CHAPTER 3

Earth's "inorganic" materials, do they change?

The nature of *Minerals and rocks*

Rocks, stones, soil, hard and soft ground materials are the building materials of earth, as we know them from our daily experience. Limestones, porestones, marbles and granites are only some of the earth's materials we use in the building and decoration industry. For these materials, we do possess basic knowledge and the experience that is needed in order to recognize them. Though, the materials that compose the earth's crust in its whole, display a great variability. Based on their atomic structure, the earth's building materials can initially be classified into two general categories: 1.The crystalline solids, in which the atoms are arranged in an orderly pattern extending in all three spatial dimensions and 2. The liquids where there is a lack of order. Liquids include, apart from water, some parts of the earth's interior, like the outer core and the magmas i.e., melted rock. However, earth in its entirety includes multi-crystal agglomerates of diverse compositions and different properties, the rocks, which are not as constant as we think. Neither are these quiet, dead inorganic materials. The rocks and the minerals have memory. They preserve information about the way, the temperature and the conditions under which they were created and other, which scientists try to encode with modern technology. While all these materials are of no interest for most people, geologists regard them as a rich information source. Some of them are "written" in unknown "scripts" and should therefore first be decoded in order to be "readable". They could also be compared to the palimpsests, the papyruses that were used over and over again. Some of them are formed by solidification of glowing material deep within the magma and others by compaction and coalescence of loose materials i.e., sediments that are deposited on the earth's surface, in seas, basins, lakes, land, rivers, slopes and cavities.

Among the 92 known chemical elements, only the following participate in the formation of the earth's crust: oxygen (O), in chemical crystalline bonds in a percentage of approximately 47%, silicon (Si) 28%, aluminium (Al) 8%, iron (Fe) 6%, calcium (Ca) 5%. The elements which are necessary for the good operation of our organism i.e., magnesium (Mg), sodium (N) and potassium (K) range from 1% to 3%. The rest, rare chemical elements participate in a percentage less than 1%. Many of the necessary or valuable – in economic terms- elements i.e., copper, manganese (Mg), phosphorous (P), gold (Au) are extremely rare, so that hard geological and extraction work is needed in order to detect them in concentrations that are big enough to be exploited.

The rocks of Earth's crust are make up of no more than a few dozen elements most of are classified *as rock-forming minerals* as such, of the nearly 4,000 known minerals*.* Eight elements (oxygen, silicon, aluminum, iron, calcium, sodium, potassium, and magnesium) make up the bulk of these minerals and represent over 98 percent by weight of Earth's continental crust. The most abundant element in Earth's crust is oxygen. It makes up 47% of Earth's crust by weight and 94% by volume. In fact oxygen atoms are so *much* bigger than most of the other atoms in common minerals that the crust is mainly oxygen atoms packed closely together with smaller atoms, such as silicon, aluminum, iron, magnesium and potassium tucked in between. The formation of the most common chemical elements on Earth, occurred billions of years ago inside distant stars. Through various processes of fusion, these stars converted the lightest elements, mostly hydrogen, into these heavier elements, fact, most heavy elements found in the solar system as well as the atoms in you body are believed to have formed from debris scattered by preexisting stars.

The conditions of genesis of minerals, because they "born", change and dissolve, and their chemical composition are connected to their crystallization form, hardness, colour and other physical properties. They are known also as crystals.

The word "crystal" derives from the Greek word "cryono*" (*feel cold, froze); the Greek word is of Homeric origin and is preserved with the same phonological pronunciation and meaning until today. Crystal was initially meaning frost, because this is only what people of that time knew as a crystalline body. The same word was also used to describe a body that was pure. The name “crystal” was given for the first time to the pure, transparent alpine quartz of the 17^{th} century, because it was assumed that this was formed by intense and constant refrigeration of water. Crystals are chemical molecules of giant dimensions that have atoms of various elements symmetrical placed on their lattice. Most of the earth’s crust minerals have as basic element of their lattice the chemical element silicon (Si), alike the organic bonds, which are based on carbon (C). There are many similarities between silicon and carbon –of course there are differences between them as well-; the most important is that both elements have four affinity units that is, four “hands” to create complex and variable macromolecules. The mineral salt we use in cooking, the iron pyrite, and the gypsum (plaster) are only a few known, though non silicate crystalline minerals. Snowflakes are also crystals of a big variety.

