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Mineral and/or living[1]

Minéral et/ou vivant

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ABSTRACT. The relationship between the mineral and the living has always been a subject of debate, but nowadays it is of growing interest, probably due to scientific advances that have blurred the classical distinction between living and non-living. The first part of this article explores various passages from mineral to living: in ancient stories (Genesis and Greco-Roman mythology) and contemporary role-playing games on the one hand, and in the emergence of life on the other, as understood by science over the centuries. The second part focuses on the reverse passages, from the living to the mineral: several possible mineralizations of organisms, *in vivo* (biomineralizations) and *post-mortem* (fossilizations, petrifications), with their artistic and literary revivals, are thus addressed. The third part evokes the proximities between the mineral and the living: natural proximities (in particular those involving epiliths such as lichens) or due to humans (from prehistoric cave paintings to Arte povera). We will finally see how certain writers and artists reach a true intimacy with the mineral world in which they project themselves and find themselves.
KEYWORDS. Clay, biomineral, origins of life, evolution, fossilization, myths, petrification, stone, science-fiction, sedimentation, stromatolith, symbiosis.

1. Introduction

All over the world, the cosmogonic stories that have been passed down to us bear witness to a universal human questioning of the nature of life and its origins. This same questioning has given rise to scientific theories, philosophical speculations, and various artistic and entertaining creations. Among all the questions related to this issue, those concerning the relationship between minerals and living beings, while they have never ceased to fuel intellectual debate, are now experiencing a new wave of interest. Numerous scientific advances in biology, chemistry and mineralogy over the past few decades, have blurred the traditional boundaries between living and non-living things (as well as between animals and plants, or even animals and humans). Without prejudging the future of these controversies, we will outline the evolution of ideas on all the links (real, supposed, or imagined) between minerals and living organisms. We will discuss the current state of research and knowledge on the role of the mineral world in the emergence of life, the mineralization of organisms *in vivo* (biomineralization) and *post-mortem* (fossilization), as well as their associations, whether natural (from coexistence to symbiosis) or inspired by artists and writers. Finally, we will indicate the conditions for true intimacy between humans and minerals.

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2. Passages and transformations

2.1. *From minerals to living beings*

> *Tout ce que nous appelons histoire est dans une large mesure dépendant de la pierre. Cela vaut de l'histoire de la Terre, de l'histoire naturelle et de l'histoire mondiale, au sens le plus vaste du terme*[2]. Ernst Jünger

2.1.1. *From myths to role-playing games*

Humans have always known that they were not the only living beings on Earth: in the myths, legends, and tales of great civilizations and popular cultures alike, everything in nature is presented as living, or at least potentially living, including stones.

In the first chapter of Genesis, the divine creator causes the earth to produce plants and animals, and he creates man "in his own image"; in the second chapter, it is specified how and from what: God does not charge the earth with producing man as it did for other living beings; it is he himself who shapes man from the earth (*adama* in Hebrew, hence Adam), then breathes life into him[3]. In the Mesopotamian epic of Atrahasis, the goddess Nintu also creates humanity from clay, and in Egyptian mythology, it is the god Khnum who, like a potter, shapes humans on his wheel with clay. This theme of clay, molded to give it human form and life, would later be taken up in Jewish mysticism and mythology with the myth of the Golem (from the Hebrew *golem*: embryo, formless, unfinished), a humanoid being made of clay, deprived of speech and free will, created to serve its creator[4]. A popular version has him born from clay after four sages, who embody the four elements, imparted their attributes to him; on his forehead is inscribed the word *emet* (truth), which becomes, when its first letter is erased, *met* (dead): the living clay has turned back into dust.

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[2] Ernst Jünger : "Everything we call history is largely dependent on stone. This applies to the history of the Earth, natural history, and world history, in the broadest sense of the term." *Graffiti/Frontalières*, « Pierres », Christian Bourgois, 1977.

[3] Genesis 1:11: God said, "Let the earth bring forth vegetation."; 1:20: God said, "Let the waters teem with a multitude of living creatures, and let birds fly above the earth across the expanse of the heavens."; 1:24: God said, "Let the earth bring forth living creatures according to their kinds: cattle, creeping things, and wild animals of every kind."; 2:7: "The Lord God formed man from the dust of the ground, breathed into his nostrils the breath of life, and man became a living being."

[4] Myth of the Golem: The first occurrence of the term golem appears in Psalm 139:16: "Galmi (i.e., my golem) Your eyes have seen" — the psalmist thus praises God who knows him even before his flesh has taken human form. Commenting on this verse, Rabbi Yonathan interprets the golem as an embryo that is still unformed; in the Mishnah, a golem is an individual whose gifts remain in a raw state. Based on the same verse, the Talmud teaches that when God created Adam, he first made him a golem, raising him from the earth to the firmament before breathing life into him. The legend of the golem became very popular in Central European Jewish folklore and has inspired many authors of fantasy works (films, series, cartoons, video games), some more faithful to the original versions than others.

Figure 1. *Auguste Rodin, Pygmalion and Galatea, 1889; plaster, marble cast; H.: 76 cm; W.: 82.4 cm; D.: 73 cm; W.: 23 kg (Work), Musée Rodin. Public Domain*

In Greek mythology, several stories tell of stone becoming flesh. The legend of Pygmalion, recounted by Ovid in *Metamorphoses*[5], features the sculptor Pygmalion, who falls madly in love with the ivory woman he has created: "He doubts whether it is a living body or the work of his chisel. He touches her and still doubts. He kisses the statue lovingly and believes that his kisses are returned. He talks to her, listens to her, touches her lightly, believes he feels flesh yielding under his fingers, and trembles, afraid of hurting her delicate limbs." (247); he then prays to the gods to grant him a wife similar to his statue, and Aphrodite grants his wish; he then marries his sculpture and calls her Galatea because she is as white as milk (*gala*, *galactos*: Greek for "milk"): "It is no longer an illusion: it is a body that breathes, and whose veins swell softly under his fingers." (280); "His kisses are felt. The animated statue blushes, opens her eyes, and sees both the sky and her lover." (290).

Over the centuries, the story of Pygmalion and Galatea has enjoyed remarkable artistic posterity: painting and sculpture, notably Rodin (fig.1), music, literature, cinema and video, and comic books have all taken it up in various ways, not to mention pedagogy with its "Pygmalion effect"[6]. Also in Greek mythology, as recounted by Ovid, Deucalion and his wife Pyrrha are the only survivors of the flood caused by Zeus. Taking refuge on Mount Parnassus, they receive orders from the oracle of Themis to throw the bones of their Great Mother behind them, in order to repopulate the earth. After some hesitation, "they walk, throwing stones behind them. These stones, losing their original roughness and

[5] Ovid, *Metamorphoses* - Pygmalion X, 243-297.

[6] Pygmalion effect: an effect that causes an improvement in a subject's performance, depending on the degree of belief in their success coming from an authority figure or their environment. The opposite effect, called the Golem effect, results in lower performance and less ambitious goals when an authority figure judges a subject's potential to be limited.

hardness, gradually soften and take on a new form. [...] The moist and earthy elements of these stones became flesh; the strongest and hardest ones turned into bones; what was vein retained its form and name. Thus, in a short space of time, the power of the gods changed the stones thrown by Deucalion into men and gave life back to the lost women through the hand of a woman."[7]

From the Renaissance onwards, Deucalion and Pyrrha provided the subject matter for several mythological paintings. Among the best known are those by two Italian Baroque painters: Giovanni Maria Bottalla around 1635 (fig. 2) and Giovanni Benedetto Castiglione in 1655.

Figure 2. *Giovanni Maria Botalla, Deucalion and Pyrrha, circa 1635. National Museum of Fine Arts of Brazil. Public Domain*

In our time, several role-playing games feature this transition from stone to flesh: in Pathfinder[8], for example, there is a spell that performs this transformation. If the affected material was once alive, its life is restored, and it returns to its previous state. Ordinary stone will also be changed into flesh. However, this flesh is inert unless a life force or magical energy is available (for example, a stone golem would be transformed into a flesh golem, but a normal statue would become a corpse). For this spell, the material components are a pinch of earth and a drop of blood.

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[7] Ovid, *Metamorphoses*, Book 1. Translation by multiple authors. Text established by D. Nisard, Firmin-Didot, 1850 (p. 251–268).

[8] Pathfinder: tabletop role-playing game published in French by Black Book Editions, under an open gaming license (OGL). It is a translation of Pathfinder Roleplaying Game (Pathfinder RPG), published in English by Paizo Publishing. This role-playing game is based on the rules of Dungeons & Dragons 3.5 edition, which it enriches and improves upon.

