CHAPTER 2

The Earth

Key words: Earth, Moon, oceanic crust, continental crust, mantle, core, lithosphere, asthenosphere, rock, mineral, rock cycle, igneous rock, magma, metamorphic rock, sedimentary rock, soil, soil profile, pedogenetic processes, parent material.

Introduction

The Earth is a rocky planet, the only one in the Solar System where life is known to have developed. The Earth, whose age has been estimated at 4.6 billion years, has a natural satellite, the Moon. The solid Earth's structure consists of three concentric shells of different composition and thickness: the Crust, Mantel and the Core. The Crust is the outermost of these layers and the most dynamic part of the planet – and on which all live exists. The Crust is made up by rocks, which are formed by aggregates of one or more minerals.

Different processes give rise to a wide variety of rocks and minerals. The alteration of rocks and minerals by weathering, chemical agents or living organisms leads to the formation of soil, which is essential for the development of most terrestrial life on our planet.

2.1. The age of the Earth

Planet Earth originated, along with the other planets of our Solar System, within a nebula - a mass of gas and a dust - around 4.6 billion years ago. This date has been determined through several different lines of evidence. The oldest rocks which have been found so far on Earth have been dated using radiometric dating methods (see Chapter 4.3) to around 3.8 to 3.9 billion years ago. Some of these very early rocks are sedimentary, and incorporate minerals derived from even older rocks, which have been dated themselves as as old as 4.1 to 4.2 billion years - just as the primordial crust of the early Earth was solidifying. We also have evidence, however, of materials formed right at the beginning of the solar system, at the same time as the Earth, and these exist as lumps of rocks drifting in space which occasional fall back to Earth as meteorites (see Chapter 1). These rocks have also been dated, and they provide a date for the first formation of a rocky planet Earth, some 4,550 million years ago.

2.2. The evolution of the Earth

The Earth, unlike the other planets, underwent significant further evolution, not just as plate tectonic processes were established and its surface largely recycled over 1000s of millions of years, but also due to the development of life. During its initial accretion as a result of solid ma-

terials colliding together in the early solar system (including as meteorites), the Earth's surface was largely molten because of the effects of these impacts of (see Chapter 1) and extreme volcanism. A chemical differentiation produced the concentric shells of increasing density which now represent the crust, mantle and core and cooling allowed the crust to solidify. Gasses emitted by the volcanoes produced a primitive atmosphere with almost no oxygen. These gasses included water vapour and carbon dioxide, some of which had been brought by asteroids and comets. As the surface of the Earth cooled, water vapour condensed into clouds, which were raining off and formed the oceans. From at least 3.5 billion years ago, photosynthesis by primitive organisms – mainly cyanobacteria - produced oxygen and began to change the chemical composition of the original atmosphere – state the composition of the original atmosphere. As a result more and more sophisticated life forms could evolve.
So we can say that the Earth has three solid shells and on top of them we find the hydrospere, biosphere and atmosphere.

2.3. Internal Structure of Earth (Crust – Mantle – Core)

The structure of the Earth is made up by three concentric shells, each with a characteristic composition and physical properties. From the surface inwards they are: the Crust, with a thickness of few 10s of km at the most; the Mantle, the intermediate part, which extends to 2,890 km in depth; and the Core, with an outer fluid part and an inner solid part to 6,360 km depth (i.e. the centre of the Earth). The Crust and Mantle are made up of rocks rich in silicates (i.e. containing silicon and oxygen); the core, however, is made up of a nickel-iron alloy. These different shells are separated by discontinuities – the Mohorovičić, Gutenberg and Lehmann, respectively, which can be identified by seismic waves.

2.4. More on the internal structure of the Earth

As well as chemically, it is possible to distinguish the internal structure of the Earth through its physical properties, as demonstrated by the way seismic waves pass through the various layers. Thus, from the outside to the inner core we can distinguish: lithosphere, asthenosphere, mesosphere, plus and outer and an inner core. The lithosphere is formed by the crust and part of the upper mantle. The asthenosphere is a band of the mantle between 70 and 250 km depth, which is partly formed of molten material and is hence less rigid then the lithosphere. The mesosphere is a solid portion of the mantle located between the asthenosphere and the outer core. The latter, unlike the layers immediate above and below, is liquid, as the inner core is solid.

2.5. Continental and oceanic crust

Continental and oceanic crust are profoundly different in thickness, composition, age and origin. Oceanic crust forms the "floor" of the oceans. It has an average thickness of around 6-7 km, an age no more than 180 million years and a more uniform composition consisting of silica-poor basalts and gabbros covered by thin sediments. Continental crust underlies the continents and their continuation below sea level. It has an average thickness of 40 km, but can reach 70 km beneath mountain ranges. The composition of continental crust is more heterogeneous, with a predominance of rocks with a general silica-rich composition similar to granite. The age of continental crust occasionally approaches 4 billion years.