The first type of rocks refers to rocks formed of magma within the earth’s crust and at high temperatures and is called *igneous* rocks (etymology from Latin *ignis*, fire) i.e., “rock of fire”. The second type refers to rocks that gradually differentiate and are formed by slow and gradual crystallization deep within the earth and is called *plutonic* rocks (etymology from the Greek “Pluton”, the name of the ancient Greek god of the underworld). We are all familiar with the granites, the most important igneous-plutonic rocks. These “rocks of fire”, which solidify quickly on the surface, were named in honour of another tireless craftsman among the ancient Greek gods, namely the Hephaestus (Volcanus in latin). These rocks are called volcanic.

Magma is the glowing molten material that comes deep from the earth, from the mantle or the lower crust. This is assumingly in fully or partly liquid state; it consists of mainly silicon bonds and gases and its temperatures range from 600^0C to 1300^oC. When the magma discharges on the earth’s surface, the gases escape in the atmosphere. The remaining molten material is called *lava*; this is what we see in pictures and in the cinema flowing as a river before it freezes into rock. The magmatic material of our planet’s innermost part constitutes the first and primary source of minerals and rocks -including the ones that were created many years ago and are under our feet as well as the ones that are being created even today in a depth of 3.5 or 15 km- which are created through the gradual crystallization process. Yet, in some regions, the process of stone formation goes on more intensive and without cease, while in other regions, it has ceased millions of years now. Slowly though steadily, new minerals and rocks are formed on the earth's surface after every volcanic eruption. Thus, we should not use only the past tense when referring to rocks; that means we should not consider that rocks have been created some time in the past and remain in a stable condition, unchanged till today, however deep and established this view may be. Present and future tense are adequate to use in order to describe the continuous creation, the alteration and evolution of rocks.

Then there is a second big rock type which includes rocks that are created literary within the water or by the action of water, of the atmosphere and the gravity: the *sedimentary* rocks. This prosy name derives from the name of their raw materials, namely the sediments, which are in fact mud with chemical properties in various concentrations or pieces of other rocks and micro-organisms.

Finally, the third major rock type is *schist*. Schists are formed by the transformation of the existing igneous or sedimentary rocks at pressure and temperature conditions other than those existing when the original rock was formed. These are rocks which were transformed when the physic-chemical conditions changed, remaining though in a quite solid state. They "suffered hell on earth" under extreme conditions. They are called also *metamorphic* rocks (etymology from Greek metamorphosis) expressing thus in best way the gradual change they have undergone or schists from their texture. Metamorphism is the transformation of one rock type into another. Metamorphic rocks form from preexisting rocks, either igneous, sedimentary, or other metamorphic rocks, that have been altered by the agents of metamorphism, which include heat, pressure, and chemically active fluids. During metamorphism the material essentially remains solid. The changes that occur in metamorphosed rocks are textural as well as mineralogical. Even if all rocks undergo several transformations, it is for the metamorphic rocks that include for the first time the concept of change and evolution of the inorganic matter, and that sounds interesting for the changes of a believed stable word.

Each of these big, main rock types is subdivided into other smaller categories, in order for us to be able to classify, study and learn the rocks. In fact, rocks constitute a continuation. Their big variety results from the mixture of a quite small number of minerals in various proportions. Minerals are the basic components of the earth's materials. Minerals are homogenous, crystalline solids that have a definite molecular structure and composition, while rocks are big material units that constitute the solid, cohesive entity of a minerals' mixture and it is them that compose the earth's crust.