In all the legends we have just mentioned, the transition from mineral to living being occurs through collaboration between humans and superhumans. Indeed, in mythical logic (biblical or Greco-Roman antiquity, contemporary fantasy reinterpretations), the decisive transformation of mineral matter into living flesh can only be accomplished with the help of a superpower: divine for the Ancients, magical in role-playing games. (The reverse transformation, from flesh to stone, will be discussed in section *2.2.5, Petrification*).

2.1.2. *State of knowledge*

The first classification of the natural world according to the degree of complexity of beings ("scale of nature") is attributed to Aristotle[9]: "Thus nature passes gradually from inanimate beings to living beings, so that this continuity prevents us from perceiving the boundary that separates them [...]."[10] For him, "[...] life as I understand it consists of nourishing oneself, growing, and decaying,"[11] which implies a dynamic orientation — vitalist before the term existed — that is absent from the "inanimate" world that is nevertheless its origin. This so-called inanimate world would be largely neglected in subsequent scientific debates on the complexity of living beings. In the 18th century, however, two great naturalists were exceptions in this regard: Linnaeus[12] , with his division of nature into three kingdoms (mineral, plant, and animal[13], but he would later discard the mineral kingdom to focus solely on living beings), and Buffon[14] , who declared that "one can descend through almost imperceptible degrees from the most perfect creature to the most formless matter, from the best-organized animal to the crudest mineral."[15]

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[9] Aristotle (384-322 BC): Ancient Greek philosopher and one of the most influential thinkers in the Western world. Certain elements of his classification of living beings were used until the 19th century. He divided science into three main areas: theoretical science, practical science, and applied science (*poietic*); Nature (*Physis*) occupies an important place in his philosophy. According to Aristotle, natural materials possess a principle of movement within themselves, and all living beings have a "soul," but one that has various functions: solely vegetative for plants, vegetative and sensitive for animals, and also intellectual for humans. In general, Aristotle sees living beings as organized wholes from which no part can be detached without difficulty, rather than formless entities such as stones.

[10] Aristotle, *History of Animals*, VIII, 1, 588 b4-b23.

[11] Aristotle, *Treatise on the Soul*, II, 1.

[12] Carl von Linné (1707-1778): Swedish naturalist who laid the foundations for the modern system of binomial nomenclature. He systematically catalogued, named, and classified most of the living species known at the time. However, as the concept of evolution did not yet exist, Linné's classification remains fixist.

[13] Carl von Linné: "Stones are aggregate bodies, without life or feeling. Plants are organized bodies, with life, but without feeling. Animals are organized bodies, with life and feeling, and which move spontaneously." *Systema Naturæ*, 1st ed. 1735; *Système de la nature*, Hachette BnF, 2016, p. 4. (A General System of Nature).

[14] Georges Louis-Leclerc de Buffon (1707-1788): French naturalist, mathematician, biologist, cosmologist, philosopher, and writer. A member of the French Academy of Sciences and the French Academy, he was part of the Enlightenment movement. He can be considered the first naturalist to protest against the supposed immutability or fixity of species. His theories influenced two generations of naturalists, notably Lamarck and Darwin.

[15] Buffon, *De la manière d'étudier l'Histoire naturelle* (On the Method of Studying Natural History), vol. I, p. 6.

In the last decades of the 18th century, Lamarck[16] replaced Linnaeus' three kingdoms with a division into two orders: “organized, living bodies” (organic matter[17]) and “raw, lifeless bodies” (inorganic matter[18]). He considered that an “immense gap” separated them, whereas in the living world itself, life forms succeeded one another and transformed continuously or gradually, which he interpreted in terms of the evolution of species. Fifty years later, Darwin[19], in his famous work *On the Origin of Species*, also proposed a continuous evolution of living species[20], but he also ignored the transition from mineral to living matter.

Even in the 20th century, evolutionary theorists[21] were only interested in living organisms themselves. The role of minerals in evolution was really taken into account only by researchers who were concerned with the origins of life.

But first we need to agree on what exactly a mineral is (from the Latin *minera*, meaning “mine” or “mining”), a question to which non-specialists will respond, like Saint Augustine on the subject of time, that they know... as long as they are not asked! In fact, this question can be answered in several ways today, depending on the field in question (geology, chemistry, anthropology, etc.) and the degree of precision required.

As a first approximation, we could say that a mineral is essentially a crystalline chemical substance formed by a geological process[22], and that this term refers to all the inorganic bodies that make up the Earth's crust. However, there are a few exceptions to this definition: for example, mercury, which is liquid at room temperature (it only crystallizes below -39°C), is still considered a mineral, and some non-crystallized and amorphous solids, such as opal and amber (derived from fossilized sap), are also classified as minerals. Another definitional ambiguity: minerals are inorganic chemicals and therefore lack the carbon present in the organic chemistry that characterizes life. However, certain minerals (oxalates, (bi)carbonates, carbonic acid, ferrocyanides) are considered inorganic even though they contain carbon.

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[16] Jean-Baptiste Pierre Antoine de Monet, Chevalier de La Marck, known as Jean-Baptiste de Lamarck: French naturalist (1744-1829) who first devoted himself to botany, then to the zoology of insects and worms. He was one of the first to name biology as the science that studies living beings. He also proposed the first solidly supported theory on the evolution of living beings (published in 1809 in his book *Zoological Philosophy*). His transformist theory is based on two principles: the increasing complexity of the organization of living beings under the effect of internal dynamics; and their diversification into species following the adaptation of their behavior or organs to their environment.

[17] Lamarck's conception of organic matter as necessarily linked to life was discredited by the advent of synthetic chemistry: in 1828, Wöhler's synthesis of urea showed that non-living organic matter exists, and by the mid-19th century, new carbon-based molecules were being synthesized that existed neither in living beings nor in so-called inert matter.

[18] Lamarck, *Opening speech delivered on 21 Floréal, Year VIII, in* Lamarck, Year IX (1801a), p. 3–5.

[19] Charles Darwin (1809-1882): English naturalist and paleontologist. His book on the evolution of living species, *On the Origin of Species* (1859), revolutionized biology. Famous among the scientists of his time for his fieldwork and research in geology, he took up Lamarck's hypothesis that all living species evolved from one or more common ancestors. Both opposed the then widely accepted theory of creationism, and Darwin argued with Alfred Wallace that this evolution was due to the process of natural selection.

[20] However, the process of this evolution — *natural selection* — differs radically from the mechanisms postulated by Lamarck, known by the somewhat reductive name of the *transmission of acquired characteristics.*

[21] Among these evolutionary theorists, we can mention the continuist Ernst Mayr (1904–2005) with his synthetic theory, and the discontinuists Stephen Jay Gould (1941–2002) and Niles Eldredge (born in 1943) with their theory of punctuated equilibrium.

[22] More specifically: in the vast majority of cases, a mineral can be described as a crystallized material characterized by its chemical composition and the arrangement of its atoms according to a precise periodicity and symmetry, which are reflected in the mineral's crystal system and space group. In principle, a mineral must be macroscopically homogeneous.

The first classification of minerals, based on their chemical composition, dates back to the early 19th century[23]. Advances in analytical chemistry and crystallography have since improved this classification[24], and there are now ten classes of minerals[25].

Let us now turn our attention to the geochemical processes that enabled life to emerge on our planet some 4 billion years ago, i.e. 500 million years after its formation, when it had cooled sufficiently and was less impacted by asteroids. The only resources available at the time were water, air, and a few hundred rock minerals. But natural geological processes (the formation of oceans and mountains, volcanism) are so slow that for a very long time, minerals were seen as "inanimate" (see our Introduction).

However, even if the details of these processes still elude us, we now know that minerals played an essential role. As Antoine Danchin aptly put it, life experienced "a dawn of stones."[26] This theory, known as the "genetic takeover" hypothesis, was proposed by Alexander Graham Cairns-Smith[27]. It replaced the "primordial soup" hypothesis[28], which postulated that the first living organisms emerged from a simple chemical broth, and posits that the current mechanisms of heredity were preceded by a primitive form of inheritance. This primitive inheritance would have consisted of the replication of a mineral template, perhaps between layers of clay[29], which would have facilitated the polymerization of simple molecules into the complex macromolecules characteristic of life[30]. This initial self-replication would have been gradually replaced by that of nucleic acids (RNA and then DNA), the carriers of genetic information. Being negatively charged like clay, these nucleic acids would have entered into a symbiotic relationship with it until they eventually achieved autonomy. And to prevent microorganisms from being diluted and destroyed, the clay layers would have closed in on themselves, thus forming protective compartments (like the membranes that protect living cells) within which small molecules could accumulate, grow, and eventually assemble. However, as stimulating and promising as it may be, Cairns-

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[23] See J.J. Berzelius, *Nouveau système de minéralogie* (New System of Mineralogy), Paris, 1819.

