What and why of Geochemistry *

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Geochemistry: what is it and why is it important?
What is geochemistry?
It is the science of understanding and applying the chemical and isotopic principles to processes on and in the Earth and other bodies in the Solar system and to exoplanets.

It encompasses:

1. establishing the abundance of elements and nuclides to these systems (Earth and beyond), where nuclide equals the number atoms as defined by the number of protons and neutrons, of which there are about 275 nuclides in Earth, including several that are radioactive
2. establishing the distribution of elements between Earth reservoirs (e.g., core-mantle-crust-atmosphere)
3. determining the processes governing the abundance and distribution of elements and how they may change with time and intensive parameters (e.g., temperature, pressure, gas fugacity)
4. documenting the chemical fluxes between different earth reservoirs – how these reservoirs interact.

Geochemistry seeks to understand the following questions related to the Earth:

1. how and when it formed
2. how and when it differentiated into the reservoirs we see today
3. how these reservoirs evolved with time
4. climate evolution on Earth

Earth's physical and chemical domains: Atmosphere & Hydrosphere - Crust - Mantle - Core

How does geochemistry tells us about all of these reservoirs? In terms of chemical principles, we will be mainly using:

1. the abundances and distribution of the elements: why is the Earth composed of silicate rocks, a core composed of metal alloys and oceans and gases?
2. the structure of atoms and how this structure influences the behavior of elements in the cosmos and the earth (what compounds (minerals), how they formed, and how elements partition between different reservoirs and minerals).
3. a branch of physical chemistry, chemical thermodynamics, used to understand formation and destruction of minerals and/or their stability fields.
4. natural radioactive isotope systems, both extant and extinct - the atomic clocks of geochronology that adds the 4^{th} dimension of time to the 3 dimensions of geological and cosmological processes.
5. stable isotopes of light elements (e.g., H, C, N, O, and S) - tracing surface processes, and non-traditional stable isotopes (i.e., multi-isotope element systems (Li through U) that can fractionate due a range of processes), a relatively new field that has wide applications to Earth sciences and beyond.

lecture 1 for Rock and Mineral Science III or Advanced Earth Science I

6. Cosmochemistry (e.g., chemical principles to understanding the Cosmos, how elements form (nucleosynthesis), when they form, and when and how the solar system formed), yes this research tells us about the heavens, but also much about the Earth

Why is Geochemistry Important?

It is directly relevant to society.

Environmental Geochemistry
Waste disposal: municipal, industrial, nuclear
Pollution: tracking it and its mitigation

Climate change
What caused the ice ages?
Global warming.

Earth Resources: their discovery and recovery

Importance to Earth Sciences:
Absolute ages of rocks and minerals, timing of Earth events.

Can have the most elegant hypothesis in the world, but if the timing doesn't hold up, it's out.

Tests of hypotheses. i.e., snowball Earth, core-mantle interaction

History of Geochemistry

In a way, Earth sciences is inextricably linked to chemistry and visa versa, because the discovery and recovery of many of the elements related to discovery of new minerals and ore deposits. For example, what is the chemical symbol for tungsten and why do we use *W* as its symbol?

Because the word *tungsten* and the chemical symbol and the *W*-bearing minerals are derived from the Swedish word "heavy stone". The Swedish scientist Scheele discovered "tungsten" in the mineral scheelite (CaWO4). Originally*W* was separated by Spanish geochemists from wolframite (Mn,Fe)WO4, named after Wolf. They recommended the name wolframium for the element, but tungsten won out. However, the elements symbol, *W*, comes from wolframite.

Geochemistry, for the most part, did not start until the early 1900s with the work of Victor Moritz Goldschmidt (Germany) and V. I. Vernadsky (Russia). Vernadsky (1863-1945) emphasized the importance of organisms to geological and geochemical processes, which led to the *Gaia Hypothesis* of James Lovelock.
Goldschmidt (1888-1947) was a major pioneer in many areas of geochemistry. Highlights of his research include: (1) X-ray diffraction determinations of crystal structures, (2) first tables of atomic radii, (3) first described distribution of elements by linking crystal structure and atomic properties, which allows us to make predictions on how elements will behave (or partition) between minerals and melts, minerals and fluids, organisms and their environment, etc., and (4) classification of the elements (lithophile, siderophile, atmophile, chalcophile).

Examples of fundamental contributions of geochemistry to Earth Science

Age of the earth: Many people over the millennium have speculated on the age of the Earth (and Sun). The timing of the Earth's formation places constraints on its origin.

1. Perhaps an early and infamous player in this story was Archbishop Ussher (1585-1656) of Trinity College, Dublin. Using Biblical doctrine and a creative imagination, he proposed that Earth formed in 4004 B.C. on October 23 at 9 AM.

2. By the early to mid 1800's, however, geologists estimated the Earth to be on the order of 100 million years old, based on the thickness of sediments observed and assumptions about rates of sedimentation. In contrast, evolutionist thought the Earth's age was limitless in order to accommodate the presumed slow evolutionary changes observed in fossil animals and plants.
3. In 1860s Lord Kelvin argued that the Earth cannot be older than 400 Ma and may be as young as 20 Ma. His proposal was based on temperatures inside the Earth and how it changed with depth in deep caves. To establish his age, he assumed the Earth initially started as a molten body and cooled to its present state. His calculations, however, were based solely on solid state cooling and did not include any component of convective cooling, which would have greatly increased the age of the planet.
4. A secondary factor that was not considered by Lord Kelvin was that there is no means of creating heat within the Earth, heat from radioactive decay. Henrie Bequerel discovered radioactivity at the turn of the century and, through use of atomic clocks, one can determine the age of the Earth and individual rocks and minerals. In 1956, Claire Patterson showed that the age of the Earth was 4.56 billion years old, a number which still stands today. The oldest minerals ever dated on Earth are 4.4 billion years old zircons from a sandstone in Western Australia, whereas the oldest rocks are the 4 billion years old Acasta gneisses of northern Canada

SNC's meteorites are from Mars

There are a distinctive group of achondritic meteorites that can be distingusihed by their chemistry, and in some cases by their young crystallization ages (e.g., 1.26 Ga Nakhlites; 1.27 Ga, Shergottites). By the 1980, coupled with data from the mid-70's Pioneer Mars probe mission, geochemists suggested that these meteorites came from Mars. However, at the time the dynamicists strongly objected, because it was believe that ejection and transport to the Earth of these samples were not physically possible. The key observation, however, was that the analyses of atmospheric gases in SNC meteorites matched exactly that of the Martian atmosphere.

Asteroids killed the Dinosaurs

It was observed at global scales that Cretaceous-Tertiary boundary clays had high concentrations of platinum group elements, pointing to the hypothesis of an impact of a large bolide that lead to catastrophic consequences for life on Earth at the time. Subsequently, there is an abundance of observational supported for this hypothesis, including the location of impact crater in the Yucatan peninsular of Central America.

Main Points

Geochemistry is application of chemical principles to understanding the Earth and solar system.

Specifically – abundance, distribution of elements and why they are like that.

Large diversity of applications including:
climate change
Earth formation and differentiation
Search for ore deposits
environmental geochemistry – how to deal with humanity's wastes
evolution of Earth's atmosphere, biosphere and hydrosphere
as well as many applications outside the fields of Earth and Planetary Science, including medicine, forensics, archeology, biology, and more.