All these materials, minerals and rocks, are called inorganic so as to be distinguished from the organic bonds and textures. However, this classification is not always clear. For instance, the extended layers of calcium carbonate sediments which are met deep in the seas and undergo a stonification process are composed by equivalent materials of the sea, mainly microorganisms i.e., living objects. This skeletal carbonate material of living organisms is of biological origin (!) and is converted into inorganic rock, the familiar limestones, through the sedimentation process. The phytoliths are also of organic origin. These are formed within the plant tissues alike the human kidney calculus. Another magnificent organic crystal is the lens of the human eye.

Are all rocks solid?

The earth's crust's materials are defined as the solid state of matter under certain physiochemical conditions i.e., at certain temperature and pressure. According to the conventional definition, rocks have a constant shape and volume. Conventionally again, solids are divided into crystalline and amorphous materials (solid liquid in fact). The atoms of a crystal are held together by strong chemical bonds and are arranged in a particular way. Atoms form simple or complex geometric shapes i.e., structures which display order and harmony in nature. The first scientists who studied the crystalline solids noticed that order and absolute symmetry are present in the inorganic world's materials. Their philosophical views were based on this order and perfectionism and were extended either to the whole universe or even to sociological explanations. Under certain physicochemical conditions, in certain regions of the earth's crust and at certain time, materials are rather constant and have a definite shape. Nevertheless, even under conditions that are considered to be constant, the atoms of the crystals are slightly vibrating i.e., they tremble around their normal position, but they do not move freely in the space. Some of their chemical constituent elements escape sometimes from their crystalline lattice; still, this is an exception, not the rule. The case is not the same with their electrons, which move more often. Even when the atoms of these elements have no electrons running ceaselessly towards all directions in certain parts of the earth's interior, we do consider them as solid state of matter.

The perfect crystalline bodies – as classified and studied with static methods by crystallography- are not that perfect. There are defects in their apparent perfectionism. Almost all crystals have some little structural defects to a certain degree. These defects can refer to atoms (ions) which have escaped the "surveillance" of the lattice's cohesion forces and have been broken off creating thus a vacancy or to foreign atoms that occupy a site in the crystal lattice at which there is usually not an atom. In the before mentioned cases, we are talking about the first defects of crystals, the point defects. Apart from these small atom or point defects, bigger defects are present in crystalline solids: line, planar or 3-dimensional defects, the precipitates[1] i.e, when parts of the crystal slip. Furthermore, the crystalline solids grow bigger or become smaller in size where vital space and appropriate conditions are available. The growth of crystals takes place mainly during their creation process within deep cavities of the earth's interior or during the solidification process of volcanic rocks on the earth's surface i.e., in the caves' stalactites and stalagmites, in the deposition of sediments and the sedimentation or transformation process. According to this process, the size of crystals grows with the use of materials that are in contact with them.

The growing process of crystals disturbs the balance between the crystalline and the gas material, liquid or amorphous solid material which is in contact with them. We are talking about growth and development even when we refer to inorganic materials! Characteristic examples are: the caves' geoforms, the stalactites, the eccentrics, the discs, the "corals" and the pearls and generally the calcareous "flowers", which start from a drop of water and as they grow bigger, they become beautiful like flowers and clusters of bushes. The crystals together with the cave in which they have grown close their circle with the ageing stage; they fade; they get destroyed; they are recycled together with other inorganic materials.