[24] Recent revisions of the Dana (1997) and Strunz (2001) classifications are based on crystal chemistry. They consider the groups of atoms that make up the mineral.

[25] Current classification of minerals: Class I: native elements (carbon and diamond, sulfur, native gold, native silver, native copper, platinum); Class II: sulfides; Class III: halides; Class IV: oxides and hydroxides; Class V: carbonates and nitrates; Class VI: borates; Class VII: sulfates, chromates, molybdates, tungstates; Class VIII: phosphates, arsenates, vanadates; Class IX: silicates; Class X: organic minerals (crystallized organic compounds found in nature).

[26] Antoine Danchin, *Une aurore de pierres. Aux origines de la vie*, Seuil, 1990.

[27] Alexander Graham Cairns-Smith, "The Origin of Life and the Nature of the Primitive Gene", *Journal of Theoretical Biology*, vol. 10, n° 1, 1966; *L'énigme de la vie*, Paris, Odile Jacob, 1990.

[28] The "primordial soup" hypothesis: formulated by Stanley Miller based on the famous laboratory experiment by Miller and Urey (1953), in which they obtained some of the basic building blocks of life from very simple compounds, by electrically simulating the effect of lightning on the primordial atmosphere.

[29] "Clays are very common on planet Earth, having been present since its formation. And not only on Earth: they are found in meteorites, asteroids, and even on Mars. For crystallographers, who study matter at the atomic scale, they are considered 'layered minerals,' whose structure is characterized by alternating layers a few angstroms thick (an angstrom is one ten-thousandth of a micrometer or one-tenth of a billionth of a meter), which can be negatively charged or electrically neutral." *In* Marie-Christine Maurel and Jean-François Lambert, "The Birth of Life on Clays," *Living Forms*, exhibition catalogue, Adrien Dubouché National Museum, October 9, 2019 – February 10, 2020, co-published with the City of Ceramics – Sèvres & Limoges, 2019, p. 34.

[30] In 1973, Aharon Katchalski demonstrated in the laboratory the polymerization effect of a specific type of clay, montmorillonite. "This clay acts like a mini-reactor; it stores and concentrates organic matter between the layers of its sheet-like structure, thus facilitating the interaction and condensation of two amino acids to form a precursor of a protein." *Ibid*., p. 35.

Smith's theory has not yet been fully verified experimentally, particularly with regard to the mechanism of nucleic acid synthesis.

2.2. *From living organisms to minerals*

Over hundreds of millions of years, living organisms gradually gained their independence from minerals – without, however, completely breaking free from them. In fact, the interdependence between minerals and living organisms takes many forms: in addition to the necessary presence of minerals during the evolution that led to the first forms of life, these organisms and all those that descended from them have remained in close contact with the mineral world. This is evidenced, in particular by the various processes of mineralization of living organisms: in nature, sedimentary rocks formed by plankton (organo-sedimentation); stromatolites, the oldest traces of life of both sedimentary and biogenic origin, as well as all living organisms that produce their own minerals (biomineralization) or mineralize *post-mortem* (fossilization, petrification). Not to mention the various more or less intimate relationships between stones and living beings, which will be discussed later.

2.2.1. *Organo-sedimentation*

First, let us remember that the evolution of each of these two worlds, which we have long thought of as separate, depends on the other: the first rocks of the Earth's crust provided the molecular resources that life needed to appear, sustain itself, and become more complex; the various plankton organisms[31] in turn contributed to the formation of sedimentary rocks over several hundred million years[32]. In fact, organo-sedimentary rocks were formed in two ways: 1° When the organisms that made up the plankton died, their shells of limestone, silica, or phosphate were excreted, dissolved, then deposited and accumulated at the bottom of the water, where they compacted to form sedimentary rocks. Some of the organisms involved in this process are visible to the naked eye (mollusk and large crustacean larvae, algae, polyps, etc.), but most are microscopic (unicellular bacteria and algae in phytoplankton, protozoa in zooplankton) and form the thickest sediments, which can sometimes reach several hundred meters. 2° Aquatic organisms decomposed after death and were transformed into coal or oil and natural gas by the compression and heating resulting from their accumulation.

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[31] Plankton (from the ancient Greek *planktós*: wandering, unstable): a group of organisms that are generally unicellular, vary greatly in size (from over 2m for megaplankton to 0.02µm for femtoplankton) and do not all appear to have the same ancestors. Plankton lives in fresh, brackish, and salt water, most often in suspension, and is the main food source for baleen whales and filter-feeding shellfish. It is the source of significant biomass as well as necromass, which is very present in certain sediments: chalk, for example, is the fossilized necromass of marine plankton. Plant plankton (phytoplankton) consists of microscopic, photosynthetic algae; although it represents less than 1% of the planet's photosynthetic biomass, it fixes about one-third of its atmospheric CO2, which is as much as terrestrial and aquatic plants combined! It is the basis of all aquatic food chains; its most numerous groups are diatoms, dinoflagellates, and cyanobacteria. To multiply, it needs sunlight and carbon dioxide, but also minerals and trace elements such as phosphorus and nitrogen. Among animal plankton organisms (zooplankton), some spend their entire lives as plankton (holoplankton), while others only spend their larval stage as plankton (meroplankton). Recent studies have shown that a large proportion of marine plankton is actually capable of behaving simultaneously as phytoplankton (photosynthesis) and zooplankton (phagocytosis): this is referred to as mixotrophic plankton (https://www.sorbonne-universite.fr/dossiers/sciences-de-la-mer/la-photosynthese-et-le-plancton-mixotrophe). In terms of their mineral composition, planktonic organisms have very few skeletal structures, and those that do have them have thin, light skeletons. Discovered between the 18th and 19th centuries, they inspired the naturalist and illustrator Ernst Haeckel, who popularized their beauty and diversity in his famous work *Kunstformen der Natur* (Art Forms in Nature), which had a profound influence on the Art Nouveau movement in the early 20th century.

[32] It should be noted, however, that not all sedimentary rocks are of biotic origin and represent only a small portion of terrestrial rocks, most of which are exclusively mineral in origin (magmatic rocks and certain metamorphic rocks).

Figure 3. *Nicolas Floc'h, CO2 → 02, 2019, 60-micron centric diatom (featured in the exhibition "The Color of Water"), Frac Grand Large — Hauts-de-France, Dunkirk, France © Courtesy of the artist / ADAGP, Paris 2022*

Fascinated by the variety of diatom shapes[33], artist Nicolas Floc'h[34] used 3D modeling technologies to create enlargements in Hainaut blue stone, which itself is made up of sedimented diatoms (fig. 3).

Another artist attracted by the exoskeletons of planktonic organisms, Isabelle Rochemars[35], transforms them through her paintings. Her exhibition "Microscopic Relics" (2021) featured two series representing diatoms and coccolithophores, respectively. The diatoms (with their silica exoskeleton called a frustule) were painted with diatom sediment; the coccolithophores (with their limestone exoskeleton called a coccolith) were painted with a pigment composed of these coccoliths, filtered from sediment collected from the ocean floor and mixed with an acrylic binder (fig. 4).

[33] Diatoms or Bacillariophyta: a division of unicellular microalgae (from 2 µm to 1 mm) found in all aquatic environments and enclosed in an external siliceous skeleton called a frustule. They can live freely or attached, alone or in colonies. Diatoms are a major component of phytoplankton. The accumulation of frustules over millions of years has formed deposits of siliceous peat, oil, or rocks called diatomites.

[34] Nicolas Floc'h: visual artist, scenographer, photographer, and videographer born in 1970 in Rennes, France. Lives and works in Paris. Teaches at EESAB-Site de Rennes. Numerous performances, participation in group exhibitions, and international solo exhibitions. Represented in Paris by Galerie Maubert. Latest solo exhibition: Frac Grand Large – Hauts de France, "La couleur de l'eau" (April 2, 2022 – September 4, 2022). This exhibition is the first that Nicolas Floc'h has devoted to his research project *La couleur de l'eau*. He photographs underwater landscapes to "make the invisible visible" – in the Baie de Somme, but also in oceans, seas and along rivers – thereby contributing to the study of fragile ecosystems. https://www.nicolasfloch.net/news

[35] Isabelle Rochemars: French visual artist. Lives and works in Cadenet, France. Numerous group exhibitions in France. Latest solo exhibition: "Microscopic Relics #2," Musée des Tapisseries d'Aix-en-Provence, with the Natural History Museum, Aix-en-Provence (September 13 – November 7, 2021).

