain disastrous geophysical phenomena, like earthquakes. Moreover, geophysical and geochemical methods have been used in the search for deposits of various raw materials like oil, gas, and various metallic ores. Geophysical and geochemical methods also have direct environmental applications.

1. Introduction

It is normal to begin every textbook or encyclopedia with a definition of key terms such as *geophysics* and *geochemistry*, in order to inform the reader of the subject matter. In school, each such definition is usually in the form *Geophysics is* …. Surprisingly, it is not easy to present such a simple definition, particularly of *geophysics*, because different meanings are currently applied to this word.

Both parts of the word *geophysics*, *geo* and *physics*, are in fact of ancient Greek origin, because "*gé*" (→ *geo*) was the name for the Earth, whereas the word "*fysis*" (→ *physics*) denoted nature, natural order, and world. However, during the long historical development of physics, its orientation and objects of interest gradually changed, becoming more specific and narrower. Since chemical processes are also important, one of the key Earth sciences is *geochemistry*.

In such an understanding, *geophysics* and *geochemistry* are branches of physics and chemistry, which study the phenomena and processes occurring in the Earth and on its surface. However, modern geophysics also studies the upper atmosphere and magnetosphere of the Earth (the most remote, fully ionised and geomagnetically controlled part of the upper atmosphere), other planets, and solar wind in interplanetary space. In all these media, particularly in the ionosphere and at other planets, chemistry also plays an important role. On the other hand, there are other branches of science, which study various parts of the Earth's system, like meteorology, hydrology, oceanology and vulcanology.

Thus *geophysics* and *geochemistry* in the narrow sense of these terms is the physics and chemistry of the solid Earth omitting those parts of solid Earth science, which are treated by other disciplines such as geology. In a broad sense, *geophysics* can be categorized by using the structure of the International Union of Geodesy and Geophysics, which consists of seven scientific Associations:

- **International Association of Geodesy** (IAG), which includes gravimetry as a part of geophysics (see *Gravimetry*).

- **International Association of Seismology and Physics of the Earth's Interior** (IASPEI); this includes geothermics (see *Seismology and Volcanology; Terrestrial Heat Flux*).
- **International Association of Volcanology and Chemistry of the Earth's Interior** (IAVCEI) (see *Volcanology: Volcanic Activity, Chemistry and Effects on the Environment*).
- **International Association of Atmospheric Sciences** (IAMAS), which deals with atmospheric phenomena and processes, including climatology.
- **International Association of Physical Sciences of the Ocean** (IAPSO), which deals with and ocean (marine) sciences.
- **International Association of Hydrological Sciences** (IAHS), which deals with the hydrosphere, or with the water cycle.
- **International Association of Geomagnetism and Aeronomy** (IAGA), which includes magnetospheric physics and solar wind (see *Geomagnetism and Geoelectricity; Aeronomy and Magnetosphere; Solar Wind and Interplanetary Magnetic Field*).

However, this list includes some scientific disciplines not included in *geophysics* and *geochemistry,* notably hydrology and climatology. Also, the European Geophysical Society has a special Section, which deals with planetology.

The situation is a bit easier with *geochemistry*. Goldschmidt's definition of this scientific discipline from the 1930s is reasonably applicable even now: *"the distribution and amounts of the chemical elements in minerals, ores, soils, waters, and the atmosphere, and the circulation of the elements in nature, on the basis of the properties of their atoms and ions"*.

For the Encyclopedia, the terms *geophysics* and *geochemistry* are defined not in a direct way (i.e. *geophysics is…)* but indirectly from the contents of the Theme 'Geophysics and Geochemistry':

- *Foundations of Geophysics and Geochemistry*
- *Geophysical systems,* which includes motion of continents, tectonic processes, interaction of surface and tectonic processes, impact of human activities on geophysical processes, special seashore problems, and terrestrial heat flow (geothermics)
- *Seismology and Volcanology*, which includes crust, mantle and core of the Earth, earthquakes (severity, frequency, mechanics, ground motion, prediction), and volcanic eruptions (activity, effects, chemistry, prediction)
- *Geomagnetism and Geoelectricity*, which deals with magnetic and electric field of the Earth, rock magnetism, paleomagnetism and geodynamics
- *Aeronomy and Magnetosphere,* which treats aeronomy, high atmosphere, ionosphere, and magnetosphere, including space weather and its impacts
- *Gravimetry,* which describes gravitational field, gravity anomalies and applications of gravimetry

- *Geochemistry and Cosmochemistry,* which includes cosmochemistry, geochemical origin of the Earth, gaseous geochemical cycles, sedimentary and stable isotope geochemistry, and environmental geochemistry
- *Planetology*, which deals with the solar system, planets, their satellites, asteroids, comets, meteors, and solar wind including its interplanetary magnetic field.