So, solids are not that solid; they grow and develop, and it is only for some short periods that they remain constant. Moreover, they get smaller and destroyed, that is they are recycled like everything does on this planet. A first-hand perception of the changeability of crystals and their fast conversion from the amorphous state into the crystalline one and vice versa is gained by the existence of snow. The snowflakes are also crystals. In particular, they represent big monocrystals when their cooling procedure is slow whereas they form agglomerates of smaller crystals when the cooling procedure is fast. The crystallization procedures of the amorphous water and the multicrystalization of flakes are conducted at quite slight changes of the atmospheric temperature and take place "in front of our eyes" in a few minutes, hours, months in case of the common snowfalls, or within some years in case of the alpine and polar "ageless" ices. The solid water crystals unfold such a big variety, depending on the type of water and the way of crystallization, that some scientists believe today that each crystal is unique. The fast water crystallization procedure, which is immediately being perceived by our senses, takes place also in the earth's crust, in it's innermost layers, ceaseless and continuously. The only difference is that it evolves in larger periods. Everything changes fast or slow. The crystals of the minerals are actually not constant. The rocks, the earth's inorganic materials are considered to be the most constant and inert materials of our world; still, at an early stage, even from the 6^{th} century, Heraclitus, the theoretical philosopher of nature points out that even in the most inert matter, there is an invisible fluidity and motion. The materials that form the earth are not that stable and solid as we think; they are indeed in a continuous motion and change ceaseless.

Reology is a branch of physics which studies the deformation and the flow of materials in time. The term “reology” derives from the greek word ‘reo”, “roi” (flow) and is used in the international scientific terminology. In Reology, a material is considered as liquid when it flows under the influence of a constant force, or better to say stress, regardless of its atomic structure. Earth shows great variety in reologic behaviour because the various materials react differently to each force which is applied to them but also because this behaviour depends on other factors as well, such as pressure, temperature, intensity of the applied forces, duration of the earth’s materials’ charge and time.

There are three borderline types of rocks’ deformation as far as their reological behaviour is concerned: 1. elastic deformation, when materials fracture 2. plastic (ductile) deformation, when materials simply deform and 3. viscous deformation that is, the behaviour of fluids we are familiar with (liquids and gases). Still, there are other medium-grade types of deformation, which are indeed the most common in nature: the elastic-plastic, the elastic-viscous and the plastic-viscous deformation. In fact, there is a continuation among the deformation types, as is the case with all things and phenomena in nature, but we keep separating them for classification, understanding and studying reasons.

The elastic behaviour is present in rocks, which retrieve their initial shape when ceasing the stress; that means, the deformation caused by the force applied to them is temporary. This phenomenon is repeated ceaseless within the planet; still, it is not countable and thus we tend to ignore it. The rocks break producing thus faults and crevices in the earth’s crust, only when the forces which press them exceed a certain limit.

In case of plastic behaviour, rocks deform because they do not retrieve their initial shape when ceasing the stress. The bigger the force is and the longer the force is applied to the rocks, the bigger the deformation they undergo. Most times, rocks become unrecognizable and look “harassed” due to this process. The plastic deformation follows the elastic one. It occurs in rocks existing in big depths of the earth’s crust, where there are usually high rates of temperature and pressure. In the contrary, in the upper layers of the earth’s crust, rocks undergo elastic deformation and fracture like the glass under surface conditions does, when the unit of the applied force exceeds their endurance limit. A solid object with elastic behaviour is characterized by linear relations between stress and strain, which is called *Newton’s behaviour*. But, as already mentioned, due to the fact that one can not distinguish between elastic and plastic deformation, many rocks and crystalline solids undergo plastic deformation even at small depths within the crust, at low temperatures, for deformations less than 1%, as comes out from short-term laboratory experiments. This phenomenon is of great importance as far as the operations of the earth’s crust are concerned. The rocks are squeezed, stretched, fractured; they bend their shape changes, fall back and generally “flow”. So, earth’s materials are not as solid and constant as we were taught.

A macroscopic observation of rocks as well as an observation of rocks under a polarized light microscope shows today an impressive variety of colours, which cover the whole visible spectrum and all shading off tints that are discernible by human eye. A colleague, geologist named them in an article of a tourist geological guide of northern Greece "Rocks of the Rainbow". This expression which may be poetic represents fully the real picture of the wide variety of colours and forms and at the same time introduces a different way of looking at our planet’s "insensate-inorganic" materials.