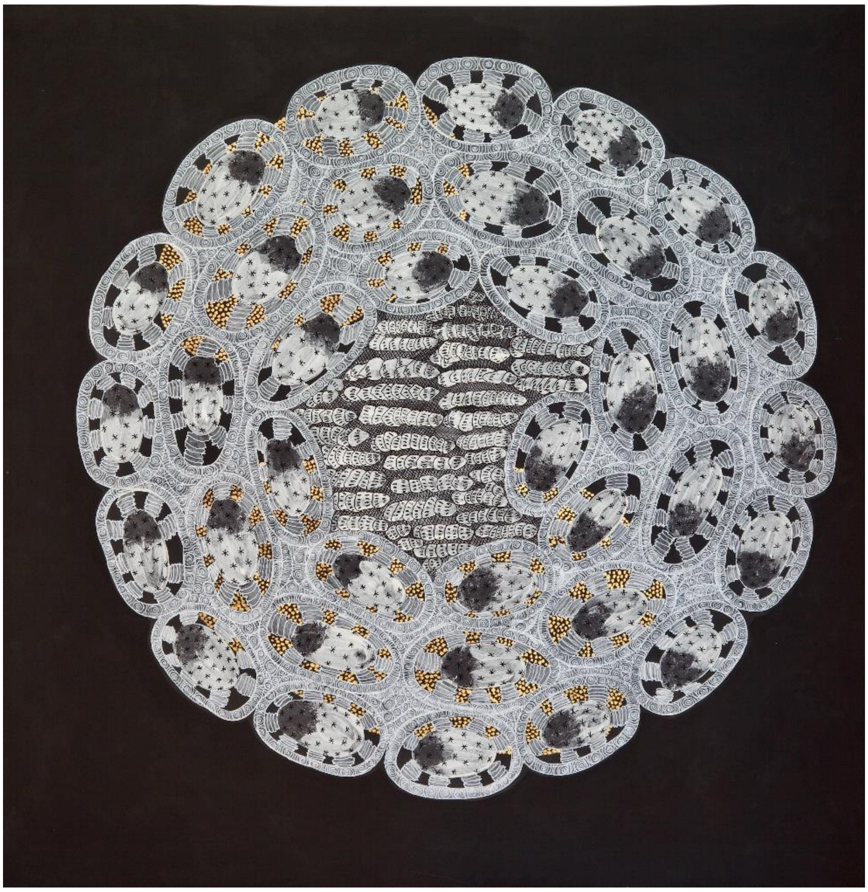

Figure 4. *Isabelle Rochemars, Microscopic Relics Series, Roaesphaera radices, 2019. © Isabelle Rochemars*

2.2.2. *Stromatolites*

Stromatolites (from the Greek *stroma*, meaning "mat," and *lithos*, meaning "stone") are the result of a particular form of organo-sedimentation caused by colonies of certain bacteria: for example, cyanobacteria carry out photosynthesis during the day and precipitate limestone using carbon dioxide; at night, they produce a jelly that traps limestone and some sediments. When cyanobacteria die, they give rise to micro-layers of limestone that serve as a substrate for the development of subsequent bacteria, eventually forming a biomineral mat (consisting of superimposed layers 0.1 to 5 mm thick, alternating between mineral and fossil-rich cyanobacteria layers). These laminar structures develop in shallow aquatic environments, both marine and lacustrine. Their growth is very slow (0.3 mm/year) and their forms are highly varied, ranging from slightly undulating bacterial mats to spectacular domes, mushrooms, or columns, which are the best known.

The earliest stromatolites, now fossilized, date back approximately 3.5 billion years and bear traces of the oldest forms of life in fixed colonies. However, as most of the Earth's earliest rocks have disappeared due to various geological upheavals, stromatolites are now found only in a few lagoons or saltwater bays[36], and those that are still active can be described as living fossils[37]. Their history reached

[36] Sites hosting active stromatolites (according to Wikipedia, article 'Stromatolite'): Shark Bay ('Hamelin Harbour', west coast of Australia); Lake Thetis (west coast of Australia); Blue Lake (southern Australia); Lake Salgada (Brazil); Laguna de los Siete Colores (Mexico); Lake Solar (Egypt); Persian Gulf, Green Lake, Salt Lake; Bahamas; Transvaal (South Africa); Hainan Island (China); three warm water lakes (27 to 35 °C) in Western Australia: the brackish lakes of Rottnest Island and Clifton, and the freshwater lake of Richmond; Le Dard, near Baume-les-Messieurs (Jura); numerous sulphurous hot springs, such as those in Yellowstone National Park; petrifying springs and streams in France: the Dard stream near Lons-le-Saunier (Jura), the petrifying waterfall stream of Saint Pierre-Livron near Caylus (Tarn-et-Garonne); Lake Dziani Dzaha in Mayotte.

[37] What is alive in today's active stromatolites is not their structure, but the bacteria that build it. Inside, they can be either almost full or contain enough empty space to harbour other microorganisms.

a long peak in the Precambrian era, when the cyanobacterial communities that formed them dominated marine life, before the oxygenation of the atmosphere allowed more complex organisms to appear. Over billions of years, they formed imposing reefs or limestone or dolomite massifs (up to 3 km thick in the Anti-Atlas Mountains in Morocco!).

Being able to contemplate these witnesses to the earliest days of life is a powerful experience. Marian Mc Guinness, a reporter for the BBC, recounts her amazement at the sight of the stromatolites in Lake Thetis after a long journey: "There were thousands of pumice-colored stromatolites, almost camouflaged beneath the ripples, submerged like migrations of ancient turtles holding their breath beneath the slightly opaque water. I was stunned. This is what life looked like in the beginning of time, not to mention the orange methane sky caused by volcanic activity."[38]

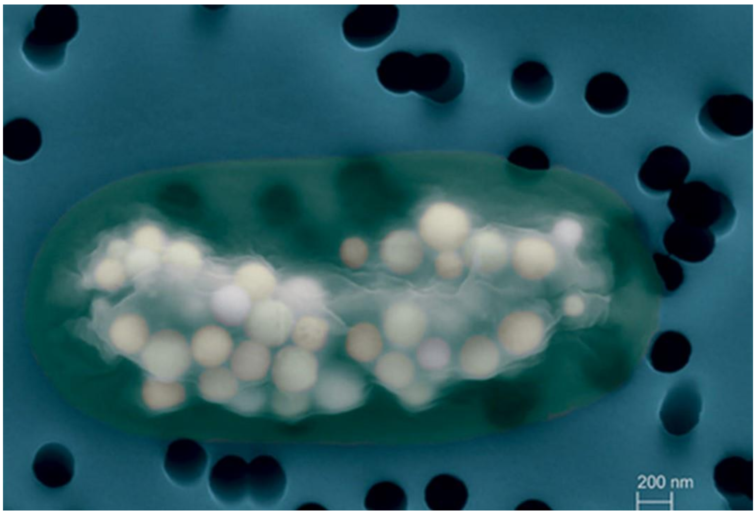

Figure 5. *Lia Giraud, Candidatus Gloeomargarita lithophora; inclusions of calcium, barium, and strontium carbonates, visible inside the cyanobacteria. © Karim Benzerara & Stefan Borensztajn*

Figure 6. *Lia Giraud, Techno-aesthetics of the Stone Carpet #4, 2019. Permanent marker drawing, between two glasses. 20.7 x 8 cm*

[38] Bbc.com: Marian McGuinness, BBC Travel, 2 March 2021. Lake Thetis is a coastal salt lake in the Mid West region of Western Australia.

Some contemporary artists, also captivated by the visual and symbolic density of stromatolites, which connect us to primitive life, have dreamed up their forms or development. The “Stromatolite” project (2013–2017) by visual artist Lia Giraud[39] recounts ongoing research, but also presents itself as a multifaceted “technical-poetic reverie” around sedimentation resulting from living organisms. The evaporations show Petri dishes containing a culture of Gloeomargarita lithophora (fig. 5), a strain of cyanobacteria discovered in 2012, which has the particularity of producing limestone inclusions within its cell wall. After the liquid has completely evaporated, a mineral residue corresponding to the petrification of the cells is obtained: the living has given way to the mineral. In the sketches of her technical utopias, for example *Techno-esthétique du tapis de pierre #4* (fig. 6), the same artist interprets the sedimentary processes linked to stromatolites: time has also mineralized. Finally, in *Remake*, a 3D printer fabricates a stromatolite layer by layer at a rate of 1 mm per year: thanks to technology, the living has inspired the mineral.

