From deep time to physics: the contribution of geology to the interpretation of some fundamental concepts

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Abstract. Our objective is to show how geology may help to make progress in the understanding of some fundamental concepts and issues dealing with space, time and movement. This leads us to the very theory of relativity in physics. A thought experiment is presented where geology has fully played a role. Deep (geologic) time is a way to speak of very slow movements, involving imperceptible changes of the ordinary space we live in. According to the relative speeds involved, what is space becomes time (when we accelerate the movements of the mountains); conversely, time may become space (at the scale of the femtoseconds where the sand grains in the egg-timer are immobile). This is not just an allegory: we can never stop, thinking we have reached a pure time and a pure space; because we are inside the world and we can only compare what moves more (on which we build time) to what moves less (on which we build space) within a relational thinking. In this context, conventions are necessary, in particular that of the constancy of a standard movement: this is what we do today with light. The uniformity hypothesis in geology plays the same role. The links between space, time and movement is discussed in various fields of geology (sedimentary sequences, metamorphism, metasomatism, magmatism, …) as they are omnipresent in prehistory.

Key words: deep time – space – movement – geology – physics – relational rationality – relativity theory – epistemology

Foreword

"Geology is the sister of time"
(Pierre Termier, 1913)

My knowledge in the history of geology is limited. I am both a geologist and a physicist, interested in the philosophy of science. I am particularly involved in highlighting the need and relevance of a *relational* (and not *substantial*) rationality in various fields of knowledge. Relation-based thinking has been discussed by many researchers; it is also called *complex* reason by French philosopher Edgar Morin (2005). Here I propose an epistemological look at the history of geology on the particular question of the trilogy time / space / movement. I will show how geology and its *deep time* inspired my reflection on the fundamental concepts of space and time in physics. Actually, the fertilization went both ways, from geology to epistemology and physics, and from epistemology to geology. This led me to some surprising conclusions, particularly that of envisaging a profound link between the concepts of time and space (Guy, 2015, 2019).

In a first part, I will make some reminders about deep time in geology. In a second part, I will delve into space: paradoxically, space was not discussed as such by geologists. I will then present my founding thought experiment that was inspired by geology. We will end with some consequences of the vision of space and time derived therefrom, both from a general standpoint and in geology. I will make an allusion to prehistory that was the main topic of the conference.

1- The contribution of geology to the discovery of deep time

Let us start our first part. In order to prepare this work, I have read several books. Stephen Jay Gould in his *Time's arrow and time's cycle* (1990) discussed the pioneering role of Hutton and compared his understanding of time with that of Newton. In *Les Travaux du Comité français d'Histoire*

de la Géologie (1980), François Ellenberger, Gabriel Gohau, Goulven Laurent and Jacques Roger, discussed the parting between short and long time and the role of different contributors such as De Luc, Gregory, Hutton, Lamarck, etc. Anthony Hallam (1983) explained the major controversies about the age of the earth. Gabriel Gohau (1987) in his *Histoire de la géologie* tells us about general concepts found in geology and its history. François Ellenberger (1988, 1994) in the two volumes of his *Histoire de la géologie* proposes a general vision and stresses the role of the elders. In his book on *A natural history of time*, Pascal Richet (1999) reminds us how physicists helped geologist in the measurement of time, but also tells us that the dialog between geologists and physicists was not always fraternal. Claudine Cohen (2022) in her *Imaginaires de la préhistoire* describes the facets and issues of geological deep time and the link between science and imagination; it is an important issue when we discuss relational rationality.

We can extract some lessons, among many, learned from the history of geology. For Aristotle (4th century BC) the earth is like the world, eternal and subject to incessant local changes that render it globally unchanging (Richet, op. cit.). Plato (358 BC) speaks of unlimited duration and constancy of processes. James Hutton (1788) (many quotes from Hutton may be found in the books of François Ellenberger) is known for his contribution to highlighting the continuous changes of the earth's surface. This author speaks of the "*interchanging of sea and land*", the "*vicissitudes of sea and land more than once*". *"The land is perishing continually". "The rising up of a continent from the bottom of the sea (is due to) an expansive power". "Our solid earth is everywhere wasted".* Georges-Louis Leclerc de Buffon in his *Histoire naturelle générale et particulière* (1749-1789, 1884) uses experimentation and physical deductions. John Playfair (1802) promotes Hutton's work and associates the immensity of the duration and the planetary movement: in one as in the other, the extent of the duration provided is unlimited. Charles Lyell (1830) stresses that the slow and continuous action of the present causes produces the whole of the geological events. In brief we can say that the geologic phenomena are very slow, as they are still today, and we must await immense durations of time before we see significant changes: this is deep time. Deep (geologic) time is relational, as based on the phenomena.