Beyond the world of crystals and rocks, another amazing and particularly kinetic world of matter and antimatter opens up in the atomic and subatomic microcosm studies modern physics: protons, neutrons, mesons, quarks and leptons with powerful interactions. This world is matter, energy and motion. “Everything flows” that is, everything is in motion and changes.

The Life Cycle of Rocks during time, the mega-cycle of their changes

The world of the rocks and the geological strata seems to be stable. Yet, this stability is an illusion which has its roots in the human experience of the surrounding word and especially time. The deepness of the geological time will be described in the next chapter. On such scales, neither the rock nor the Earth's crust can be considered as a stable unit. On the contrary, the structure of the rocks is particularly changeable and varying. The rocks vacillate from one form to another ceaselessly; they are formed, destroyed and regenerated under the following rule: "whatever is old is made new again". That is the rejuvenation of rocks, another kind of their mobility.

The rocks that are exposed to the conditions of the Earth's surface, where there is a ceaseless flow of underground or surface water either in the form of rain or snow, and where they are subject to a steadily moving atmosphere of various climate scenarios and physicochemical processes, are slowly but steadily subject to decay or better to say alteration. They are disintegrated through weathering and they break into pieces. Finally, under the effect of gravity, the fragments are transferred near or far, by the water, the air and the animals, by a process called erosion. They break into the minerals, the chemical bonds and the elements they consist of and start a new cycle. These various weathering and erosion fragments are gathered in large quantities and settle in the most tranquil environments. They settle in the tranquil hooks of the rivers, in the plains after a flood and on the bottom of the lakes and the seas, where they form strata and receive, among others, the skeletal material of many organisms. Even with a little pressure caused by the superjacent strata and with some heat coming from the earth's interior, they go through the petrification process until they become hard and tough, just like the bedrock. These "external" processes, as they are wrongly called in geology, aim at smoothing the relief of the Earth's surface until it becomes flat. They are called "external", because they refer to forces and processes outside the solid Earth. Nevertheless, they are too terrestrial! If it was only for these forces that acted on the rocks, the surface of the Earth would have become flat long time ago. The Earth would have become a vast plain, which would have been probably covered by its abundant water. This is though not the case, because there are “internal” forces acting at the same time with the “external” ones. The “internal” forces come from the earth’s interior and they either form ceaselessly new rocks or they metamorphize the existing ones, as already mentioned above. They also put the Earth’s crust in motion; they elevate the lands, produce earthquakes and act in the underground for the formation of the mountains: unity, contrast and fight between opposite terrestrial forces which are in constant antagonism.

But the cycle does not stop at this point. When rocks of any type are in the earth’s depths or in intensive tectonic crush and pressure zones, they are exposed to totally different conditions than the ones that gave birth to them. Slowly and steadily, they begin to alter again, they undergo partial or total recrystallization and they are finally metamorphised. The term “metamorphose” (meaning transformation), which was aptly proposed by Aristotles, maintains today the same meaning in English as in Greek and constitutes a universal terminology in the field of geology to name the above mentioned kind of rock. This is probably the most apt term on an international scale, to describe this significant alteration of the inorganic materials of the Earth’s crust. Metamorphose, in petrogeny, means that the structure and the chemical composition of the rocks’ minerals change, one after another, under the new conditions of pressure and temperature. In particular, chemical elements are moved from one rock to another, so new, different minerals form. Moreover, many of these minerals bear the imprints of the high pressure they were put under and appear thus as very thin sheets with intensive schistosity (Greek world). Their second name, crystalline schists or simply schists, derives exactly from this structure. Only a few minerals of this category can change, while the rest remain as they were in the bedrock. In this case, we are talking about a partial metamorphose. Still, they can also undergo a total metamorphose. Further, the physicochemical processes that metamorphize the rocks can be so strong, that they totally disrupt them, they destroy their crystalline structure. That is, they convert them into molten material. This material, which is new magma now, can “rest” on its liquid state only “for a while”, because sooner or later, it will enter the cycle of recreation and will contribute to the formation of igneous rock. In this way, a constant transformation of the rocks takes place; there is a dynamic of a ceaseless procedure, which runs a megacycle on the long geological time scale. So, the rocks do also move and change under our feet, at paces, which of course can not be conceived in our short life span. During our brief life, we may notice, at the very most, an alluvium after a flood, how a coast changes year by year, some wear on the marmoreal monuments, some rocks falling from the mountains, how pebbles, boulder and sand are carried by mountain streams and rivers, and of course, the creation of new volcanic rocks after the lava which comes from new volcanoes cools down.