In 2017, visual artist Sophie Papiau[40] offered her own interpretation with her sculpture installation *Stromatolites* (fig. 7), evoking the organo-sedimentary structure through the juxtaposition of two materials that could only come together through the artist's will: fabric and ceramics — ruffled fabric evoking sedimentary folds; white, matte, and grainy ceramics, like a transfiguration of the clay mud linked to the origins of life.

Figure 7. *Sophie Papiau, Stromatolites, 2017, ceramics, milk, fabrics, H + or - 75 cm. Installation composed of several floor and wall sculptures, each comprising a volume of gathered fabric sewn onto a milk-patinated ceramic. © Sophie Papiau*

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[39] Lia Giraud (born in 1985): French artist and doctor of visual arts (SACRe/PSL; see *L’œuvre processus. Pratiques dialogiques entre biologique et technique, vers une écologie de l’œuvre.* Art et histoire de l’art. PSL Research University, 2017. French. NNT: 2017PSLET037), professor of photography at the Beaux-Arts de Marseille. Her installations explore the evolution of our conceptions of and relationships with living things in a technoscientific context. For her interdisciplinary research focused on the creation of ecosystems at the frontier between science and society, she brings together biologists, thinkers, artists and citizen communities. Her work has been featured in numerous exhibitions (Centre Pompidou, Le 14, Le Cube, Le Bel Ordinaire, Festival Images de Vevey, Naturpark Our, Dutch Design Week), publications (Artpress, Tracks, Wired, Vice) and educational interventions aimed at the general public.

[40] Sophie Papiau (born in 1967): French visual artist. Studied visual arts at the École des Beaux-Arts in Brest, Quimper and Angers. Fascinated by science, she uses images from this field as a source for her artistic work. Selected in 2003 for the contemporary art exhibition at the National Museum of Natural History in Paris. Latest solo exhibition: *Pink Forest*, textile, ceramic and thread installation / evolving installation, Pulchri Studio The Hague NL, 7 to 29 May 2022.

2.2.3. *Biomineralization*

Another way of making living beings partially mineral is biomineralization, the process by which they themselves produce minerals capable of hardening some of their tissues. The shells of mollusks, the bones and teeth of vertebrates, and their nails and claws are structures resulting from biomineralization. It exists in all plant and animal groups, and more than sixty biomineral molecules have been identified in the organisms concerned — silicates in algae and diatoms, carbonates in invertebrates, phosphates and carbonates in certain vertebrates. A distinction is made between induced biomineralization and controlled biomineralization: in the former, the material simply results from interactions between the organism's metabolism and its environment, where the biomineral is excreted or precipitated; in this case, the structure of the biomineral resembles those observed in spontaneous and abiotic crystallizations or chemical precipitations. The second type of biomineralization, on the other hand, involves two specialized processes: the production of crystal layers and the control of their arrangement within an organic matrix. The structure of the biomineral produced is therefore much more complex. A single organism sometimes contains different specialized tissues, each with its own function: in bivalve mollusks, for example, an internal tissue produces mother-of-pearl[41], while an external tissue contributes to the growth and repair of the shell. Other biominerals that are very common in nature include: raphides, fine crystals of calcium oxalate or calcium carbonate, found in the leaves and stems of many plant families; hydroxyapatite (calcium phosphate) crystals, found in various mineralized tissues[42] as well as in pathological calcifications (kidney stones or Randall's plaques).

2.2.4. *Fossilization*

Fossilization (from the Latin *fossilis*, meaning "drawn from the earth") is the mineralization of a living organism or its past activity, or simply its imprint, preserved in sedimentary rock. It results in either more or less well-preserved remains of the organism itself (bones, teeth, leaves, mycelium, biofilms, etc.) or various imprints left by it (fig. 8). But this mineralization is very different from biomineralization: while the latter is a synthesis within the organism itself that takes place throughout its life, fossilization is a gradual replacement of its organic parts by minerals, which takes place in sedimentary rock and *post-mortem* over thousands or even millions of years, depending on the surrounding conditions. For an animal carcass, the first condition for fossilization to begin is that it must be immediately covered with a layer of sand, mud, or other sediments, thus escaping scavengers. Oxygen then decomposes the soft parts of the carcass, leaving only the hard parts. Gradually, new layers of sediment accumulate, burying it deeper and deeper, exerting increased weight and pressure on it. If a mineral-rich groundwater table appears, it seeps into the pores of the hard parts and mineralizes them until the bone turns to stone. However, it is very rare for fossils formed in this way to be found[43] (fig. 8). For this to happen, geological movements must not have buried it too deeply — in which case it would eventually be destroyed — and it must have risen close to the surface, accessible to potential archaeologists. As all these conditions are

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[41] Mother-of-pearl consists of 5% organic matter and 95% aragonite crystals. It is constructed like a protective wall whose rigid mineral bricks are arranged in columns according to preferred directions, under the control of their organic cement, which gives them elasticity.

[42] For example: bone, enamel and dentine; mineralised tendons in turkeys; the tusks of certain mammals, ivory in elephants, antlers in deer; the claws of certain crustaceans; the scales of certain fish such as sharks (see Stanislas von Euw, 'Bone biomineralisation: from the structural characterisation of the mineral to its 3D organisation'. Chemistry. Pierre and Marie Curie University - Paris VI, 2014. NNT: 2014PA0

[43] According to Wikipedia, only about 300,000 fossil species are currently known, which is 20% of the number of living species and less than 6% of the estimated total number of species that ever existed. The fossil record spans from 3.5 billion years ago to the present, but 99% of the fossils date back only to 545 million years. Furthermore, while large fossils (macrofossils) are more frequently unearthed, studied, and displayed, by far the most numerous are microfossils, which include stromatolites, some of which are among the oldest fossils, composed of sedimentary rocks formed by bacterial activity.

rarely met, the fossilization process remains exceptional (the proportion of organisms that fossilize is between 0.01 and 0.1%), and discovering a fossil is always something of a miracle.

Figure 8. *Fish fossil, southern France, 1992. Personal collection of Marie-Christine Maurel. Photograph by Marie-Christine Maurel*

Some fossils do not come from parts of organisms that are likely to become petrified: in the case of ferns, for example, the leaves were covered with mud in which they left their imprint, then over time and under the pressure of being buried, this mud solidified and eventually rose to the surface in the form of rock. As for the fossilization of soft organs or organisms such as jellyfish, it is very rare, as it can only occur in the total absence of oxygen (which would cause decomposition), i.e., under a sedimentary cover that is particularly airtight (silt, mud, or even volcanic clay).

Etched in stone, fossils also leave an indelible mark on the minds of all who observe them — scientists, artists, and writers alike, foremost among whom is undoubtedly Roger Caillois, who was literally captivated by the beauty of the mineral world. For him, fossils are "countless writings [that] add to those of stones. Images of fish, as if among tufts of moss, evolve among manganese dendrites. A sea lily in the slate sways on its stem. A ghost shrimp can no longer feel the space around it with its long broken antennae. Ferns imprint their crosses and lace patterns in coal. Ammonites of all sizes, from lentils to mill wheels, impose the mark of their cosmic spiral everywhere. The fossilized trunk, turned to opal and jasper, as if by a motionless fire, is clothed in scarlet, purple, and violet. The bones of dinosaurs are transformed into ivory tapestry, dotted here and there with touches of pink or azure, the color of sugared almonds."[44]

Due to their mysterious beauty, fossils have often been considered authentic works of art, with nature as the artist. They are often displayed in exhibitions and traded for profit. Fossil hunting is also practiced by amateurs and scientists (fig. 9). As for artists, they are not content with exhibiting real fossils, but sometimes create them from scratch, as potter Jonathan Keep[45] did in 2013 with his series *Petrified Trees* (fig. 10), in which fossilized trees are "embodied" by 3D-printed glazed sandstone sculptures, or Isabelle

[44] Roger Caillois, *L'écriture des pierres* (The writing of stones) (Skira, « Les sentiers de la création »), Paris, Champs / Flammarion, 1981, p. 129-130.

[45] Jonathan Keep: artist, ceramicist, and art consultant. Born and raised in South Africa. Graduated with a degree in Fine Arts from the University of Natal (1979). Moved to England in 1986. Received a Master's degree from the Royal College of Art (2002); winner of the Lattice Group Awards; recipient of a Woo Foundation fellowship. Has participated in numerous artist residencies and exhibitions in the UK and abroad, including the British Ceramic Biennial (2013) and the Taipei Ceramic Biennial (2014). Considered a pioneer in the field of 3D-printed ceramic art. He developed a production method in which the shapes of his ceramics are programmed using computer code, and the digital data is then transmitted to a 3D printer that he designed and built himself. His website features several designs for clay 3D printers, which he makes available for free download.

