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ROCKS

A Very Short Introduction

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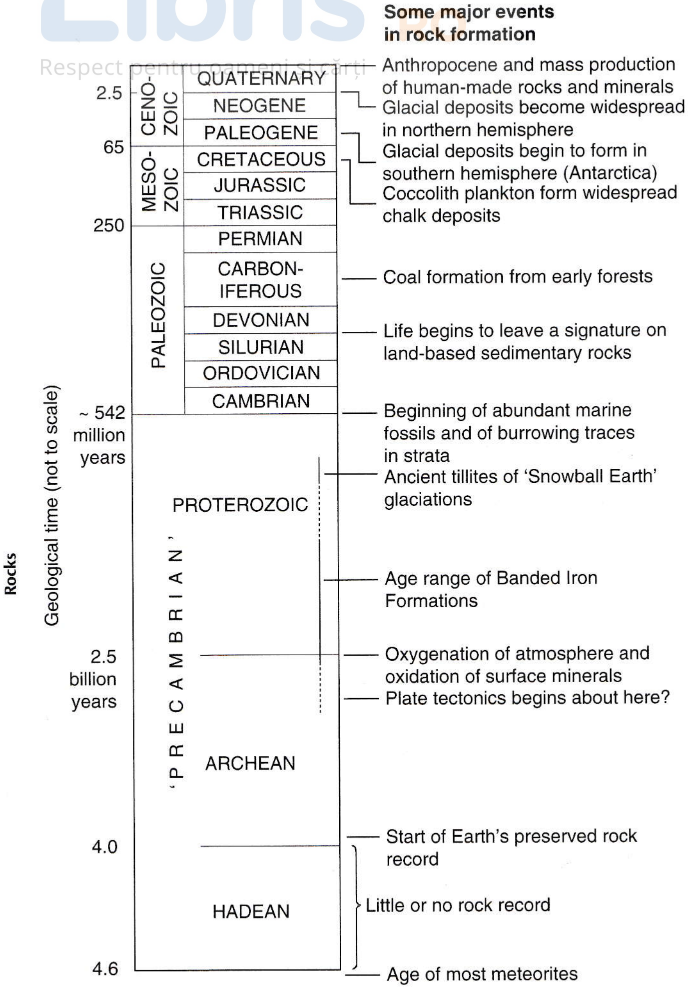
Contents



1. **GEOLOGICAL TIME SCALE.**

Prologue

Rocks, more than anything else, underpin our lives. They make up the solid structure of the Earth and of other rocky planets, and are present at the cores of gas giant planets. We live on the rocky surface of the planet, grow our food on weathered debris derived from rocks, and from rocks we obtain nearly all of the raw materials with which we build our civilization. Increasingly, we are making rocks on a planetary scale, in the form of gigantic amounts of concrete, brick, and ceramic. More widely, rocks contain our sense of planetary history: indeed, in a very literal sense they *are* the evidence from which Earth history, as encapsulated in the GEOLOGICAL TIME SCALE (Figure 1), is constructed. And, in their guise as petrified history, rocks are a guide to our future, too.

This VSI will give some flavour of the scale, structure, and diversity of rocks on Earth as well as in outer space and on other planets. It will consider how rocks act as planetary foundations—even planetary regulators. It will consider how rocks are formed, how they evolve within enormous cycles of transformation, and how we examine them and glean histories from them. There is almost an infinite variety of rocks and, properly interrogated, they can tell an almost infinite number of stories. These pages, hopefully, will represent some sort of starting point.

Chapter 1

Primordial rocks

First things first: what is a rock? It is a piece of solid matter that is made up of minerals—a mineral being a chemical compound of fixed composition, or fixed within certain limits. A rock may include a variety of minerals or it can be made up of only one. For instance, a quartzite is a rock that is essentially made up of many grains of the mineral quartz, SiO_2, while the igneous rock anorthosite can wholly consist of crystals of the mineral anorthite, $CaAl_2Si_2O_8$. But if you were given only a single grain of quartz or just one crystal of anorthite you would not really call either of these a rock—rather, they would be a grain and a crystal, respectively.

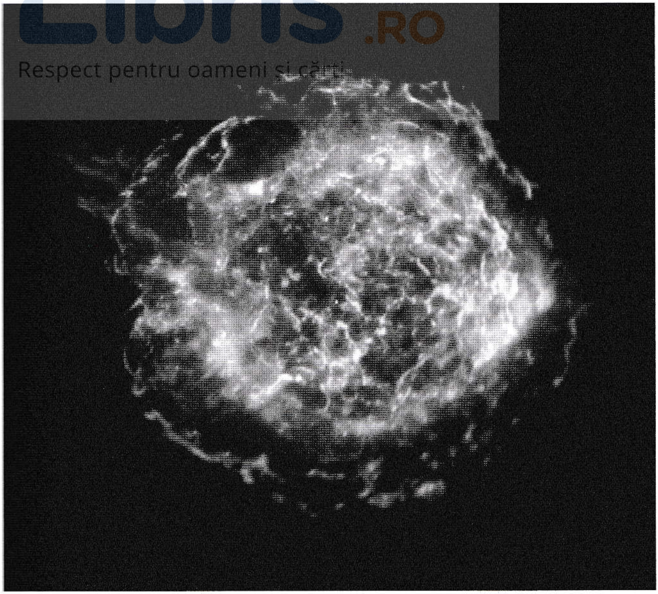
A liquid—magma, for instance—is not regarded as a rock, but it will turn into one if it cools. This is not just a matter of solidity versus liquidity, but within magma the component particles (atoms and molecules, usually in their electrically charged form as ions—i.e. each atom or molecule either has one or more electrons than it has protons in the nucleus, e.g. Cl^-; or one or more fewer electrons, e.g. Na^+) are moving more or less freely, and have no fixed position relative to each other. Now, if that magma is chilled so strongly that it freezes exceedingly quickly, or if it cools and solidifies as an exceedingly viscous, water-poor melt, these atomic particles will stay randomly dispersed, but now more or less fixed in place. This is solid glass. There are magmatic rocks of this kind—obsidian, formed in rapidly chilled lava, for instance—that are hence amorphous: lacking crystalline structure.