The solid rocks of the Earth's crust are not that firm and unvarying as way may think. Apart from the daily vibrations of the crystal atoms, the loss of fragments from the crystal lattice, the movements of the electrons, the small dislocations and generally the physicochemical processes they undergo, they perform also mega-mobility over geological time. The rocks that have been formed by the gradual cooling of the magma, the igneous rocks, seem to dominate the solid crust, as they constitute almost 95% of its mass. That is, the igneous rocks constitute the basic elements of the Earth's crust. Their visible part covers only 17% of the Earth's total surface, as most of them are covered by other kinds of rocks, mainly by sedimentary rocks. The sedimentary rocks, even if they constitute a small part of the Earth's crust's total mass, extend to 76% of its surface and have an average thickness of only 800 meter. Actually, in some places, there may be depositions of sediments with a thickness of only a few centimetres to a few meters or sedimentary rocks with a maximum thickness of 10 kilometres, like in the Thermaikos Gulf in Thessaloniki, Greece, or in the Baikal Lake of Siberia as well as in many other regions with oil deposits. Nevertheless, they are of utmost importance, because they are produced by the surface processes with the contribution of the atmosphere, the water and life, as already outlined. The sedimentary rocks, life and its processes are inextricable. These rocks constitute actually the immediate record archives of the organisms' remnants, their variability, and the fluctuations of the climate and generally the historic evolution of the bioplanet.

This geological minerals and rocks transformation cycle, which was known already from the times of R. Hooke (17th century), is continuous, daily and very slow. It shows the mobility and the continuous transmutation of the

Earth’s crust’s matter. It is a ceaseless and dynamic process, which constitutes a very significant part of our planet’s continuous evolution processes and liveliness. Still, it is not independent from the other alteration cycles, like that of the earth’s crust and above all, the water cycle.

Vernadskian or alive rocks

All known chemical elements are distributed either in the Earth's crust, hydrosphere, atmosphere or in various tissues of animals and plants, that we call biosphere. Vladimir I. Vernadsky (1863-1945), a Russian mineralogist - geochemist, maintains that the biosphere is a very thin stratum on Earth’s surface, water and lower Atmosphere, a separate “geological envelope,” consisting of living matter. This matter, which we call organisms is Earth’s matter in fact, that is the extension of rocks and minerals, the force of which exerts changes in its physical, chemical, and mechanical properties. Minerals, rocks and organisms are the products of this planet, changeable in different time scale and physicochemical conditions. Life could be considered as “rocks” and “minerals” of a given composition different from that of “inorganic” material, that is “alive rocks”. Their difference is mainly in the composition and quick changes. Moreover, the organisms are permeated by cosmic energy, sun heat mainly, which works even greater changes. Thus the biosphere, the stage on which changes are played out, will evolve over time.

The element of Life, that is Carbon is in fact an “inorganic” element, , which is crystal in Limestone deposits, marbles, chemical composition in petroleum, dissolve in sea waters. Life, either in oceans or on land mainly, is based on plants mainly and on organism that can build their own organic material from inorganic, by a process called photosynthesis. This is the fixation of carbon, the basis of life on this planet. Minerals and rocks are created by Earth’s “internal” process mainly, plutonism, volcanism and metamorphosis, as well as by “external” sedimantation in waters with the contribution of atmosphere and the sunlight energy. Elements of Life is part of this cycle and all kind of organisms are “moving rocks”.