Thus now we understand what is included within *geophysics* and *geochemistry*, and we can look in more detail at various branches of *geophysics* and *geochemistry*—in particular at those structures and processes in the Earth's system which are treated by *geophysics* and *geochemistry,* at societal impact of knowledge provided by *geophysics* and *geochemistry,* and on the past and future of *geophysics* and *geochemistry*. However, before doing this, it is necessary to describe broad international collaboration in the fields of *geophysics* and *geochemistry*.

Geophysics and *geochemistry* are mostly concerned with phenomena of size and interactions crossing national borders and even continental borders; simply speaking, quasi-global phenomena or at least large-scale phenomena. On the other hand, military application (and misuse) of geophysical knowledge is limited, even though geophysics serves for detection of nuclear weapon test explosions (including underground explosions), and the need for geophysical information for correct determination of orbits of military satellites, etc. For these reasons, international collaboration in geophysics has been quite broad and truly international, at least since the International Geophysical Year (IGY, 1957-1958) and has been little disrupted by the various "cold" political periods. Even before IGY, international collaboration in geophysics and geochemistry was fairly good.

The are several international non-governmental scientific bodies, like the International Union of Geodesy and Geophysics described above, and others such as Scientific Committee for Solar-Terrestrial Physics (SCOSTEP), Committee for Space Research (COSPAR), and International Biosphere-Geosphere Program, which provide official but voluntary umbrellas for international collaboration. One of the important roles of those scientific bodies is to promote science in developing countries. There are also governmental organisations, like UNESCO, which run some geophysical projects. Last but not least, there are regional scientific non-governmental bodies, like the American Geophysical Union, European Geophysical Society, and the European Union of Geophysics, which are in fact international, because they have members distributed around the world, even though the majority is usually from a given region. Thus there are many umbrellas, which allow and actively support international collaboration in the field of *geophysics* and *geochemistry*.

2. Why Study Geophysics and Geochemistry?

Geophysics deals with physical properties of the solid Earth and the upper atmosphere (up to the magnetopause). In other words, it deals with our distant environment; not with our garden, with our neighbour's smoking chimney, or with pollution from vehicles. However, understanding of the Earth and our habitat, is of primary importance for long-term sustainable development of humankind. Geophysics is important for development of other Earth and planetary sciences. It is also important for its practical implications, even in everyday life.

Some geophysical phenomena pose a real threat to us, for instance earthquakes or mine collapses. Earthquakes have been responsible for the death of many thousands of people and devastating destruction of large areas. Modern civilisation becomes more and more dependent on modern technologies and satellites, and as such is more and more vulnerable to space weather phenomena (see *Magnetosphere and Its Coupling to Lower Layers*), particularly to geomagnetic storms.

Thus there are two reasons for studying geophysics (and geochemistry):

1. To understand the broad global environment we are living in, i.e. planet Earth.
2. To predict and possibly prevent risks and damages associated with some disastrous geophysical phenomena.

The study of geochemistry is of great importance to the Earth and planetary sciences (see *Geochemistry and Cosmochemistry*), on both purely scientific and more immediate practical grounds, because chemical processes are fundamental to understanding how the planetary bodies formed and evolved at all scales, from atomic to solar system. Consequently, geochemistry plays a central role in understanding a diverse set of scientific questions, such as the formation and differentiation of the Earth and planets, the origin and evolution of life, the controls on global climate and climate change, and the formation and management of natural resources. Such questions include many of those that are critical for humankind to understand the context of its existence and to chart its future. Environmental geochemistry becomes more and more important for our everyday life (see *Environmental Geochemistry: Geoindicators*).