Rochemars — mentioned above for her paintings of coccolithophores based on sedimentary microfossils.

Figure 9. *Fragment of silicified wood. Arizona, 1997. Personal collection of Marie-Christine Maurel. Photograph by Marie-Christine Maurel*

Figure 10. *Jonathan Keep, Petrified tree series, ceramic printing 3D, 2013, © Jonathan Keep*

2.2.5. *Petrification*

Long before science took an interest in the phenomenon of petrification (almost synonymous with fossilization in geology), numerous myths and legends attest to the fascination of ancient civilizations and popular cultures with rocks, megaliths, and minerals in general, which were considered to have originated from living beings, real or imagined: in a well-known biblical episode (Genesis 19:26), Lot's wife is turned into a pillar of salt for defying God's command not to look back at the destroyed cities of Sodom and Gomorrah. In Greek mythology, the gaze of the Gorgon Medusa had the power to petrify her enemies, and it was from the blood flowing from her head, severed by Perseus, that the basilisk (a mixture of snake and rooster) was born, also deadly and often held responsible for certain megaliths[46]. Another heroine of Greek mythology, Niobe, daughter of Tantalus (himself the son of Zeus) and queen of Thebes, was petrified when her children were killed by those of Leto (Zeus' mistress), whom she had humiliated. Zeus then turned her into a rock, from which her tears flowed in the form of a spring. In Scandinavian mythology, trolls (deformed and malicious creatures, half-human, half-animal, inhabiting mountains or forests) turn to stone in sunlight.

The theme of petrification has also inspired literature[47] and cinema[48].

In addition to natural or legendary, literary, cinematic, and playful petrifications, there are also technical ones, which involve the embalming of human corpses. In February 2012, an article entitled "Turning bodies to stone: the secrets of petrification revealed"[49] reported on the detailed analysis of eight human mummies from the 1800s by a team from the Eurac Institute for Mummies and the Iceman (Bolzano, Northern Italy). The remarkably well-preserved corpses are the work of anatomist Giovan Battista Rini (1795-1856). To uncover their secrets, researchers scanned the mummies with X-rays, revealing two major technical phases of petrification: immersion of the bodies in chemical solutions composed of heavy metals, and injection of mercury into the internal tissues; once saturated with heavy metals, the corpses were petrified.

3. Proximities

When we examine the links between minerals and living organisms, we see a whole network of dynamic and intertwined relationships emerge. Minerals that come to life (biologically or mythologically) are matched by living organisms that return to minerals, either partially or completely, through synthesis or fossilization. However diverse these interdependencies may be, they do not sum up

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[46] In particular, it is said that a basilisk is buried beneath the dolmen of Épennes (Vienne).

[47] J.R.R. Tolkien, in *The Hobbit* (1937), where trolls are turned to stone for discussing at length how to cook their prisoners; J.K. Rowling, in *Harry Potter and the Chamber of Secrets* (1998), where Slytherin's Basilisk petrifies several Hogwarts students, a cat, and a ghost, all of whom caught its gaze in a reflection; C.S. Lewis, in *The Chronicles of Narnia*, Book 2 (2013), where the White Witch's scepter has the power to petrify living beings; the author Riichiro Inagaki and the artist Boichi, creators of the shōnen manga *Dr. Stone* (2018), in which a bright light appearing in the sky transforms all of humanity into stone statues; 3700 years later, only two teenagers awaken in this Stone World and try to find a "cure" to reverse the petrification and bring humanity back to life; and finally, Alain Damasio in *Les Furtifs* (2019), where beings who live in the hidden corners of the world and eat anything they find (including stones) to fuel their constant metamorphoses, become petrified as soon as they are seen by a human.

[48] In *The Visitors of the Night* (Marcel Carné, 1942), the two lovers are ultimately petrified by the devil, but their hearts continue to beat in unison; in *Pocket-Sized Love* (Pierre Kast, 1957), a biologist invents a process that allows him to reduce and preserve matter through petrification, enabling him to transform the young woman he loves into a statuette; and finally, in *The Petrified City / The Monolith Monsters* (John Sherwood, 1957), black, shiny rocks released on Earth by a meteorite impact are actually crystalline forms of extraterrestrial life that, upon contact with water, feed on the silica of the bodies they touch, including those of human beings, who are immediately turned to stone. Petrification is also a classic spell in role-playing games like *Dungeons & Dragons*, in video games like Temtem or Lord Odyssey, and it is central to the plot of Pokémon: *Mystery Dungeon*.

[49] https://www.maxisciences.com/momie/changer-les-corps-en-pierre-les-secrets-de-la-petrification-3

all the interactions between minerals and living things, which also include their simple coexistence, in other words, the sharing of the same space-time — in nature, between stones and the epilithic species that cover them or the plants that grow in their crevices, or as a result of human intervention (vegetation, rockeries, works of art).

3.1. *Life among stones*

It is striking and sometimes even moving to see plant life finding an unlikely path between two stones that appear to touch. We then realize that the apparent fragility of a blade of grass hides something else entirely, something that philosophers and scientists throughout history have sought to name: the "life force" of vitalists, Schopenhauer's "will to live," Bergson's "élan vital" (vital impulse)... In all of these, it is at least possible to recognize the genius inherent in living things, which makes them appear as soon as environmental conditions allow.

Figure 11. *Various lichens on a stone (photograph taken at the Dynjandi Falls site, Iceland, in July 2004. Wikimedia Commons*

Epilithic or lithophilic[50] species — animals, fungi, plants, or microbes that live on the surface of rocks — show even greater proximity to the stones that shelter them. These species are particularly resistant to stresses such as exposure to wind, dehydration, and ultraviolet rays, as well as variations in temperature, humidity, and light. Epilithic plants can be terrestrial or aquatic: the best-known terrestrial epiliths (some of which are also epiphytes) are mosses, lichens[51] (fig. 11), and certain ferns such as *Pyrrosia rupestris*, or rock moss, and *Asplenium nidus*, or bird's nest fern; aquatic epiliths — microalgae and microbes — form a biofilm that serves as food for many species. Epilithic plants and lichens are always photosynthetic; they absorb moisture from the air, collect dew, and find the mineral salts they need either in suspended particles or in humus or dead organic matter accumulated on the rock. Some species secrete organic acids that allow their roots to penetrate the rock and draw nutrients from it. Their

[50] Epilithic: from the Greek *epi*, meaning "on" and *lithos*, meaning "stone"; lithophile: from the Greek *lithos* and *philos*, meaning "loving".

[51] Lichens: a symbiotic relationship between an alga and a fungus or cyanobacterium; the alga provides nutrients to the fungus through photosynthesis, while the fungus protects the alga from sunlight and desiccation. This symbiosis also involves the presence of numerous bacteria and a recently discovered unicellular fungus. In this complex yet delicate ecosystem, cooperation is essential.

growth is very slow (a few microns per year for some species) and some lichens can live for several centuries. In tropical areas, many species colonize rocks and form vertical ecosystems of varying complexity. Some reptiles sometimes spend their entire lives there, over several generations, without ever coming down to the ground.

Of all epiliths, lichens are the most fascinating, both for biologists and artists: among them are the painter Antoni Pixtot (1934-2015), a close collaborator of Dali, whose painting *Sant Jordi* illustrated the poster for the symposium of the International Association of Lichenology (Barcelona, 2000), and the contemporary engraver and intaglio artist Thomas Fouque[52], whose point-by-point engraving on metal allows him to follow the infinite cycle of the phases of life — germination, blossoming, maturity, and decay — in order to detail their beauty (fig. 12).

Figure 12. *Thomas Fouque, Hanging Garden, drypoint engraving, 8 x 8 cm, 2015*

As for writers, it can be said that lichens found their naturalist poet in Camillo Sbarbaro (1888-1967), who not only described 127 new species, 20 of which bear his name, but also wrote an unforgettable text, “Lichens,” divided into nine short paragraphs. In it, he marvels at the diversity of colors, shapes, and substrates of lichen: “Lichen is the most polychromatic of plants. Its range, which extends from milky white to stygian black, rises to all the high notes, through an orchestration of tones and nuances in which the most sumptuous repertoire of colors unfolds.”[53] “Lichen is the most multiform of plants. Koerber was deluding himself when he claimed to be able to classify them under the names of crustose, foliose, and arborescent. How many meanings must these adjectives take on in order to encompass, as best they can, the polymorphism of lichens!”[54] “One takes limestone as its home, while another flees from it to the point of being unable to tolerate its presence in the composition of the rock. One adopts sandstone or puddingstone, another gypsum, and yet another trachyte and basalt.”[55] But how do they manage to attach themselves to rocks? The process is both mechanical and chemical: on limestone rocks,

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[52] Thomas Fouque (born in 1986 in Bastia): printmaker and intaglio engraver. Graduated from the École Nationale Supérieure des Arts Décoratifs (2012). Completed advanced training in intaglio printing at the Moret workshops in Paris (2012-2013). Has printed thousands of prints, collaborated with numerous artists, created original engravings for others, and developed new printing techniques. His work as a printmaker is complemented by a more personal artistic practice, primarily focused on printmaking.