However, if freezing takes a little more time or if the magma is less viscous as it cools, the atoms are able to take up their positions within the molecular lattice of minerals. In these positions, within what is now a crystalline rock, they are in their preferred (lowest) energy state, and so the tendency towards mineral formation in a rock is very pronounced.

The first minerals

If we want to reach back to the earliest minerals of all, we need to take a long journey in space as well as time. For this process, one needs stars—in fact one needs *dying* stars, and so minerals are not part of the primordial matter of the Universe. Rather, minerals appeared some millions of years after the Big Bang, that mysterious and singular event in which all matter and energy (and the laws that govern them) in the Universe originated. The Big Bang, for all of its extraordinary and unrepeated temperatures (briefly, of trillions of degrees), produced only hydrogen (mostly), helium (in modest amounts), and a smattering of lithium: not a promising basis to make minerals from. These primordial elements formed outrushing, expanding, cooling gas clouds. Then, at some stage, gravity came into play.

Gravity pulled parts of these gas clouds together, until they collapsed to form the first stars, and ignited the nuclear furnaces that began transmuting those original elements into those of the rest of the periodic table. The normal processes of nuclear fusion begin this process. But, it is the dramatic finale of large, fast-burning stars—supernovae—that both explosively completes the process of elemental construction and, simultaneously, flings this newly minted matter out into space (Figure 2).



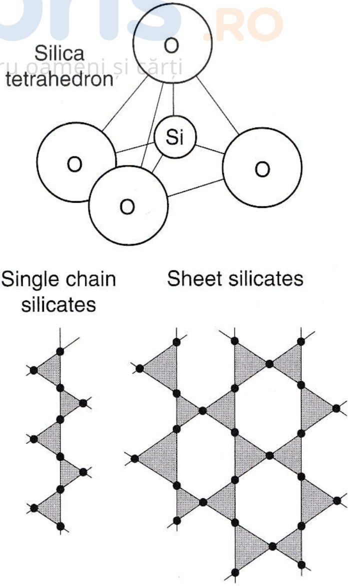
2. **Remnant of the Cassiopeia A supernova. It is in stellar explosions like this that most of the chemical elements—the building blocks of rocks—are formed.**

The new elements—silicon, oxygen, iron, magnesium, and all the others of the periodic table—initially speed out as high-temperature plasma. As they cool, they condense and then solidify—and the first minerals appear. It is rather a limited array. About a dozen minerals have been detected so far by their spectroscopic signatures, drifting in interstellar dust, or by having been found as 'presolar' grains of interstellar dust within the meteorites (see later) of our own solar system. The presolar grains can be recognized by the patterns of isotopes of their constituent elements (isotopes are forms of atoms with different numbers of neutrons in the nucleus in proportion to the number of protons, which is constant for any given element). Having been formed by different atomic pathways in different supernova explosions, the proportions of different isotopes in these grains can be wildly different to those within our solar system: to a geochemist armed with a mass spectrometer, presolar grains can be as distinctive as oranges within a basket of apples.

These first minerals comprise carbon in the form of diamond, some in tiny whisker-shaped crystals; a few carbides and nitrides; a few oxides, including corundum; and some particles of a form of olivine, which is a member of the most important mineral group (to Earthlings, at least), as a *silicate mineral*.

Silicate minerals dominate the surface of our planet. They are so named because they are based on a combination of oxygen (the next most common element in the cosmos after hydrogen and helium) and silicon. The near-universal building block of these minerals is the *silica tetrahedron*—where each silicon atom is surrounded by four oxygen atoms (Figure 3). The purest form is simply silica, or the mineral quartz, SiO_2, where, to maintain the balance of electrical charges of the ions (Si^{4+} and O^{2-}), oxygen atoms are shared between silicon atoms in the adjacent tetrahedra. In other silicate minerals, other elements can be involved: in olivines, for instance, the tetrahedra form chains, with different combinations of iron and magnesium ions in the structure.

In other silicate minerals, yet other ions can be involved, such as calcium, sodium, and potassium in the feldspar minerals, where the silica tetrahedra form a framework in which aluminium-oxygen octahedra are interspersed. In yet others, the micas, the silica tetrahedra are arranged as sheets, which helps to explain the way in which members of this mineral family split into perfect, thin, parallel flakes along mineral cleavage planes. Other common silicate minerals are pyroxenes, amphiboles, and even the tiny minerals that make up clays. Together, they are the fundamental building blocks of a rocky planet.



3. **The silica tetrahedron—the fundamental component of most crustal rocks—together with a couple of the typical arrangements it takes within minerals.**

To return to our primordial mineral formation: perhaps some of these coalesced together, in the supernova aftermath, to create the first microscopic rock fragments. We have no evidence of this, though. For real rocks, a second star generation is needed.

Birth of a star system

The process here is very much like the process that gave rise to the first stars—only here the collapsing gas clouds include that already-formed mineral dust. For the future of everything—including of life itself—this makes all the difference.

As before, most of the collapsing gas-plus-dust cloud aggregates in the central body—the star—which in this case has a more