3. Structure of the Earth's System

As stated above, geophysics and geochemistry deal with the Earth system from deep Earth up to the most remote parts of space which can be considered to "belong" to Earth, and beyond. Figure 1 shows a schematic height structure of the Earth's system as studied in geophysics. Both the solid Earth and the atmospheric/space part of the Earth's system are included.

The uppermost part of the solid Earth between the Earth's surface and the Mohorovicic Discontinuity is called Earth's crust. The crust is so thin that it is almost invisible in Figure 1 (green colour). The crustal thickness is rather variable. It ranges from between about 5 and 10 km below the ocean bottom, being thicker below oceanic shelf, and reaches typical value between 30 and 40 km below continents (but locally only 20 km and up to 70 km beneath the highest mountains. Below the crust, the Earth's mantle is located. This is the part of the Earth that extends down to the Earth's core at a depth of 2900 km, where again a well-pronounced seismic discontinuity has been detected. The mantle contains nearly 70% of the mass of the Earth, and over 80% of its volume. The Earth's core is the inner part of the Earth below the Earth's mantle. The probable composition of the core is as follows: iron, nickel and about 10% of lighter materials. The core consists of two parts, the outer core and inner core, which are considerably different in their physical properties. The outer core is considered to be liquid. In this liquid and electrically conducting material of the outer core, the geomagnetic field is generated. The inner core extends from a depth of 5150 km to the Earth's centre. It is considered to be the part of the core that has already solidified.

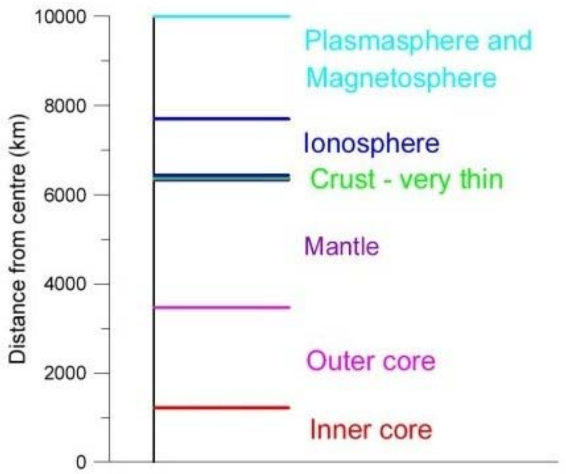

Figure 1. Altitudinal scheme of the Earth's system.

Meteorologists and atmospheric physicists and chemists investigate the first fifty kilometers above the surface, the troposphere and stratosphere. The region above that, where free electrons are present as a consequence of ionization processes, is called the ionosphere. In terms of the neutral atmosphere, the ionosphere consists of the mesosphere (about 50-85 km), thermosphere (about 85-500 km) and exosphere (above 500 km). The exospheric density is so low that the motion of neutral particles may be considered in the first approximation to be collisionless. Above the ionosphere, when the atmospheric gas is almost fully or fully ionized, the motion of individual particles is no longer governed by gravity. The geomagnetic field and its field lines become the controlling factor of particle motion. Therefore the plasmapause, a well-defined boundary between the two upper layers, the plasmasphere and the magnetosphere, is confined to a magnetic field line, not to a height. The average height of the magnetopause, the upper boundary of the magnetosphere and the part of space governed by the Earth via its magnetic field, is 9-10 earth radii in sunward point, which is well outside Figure 1.

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Biographical Sketch

Jan Lastovicka, is currently director of the Institute of Atmospheric Physics of the Academy of Sciences of the Czech Republic and vice-president of the International Association of Geomagnetism and Aeronomy. He graduated in geophysics at Charles University in Prague in 1966. He got CSc (= PhD) in 1974 and DrSc (~ Prof.) in 1987, both from the Czechoslovak Academy of Sciences. In 1967-1994 he was with the Geophysical Institute of the Czechoslovakl Academy of Sciences, from doctoral student to head of Ionospheric department. Since 1994 he has been working in the Institute of Atmospheric Physics of the Academy of Sciences of the Czech Republic. His main research interests are: ionosphere, solar-terrestrial relations, middle atmosphere (including ozone and effects of atmospheric waves on the ionosphere), and long-term trends (potentially of greenhouse origin). He is author/co-author of more than 220 published papers in scientific journals and various proceedings, and more than 210 presentations at scientific meetings. He organized a number of international scientific meetings.