[53] Camillo Sbarbaro, “Lichens 7”, excerpt from *Copeaux*, followed by *Feux Follets*; translated from Italian to French by Jean-Baptiste Para, Clémence Hiver Publishing, 1992. https://poezibao.typepad.com/files/camillo-sbabaro-lichens.pdf.

[54] “Lichens 6”, *ibid.*

[55] “Lichens 4”, *ibid.*

the oxalic acid in lichens promotes the dissolution of calcium carbonate, and the thalli[56] transform it into calcium oxalate; on acidic rocks, the lichen physically attacks the rock by dissociating the minerals.

Ubiquitous, lichens grow on the hardest rocks and seem to resist everything: “Lichens thrive from the cloud region to the spray-splashed shores. They climb peaks where no other plant can take root. The desert does not discourage it; the glacier cannot expel it; nor can the tropics or the polar circle. It defies the darkness of the cave and ventures into the crater of the volcano. It fears only the proximity of man.”[57] Two species of lichen, *Rhizocarpon geographicum* and *Xanthoria elegans*, collected in the Alps and Spain, even survived a year and a half on the walls of the International Space Station (ISS) in 2014, before resuming their growth on Earth! A “resurrection” that writer Pierre Gascar[58] contrasts with the threat of extinction they face: “So as I bent over the lichens, sometimes picking up these scales scattered here and there, I kept wondering whether I was witnessing the death of the world or its revival.”[59]

The coexistence of stone and vegetation is sometimes a silent struggle, as shown by the remarkable combination of serpentinite and Firmin's stool: serpentinite is a very ancient rock, scaly in appearance and green in color with darker or yellowish moiré patterns. It extends several hundred meters into the ground, and its high magnesium, iron, and other heavy metal content makes it toxic to plants... Except for Firmin's stool, a plant endemic to Puy de Wolf[60], shaped like a candelabra and with small white flowers, which is not only able to tolerate very high concentrations of metallic elements, but also to extract them from the soil and accumulate them in its leaves, thus opening up real prospects for soil decontamination. Elsewhere, erosion sculpts shapes into the rock that often resemble living beings, as in the Mourèze cirque (Hérault) made up of dolomite[61]: “It is easy to imagine monsters here, animals there, or even walls and castles. In a chaos of rocks, erosion has carved out strange shapes worthy of a fairy tale, to which humans have given names: the Skull (7 meters high), the Standing Lion, the Sphinx, the Frées, the Turtle, the Bison...”[62]

3.2. *When stones speak of life*

Attributing life to stones seems to be a recurring temptation for humanity[63]: while it may be risky to interpret Paleolithic rock paintings (animals and human figures in a hunting context) in this way, we must nevertheless recognize that, beyond its materiality, this art "designated a relationship in which the stone was anything but a simple surface for inscription [...] and in a sense, we can say that the painters

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[56] Thallus: The vegetative structure of lower plants (algae, fungi, lichens); it does not have leaves, stems, or roots.

[57] Camillo Sbarbaro, « Lichens 3 », *op. cit.*

[58] Pierre Fournier, better known as Pierre Gascar (1916-1997): French journalist, literary critic, author, essayist, and screenwriter. After being a prisoner in a German prisoner-of-war camp during World War II, he became a journalist and writer. In 1953, he won the Goncourt Prize for his novel *Le Temps des morts* (The Time of the Dead). In his short story *Le Présage* (The Omen), first published in 1972, he issued a near-prophetic warning about global environmental crises, focusing on lichens — the first living organisms to disappear due to air pollution.

[59] Pierre Gascar, *Le Présage*, 1972, rééd. Gallimard, 2015.

[60] Puy de Wolf: located in Aveyron (France), this serpentine rock formation is the largest in Europe. Home to rare flora, Puy de Wolf is a testament to the exceptional biodiversity of this region. It has been part of the Natura 2000 network of protected areas since April 2004.

[61] Dolomite: a sedimentary carbonate rock composed of at least 50% dolomite, a double carbonate of calcium and magnesium, which crystallizes in rhombic prisms.

[62] Patrick de Wever, *Histoires secrètes de cailloux*, Belin, 2021, p. 93.

[63] See François Farges, “Mineral Vibrations and Other Vital Crystallizations,” in *Being Stone*, catalog of the exhibition “Being Stone” presented at the Zadkine Museum (September 29, 2017 – February 11, 2018), Éditions Paris Musées / Zadkine Museum, 2017, p. 102.

confided in it, the gesture of placing their hands on it being inseparable from an emotion whose vigor and tremor we can still feel."[64]

As for works of art, throughout history many have drawn inspiration from the links between minerals and living things. Furthermore, certain stones, known as picture stones (or figurative stones, graphic stones, or dream stones when they come from China), strongly evoke paintings, and there are many different types. Some were long mistaken for fossils, and the distinction between the two was not fully established until the mid-18th century. In fact, some fossils can be confused with dendrites, which are pseudo-fossils whose tree-like structures (images of branches or forests) are produced by water loaded with iron oxide (brown in color) or manganese (black in color) that has infiltrated cracks in limestone. *Paesine*[65] stones are the best known of the picture stones and, once sawn and polished, they evoke landscapes of ruins, different at each cut; Chinese dream stones, known and polished for twelve centuries, suggest wild and poetic landscapes (steep ravines, trees, mosses, water, etc.) through their veining; septaria (nodules of calcite, aragonite and clay) can reveal animals, people, faces or masks; the meanders of alabaster and agate, jaspers and marbles have been interpreted by the Jesuit Athanasius Kircher, “as birds, turtles or crayfish, cities, rivers and forests, crucifixes, bishops, skulls, Infidels with turbans”[66].

During the 20th century, the advent of contemporary art, by freeing itself from the figurative diktat, opened up other perspectives: the museum was no longer the only possible exhibition setting, and the living itself could burst into the works. Towards the end of the 1960s, the first Land Art artists were precursors in this regard, installing often gigantic works in the middle of nature (initially, mainly in the American deserts). Among them, the sculptor Andy Goldsworthy[67] (like other great figures of Land Art such as Nils Udo, Richard Long and more recently Cornelia Konrads) liked to immerse himself in natural places chosen to bring about new encounters between vegetation and stone – often cairns or low walls. His sculpture *Hanging trees* (fig. 13) highlights the ephemeral nature of wood versus the permanence of stone.

Figure 13. *Andy Goldsworthy, Hanging Trees, one of several similar sculptures along Oxley Bank, 2007, © Malcolm Morris, Creative Commons*

[64] Jean-Christophe Bailly, « Souveraineté des pierres », in *Être pierre*, *ibid.,* p. 20.

[65] *Paesine*, also known as “patterned stones” or “landscape stones” and sometimes referred to as “ruin marbles”, “Tuscan marbles” or “Florence marbles”: a type of marly limestone from the Eocene period (early Tertiary) found in deposits in the Florence region.

[66] Athanase Kircher (1602-1680), *Mundus subterraneus […], quo […] universae denique naturae majestas et divitiae summa rerum varietate exponuntur,* Amsterdam, Jansson, Weyerstraet, 1664-1665.

[67] Andy Goldsworthy (born 1956): British sculptor and one of the leading artists of Land Art and Arte Povera. Since 1979, he has been creating ephemeral natural sculptures composed of stones, sand, leaves, snow, and ice. He does not seek to “put his mark” on the landscape but to work in harmony with it, paying attention to the time manifested by natural phenomena in motion. In France, two of his permanent works (*Refuge d'art* and *Water cairns*) are located in the Haute-Provence geological reserve.

In the current context marked by eco-anxiety due to the climate and biodiversity crises, we are seeing an explosion of works linked to nature – to celebrate its qualities, use its materials or be moved by its fragility. The art of sculptor Marinette Cueco[68] – which is related to Arte Povera – achieves all of this. In a humble attention to nature, she gathered and collected the most ordinary materials (leaves, bark, twigs and mosses, slates and pebbles, etc.) and braided, knitted or knotted them. The result is spidery nets and tender and singular assemblages (shards of slate and magnolia petals, slates and rushes, etc.) from which sometimes emerges a kind of writing of origins (fig. 14).