2.6. The Moon

The Moon is the Earth's only natural satellite and a rocky body with a spherical shape. It is one of the largest satellites in the Solar System and, unlike the Earth, is devoid of a hydrosphere and atmosphere. Its radius is about 1/4 of the Earth, the mass is 1/81 and the force of gravity on the Moon 1/6 of that on the Earth. The gravitational pull of the Moon affects the Earth, most significant by creating tidal cycles. Although the Moon may appear bright in a night sky, this is due only to the reflection of sunlight. The Moon has complex and simultaneous movements (i.e. rotation and revolution) and the Sun, Moon and Earth are periodically aligned. When the Moon is between the Earth and the Sun it is known as a solar eclipse, when the Earth is between the Sun and the Moon it is known as a Lunar eclipse.

2.7. The forming of minerals

Minerals are solid substances, typically inorganic and characterized by a defined chemical composition. In a mineral, atoms are arranged in an ordered structure or lattice known as a crystalline structure. The genesis of minerals can take place in a number of ways, typically through processes of crystallization from a liquid. This can be through the cooling and crystallization of a molten magma, precipitation from a hot aqueous solution during igneous or metamorphic processes, evaporation of aqueous solutions (including from seawater), sublimation of a gas directly into a solid and transformation in an essentially solid state from one material to another due to the effects of temperature or pressure (especially at depth). There is also the group of organic minerals that can be formed by the decomposition or restructuring of organic molecules derived from plants and animals after burial in sediments.

2.8. How to test and describe a mineral

Minerals can be studied and classified on the basis of their chemical composition, crystalline structure and related physical properties. The main properties which can be tested are: density, hardness, cleavage along planes of crystal weakness, lustre (i.e. "sheen"), colour, fracture, malleability, ductility, fluorescence and light refraction angle. According to chemical composition, minerals can be divided into eight main families or groups. Among these, the most widespread and numerous in the Earth's crust are silicates. They consist of mainly of oxygen linked to silica in combination with metals such as iron, magnesium, aluminum or potassium. Other important mineral families are carbonates, formed by carbon linked to oxygen usually in combination with calcium, but sometimes including magnesium; oxides, containing oxygen combined with metal elements; sulphides, metals combined with sulphur and sulphates, where oxygen is also combined with sulphur and linked to a metal (most commonly calcium in a rock-building sense).

2.9. How minerals make rocks

A rock is a solid aggregate of one or more minerals. According to their origins, crustal rocks are divided into three categories that are the result of three different formation processes: igneous, sedimentary and metamorphic rocks. Igneous (or magmatic) rocks derive from the solidification of magma which is produced by melting materials deep in the crust or even in the mantle. Sedimentary rocks are derived from the deposition and accumulation of inorganic and organic materials on the Earth's surface. These rocks are often stratified and may contain fossils. Metamorphic rocks are formed from pre-existing rocks, which have been subjected to high temperatures and pressures which can lead to their structure and composition being profoundly changed.

2.10. Different types of rocks

Igneous rocks are classified into "intrusive" or "extrusive" (or volcanic) rocks depending on whether the cooling and crystallization of the magma is, respectively, at depth or on the Earth surface. Sedimentary rocks can be divided into three main groups according to the origins of the material of which they are formed: clastic rocks are formed by the accumulation of fragments of other rocks; biogenic sedimentary rocks, result from the accumulation of fossil remains of organisms, such as shells or organic structures (such as woody material that can form coal); chemical sedimentary rocks are derived from precipitation of salts from supersaturated waters. Metamorphic rocks can be formed in two main ways: by "Contact" metamorphism, caused by temperature changes that affect the rock surrounding a hot magma rising through the crust and through "Regional" metamorphism, caused by increases in temperature and pressure within igneous or sedimentary rocks – or even pre-existing metamorphic rocks – buried deep in the Earth's crust, for instance as a result of continental collision during plate tectonics.

2.11. Examples of characteristic rocks

Examples of igneous rocks are granite (see 2.16), obsidian and basalt. Obsidians are extrusive rocks formed by the very rapid cooling of lavas – for instance on flowing into the sea – to form a volcanic "glass". Basalts, are the most common extrusive rocks, and form the ocean floor; they are formed by the cooling of magmas rich in minerals containing iron, magnesium and calcium. Granite, however, is an intrusive igneous rock formed from the crystallization of a rock rich in silica, its large crystals being the result of slow cooling several kilometers underground. Sedimentary rocks, include a very wide range of types, including clastic rocks which vary from fine grained mudrocks, to coarser sandstones to pebbly conglomerates. There are also "carbonates", which include limestones formed from the remains of shells and plankton, and evaporites, such as salt and gypsum, formed as salty lakes or enclosed seas evaporate. Among the most widespread metamorphic rocks are finely splitting slates, layered schists and banded gneisses, which often represent the results of, respectively, low, medium and high temperatures and pressures on muddy sedimentary rocks.