Figure 14. *Marinette Cueco, Installation - Broken Slates and Magnolia Petals, Dunkirk LAAC Room 4 "Slates" 2021, © Cathy Christiaen, City of Dunkirk*

Another contemporary representative of textile sculpture, Simone Pheulpin[69] also works on minerals and plants; on but not with, because it is from cotton that the artist shapes strange structures mimicking both minerals and plants – sometimes coral, or slabs of striated limestone, eaten away at the edges by lichen (fig. 15). Ceramists also take advantage of the porosity between mineral materials and living organisms and thus contribute to the contemporary questioning of the limits of life[70].

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[68] Marinette Cueco (1934-2023): French sculptor who creates from plants and minerals. Since 1960, she has practiced weaving and tapestry, and since 1978, she has applied these techniques to plants. Her works range from the most monumental sculptures (*in situ*, ephemeral) to the most reduced formats (suitable for museum exhibitions). Last solo exhibition: "L'ordre naturel des choses" (The Natural Order of Things), Lieu d'Art et d'Action contemporaine (LAAC) in Dunkirk (October 16, 2021 – March 6, 2022).

[69] Simone Pheulpin (born 1941): French textile artist. Her pieces result from the repetitive folding of strips of raw cotton from the Vosges, stacked and attached to each other with cleverly concealed pins. Her works can be found at the Victoria and Albert Museum in London, the Art Institute of Chicago, and the Musée des Arts Décoratifs in Paris. She is represented by the Maison Parisienne gallery in Paris. Most recent solo exhibition: "Simone Pheulpin, Plieuse de Temps," Musée des Arts Décoratifs (December 7, 2021 – January 16, 2022).

[70] See *Living Forms, op. cit.*

Figure 15. *Simone Pheulpin, 'Geneviève' - Eclipse series, 2008-2023, © Antoine Lippens*

In 2013, the sculptor Giuseppe Penone[71] invested Versailles with trees but also with marbles whose lines he followed to reveal the veins: "from the veins of the stone to those of a body, from the lines to those of muscles or nerves, from the mineral to the organic. Or to the plant: they look like fossilized roots that the artist, now an archaeologist, would have slowly revealed, as if during excavations."[72] Through his gesture, the sculptor will "exhume the form contained in the natural material, rediscover the heart, the soul, the vital flow, by revealing the veins of the marble."[73] He thus reaches the deep essence of the stone, an experience that echoes that of Rudy Ricciotti, architect of the Mucem (Museum of European and Mediterranean Civilizations): "touching a stone wall is touching a reality just as profound as that of a tree. The stone wall speaks, it says things..."[74]

Contemporary gardeners and landscapers are also working in many ways on new alliances between stones and plants: rockeries are "artificial" gardens copying natural mountain gardens: on the mineral side, we will find rocks, slate slabs, pebbles or volcanic stones; on the plant side, low or tall perennials such as mountain shrubs (alpine rhododendron, azalea, creeping willow, alpine clematis, etc.). More recently, the green walls (also called living walls) invented by the botanist Patrick Blanc are vertical gardens or ecosystems, more or less artificial and which can be distinguished from green walls with climbing plants. Green walls are designed either as decorative elements, or as works of art using plants, or even as a contribution to urban ecology – through their positive influence on the microclimate, urban flooding, air quality, and the food supply they represent for various animals.

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[71] Giuseppe Penone (born in 1947): Italian artist, lives and works in Turin and Paris. Associated with the Arte Povera movement since 1969. His work, constantly linking humanity and nature, always involves his own body (imprints, measurements, gestures) and addresses the metamorphoses that time produces on organic, vegetable and mineral materials. Penone's works are exhibited worldwide and he has been awarded several international prizes. A retrospective was dedicated to him in 2004 at the Pompidou Center. In 2007 he represented Italy at the Venice Biennale.

[72] Philippe Dagen, *Le Monde*, 13 juin 2013.

[73] *Ibid.*

[74] Rudy Ricciotti : *Une rencontre animée par Carine Merlino pour la revue BÉTON PLURIEL* | Cassis – Juin 2014 ; https://jeanpaulcurnier.com « Le philosophe et l'architecte ».

4. Conclusion

Until now, the relationships between minerals and living things have been approached from two angles: their reciprocal transformations (the mineral origins of living things and their petrifications) and their *in vivo* exchanges (biomineralizations, neighborhoods, and symbioses). A third avenue remains to be explored, that of a true intimacy between humans and the mineral world (stones, rocks) into which they project themselves or find themselves, as the poet André Frénaud describes when he evokes « the path of ferruginous blood in the stone. / The movement of my blood that recognizes itself there. »[75] Establishing this kind of relationship (necessarily asymmetrical) implies being more or less part of the continuity of the mineral — in a sensory, scientific, or poetic manner. We have already mentioned the importance of touch, which allows the sculptor or architect to reach the heart of the stone he is working on, or the evolutionary transformations common to minerals and living things, although according to distinct rhythms and modes, as François Farges judiciously reminds us: « Far from an anthropocentric Gaia, minerals are not born, they are formed. Rocks do not live, they exist. Crystallizations do not die, they disappear. »[76] However, Roger Caillois emphasizes about crystals that, even if they are not alive, they still know right and left, they are born, grow and heal[77].

However pertinent the rational arguments in favor of a continuity between the mineral and the living, human intimacy with the former is rather imaginary. Some, like Caillois (him again!), surrender to its mystery: « Je parle des pierres nues, fascination et gloire, où se dissimule et en même temps se livre un mystère plus lent, plus vaste et plus grave que le destin d'une espèce passagère. » (I speak of bare stones, fascination and glory, where a mystery is hidden and at the same time revealed, slower, vaster and more serious than the destiny of a passing species.)[78], as is the poet Yves Bonnefoy: « Such is the stone. I cannot bend over it without recognizing it as unfathomable, and this abyss of plenitude, this night which covers an eternal light, is for me the real in an exemplary way. Pride which founds what is, dawn of the sensible world! »[79] Others, far from these "visionary mineralogies" of which André Breton spoke (regarding the poet Novalis), resort to fiction: *La mort de la Terre* (The Death of the Earth), a science fiction novel by Rosny Aîné (author of the bestseller *La guerre du feu* (The War of Fire) features beings "of a mineral nature and helical shape", the "ferromagnetists", who have largely supplanted humans but are themselves destined to be supplanted by crystals: « The innumerable souls of the crystals were awakening to the light [...] Targ saw in it a reflection of mineral life, of this vast and tiny life, threatening and profound, which had the last word with men, which would, one day, have the last word with the ferromagnetic kingdom. »[80] Finally, in "The Tale of the Stone," Tim Ingold imagines a talking stone, which looks back on its entire life and imagines its end: « Perhaps one day, the heat generated by all these cement furnaces and the fossil fuels they consume will cause the oceans to rise, and I will find myself, as I was at the beginning, under the waves. Little by little, I will be covered in marine debris,

[75] André Frénaud, *Il n'y a pas de paradis*, Paris, Gallimard « Poésie », 1962, p. 92.

[76] François Farges, « Vibrations minérales et autres cristallisations vitales », *op. cit*.

[77] See on this subject, and on the poetic mineralogy of Caillois in general, the beautiful article by Juan Rigoli: "Life in stone" https://www.cairn.info/revue-litterature-2013-2-page-96.htm

[78] Roger Caillois, "Incipit" de *Pierres*, [1966], followed by other texts, Paris, Gallimard, "Poésie" collection, 1989.

[79] Yves Bonnefoy, « Les tombeaux de Ravenne », *I* 18. (*I : L'improbable*), *L'Improbable et autres essais*, Paris, Essais/Gallimard, 1983.

[80] Rosny Aîné, *La mort de la Terre* (The Death of the Earth), serialized in *Les Annales politiques et littéraires*, 1910; reprinted by GF Flammarion, 1997, p. 72.

and I will end my life like a fossil, not in the air but buried deep down, a stone within a stone. I will finally have returned home. »[81]

Thus closes the hierarchically tangled loop of the mineral and the living: after having contemplated the mineral becoming alive at the dawn of life, the living becoming mineral again *post-mortem* or through the grace of art, the inclusions of the mineral in the living (biominerals) and of the living in the mineral (fossils), we are finally faced with the oxymoron of the mineral itself being alive!

[81] Tim Ingold, « Conte de la pierre » (A Tale of Stone), inspired by a visit to the ancient Greek temples at Selinunte, Sicily, in *Being Stone*, *op. cit*., p. 74.