2.12. The Rock cycle

Igneous, sedimentary and metamorphic processes are not independent of each other but can be linked within a single Rock Cycle, in which the materials of the Earth's crust are continuously rearranged and recycled, a process driven by plate tectonics. A first stage creates igneous rocks through intrusive or volcanic processes. When such rocks reach the Earth's surface, weathering and other sedimentary processes cause their breakdown, followed by transport and accumulation of the resulting debris to make sedimentary rocks. As these sedimentary rocks are buried deep within the Earth's crust, the increase in temperature and pressure can cause them to recrystallize to form metamorphic rocks – and ultimately if they are buried deep enough, they can melt to form new igneous rocks. The latter can rise to the surface, become exposed, and so the whole process begins again.

2.13. Soil types and buildup

Soil forms from the outermost surface of the Earth's crust where it is exposed to the atmosphere (i.e. on land). It is the interface between the lithosphere, hydrosphere and biosphere. Soil typically consists of rock particles and organic material (such as humus) with different proportions depending on the soil type. Water content is also important. Most soils can be divided in layers known as "horizons". The most commonly identifiable horizons are a surface organic-rich horizon, a horizon of leaching below (in which muddy or sandy components are predominant) and a lower "illuviation" horizon, where very fine clay particles accumulate. Soils originate when surface rocks or other deposits are broken up by weathering, including both physical breakdown (for instance through freezing), as well by chemical processes or by living organisms. These are known as pedogenetic processes and they can be very slow, with the formation of only one cm of soil every hundred to a thousand years on average.

The main factors that influence the formation of soil are the composition of the original rock (known as the "parent material"), the climate, living organisms and the geomorphology of the surrounding area. As a result of the numerous factors involved, a very wide variety of different soils can be formed. For example in tropical regions, where the soil organisms and bacteria can be very active, organic material can be rapidly decomposed meaning that the humus layer can be very thin or absent. In contrast, in temperate regions where the microbial decomposition is reduced, the uppermost humus layer of the soil can be more developed and the soil may be more fertile. Soils can be very variable in thickness, from a few cm to several metres, depending on these factors. Soil grows from its uppermost level down into the rock, the parent material.

2.14. Soil zones and life in and on the soil

A well-developed soil with horizons differing in composition and physical properties, has a characteristic vertical "soil profile". It is an invaluable resource because it supports and provides nutrients to plants and other autotrophic organisms. Plants, in turn, as well as producing organic molecules, assimilate other essential elements from the soil making them available to animals, including ourselves. Living organisms such as bacteria, fungi, plants and animals facilitate the decomposition of organic remains, contributing to soil fertility and promoting the mixing and aeration of the soil itself.

2.15. Soil uses by humans

The history of the use of soils by humans is focused on activities related to survival, economic development and characteristics of the soil itself, and people have used the soil for many purposes. Over time, however, the pressure on this resource has intensified, often without taking into account the diversity of soils, their function and their potential - as well as their vulnerability.

The transformation from a “natural” use of the soil, such as forests and wetlands, into a “semi-natural” use such as agriculture, or even an “artificial” use, such as for construction and industry, has led to the loss of fertile soils. Further negative impacts, include land fragmentation, biodiversity loss, changes in the hydrological cycle and changes in microclimate. Little is often done to counter or mitigate this situation, in large part due to a lack of awareness within society – at all levels from decision makers downwards – about the importance of soil, and why it is necessary to safeguard its functions.

2.16. How sand, granite or marble is formed

Sand is a clastic sedimentary rock composed of individual sedimentary grains ranging from 2 mm to 1/16 mm in size. It is formed as a result of fragmentation, transportation and deposition of fragments produced as a result of chemical alteration and physical disintegration of a pre-existing rock. Granite is an intrusive igneous rock rich in quartz and is formed as a result of the slow cooling of a magma within the Earth’s crust, typically at depths between 1.5 and 50 km. Marble is a metamorphic rock composed mainly of calcium carbonate (CaCO3). It is formed by the metamorphic action of temperature and pressure on sedimentary limestone or dolomite, which causes complete recrystallization into a welded mass of calcium carbonate crystals (i.e. of the mineral calcite or rarely dolomite), destroying original sedimentary structures such as fossils and sedimentary layering in the process.

Intended learning outcomes:

- Knowing the age of the Earth.
- Understanding the main stages that led to the formation of the Earth.
- Describing the internal structure of the Earth.
- Describing the characteristics of the Moon and the minor bodies of the Solar System.
- Explaining the differences between minerals and rocks.
- Describing the processes of mineral formation.
- Being able to identify the most important features of the minerals.
- Describing the processes of rocks formation.
- Describing the rock cycle.
- Defining what soil is, how it forms and what are its characteristics.

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