From my epistemological perspective, I would stress that, in the aforementioned works, the existence of time is not questioned; it is not defined either, although the works by Newton were known, especially in England by Hutton and Lyell. For his part, Newton (1687) defines an abstract, I would say substantial time, detached from phenomena: "*Absolute, true, and mathematical time, of itself, and from its own nature, flows equably without relation to anything external, and by another name is called duration; relative, apparent, and common time, is some sensible and external (whether accurate or unequable) measure of duration by the means of motion, which is commonly used instead of true time; such an hour, a day, a month, a year".*

2- The paradoxical absence of a discussion on *space*

In the previous lines, the scholars we quoted above did not find any problem with space. However, we understand the dimensions of time through spatiality: the immensity of time is understood through the slow changes of our surrounding, concrete, space, because of natural agents (erosion, mountain rising). The consequences of deep time on the understanding of geometric / geodesic space are not discussed.

Newton (1687) detached everything, as much space as time, from objects: "*Absolute space, in its own nature, without relation to anything external, remains always similar and immovable. Relative space is some movable dimension or measure of the absolute spaces; which our senses determine by its position to bodies; and which is commonly taken for immovable space".* Because of the general absence of discussion on space in geology, geological space seems to remain a Newtonian space, it rather looks as absolute. The question of the relation of space with material landmarks should be that of a relational character.

Ever since Antiquity, however, the geometrical representation of space has kept being studied by geographers and physicists. The geometric position of towns, mountains, harbours, etc. has been the subject of (mathematical) geography by the Greeks. In the 17-18th century, there was the development of triangulation and geodesy; the map

of France has been drawn, the shape of the earth as debated (Cassini, Bouguer, La Condamine, etc.). Guettard proposed a mineralogical map of France (1746), and initiated geological mapping in Europe. Geologists identified changes in concrete space within an abstract space they did not contest? The duality of meanings for these two "spaces" is discussed elsewhere (Guy, 2021).

So, we must still clarify the link and articulation between tangible space and concrete time as offered by geology, *even speaking of an identity of space and time*. Geology helps us to think about a strong, fundamental link between space and time. This renews our approach. Deep time refers to material space; both are relative to the phenomena, but each one is relative to the other.

Interlude: relational thinking

But before we go to our thought experiment it is useful to make a stop about relational thinking. The matter is to define the functioning of a relational rationality, and apply it to our subject. We speak of relational rationality when we cannot go outside the world; we can only compare objects with one another; we are then led to adopt arbitrary (open to free will) conventions to stop endless regressions in a (provisional) fiction. In this understanding, movement has the primary role. It is the support of the embodied cognition (imagination, intuition, body knowledge; cf. phenomenology). Relational rationality is opposed to substantial rationality, when we believe we can contemplate the world from the outside, each object being looked at independently from the others.

3- Space-time: a thought experiment inspired by geology[1]

So let me present my founding thought experiment and show how geology took me so far away. In my understanding, time does not exist. It does not exist alone, as an independent substance of the world. It is abstracted from the world, from which it cannot, ultimately, be separated. Specifically, for me, time is abstracted from the motion in space of material entities at large. However, when we abstract time, we construct an object which has pragmatic effects that can be studied and discussed.

To understand time is to understand its abstract nature and the very process of abstraction leading to it. To tell it short, time and space are the same. To avoid too many words, I make use of what French philosopher Bergson called the philosophical intuition, I call it the comprehensive, relation-based thinking, made of images, that comes in composition, not in opposition, with the discursive, disjunctive, substance-based thinking, mostly made of words. For issues that concern us, we especially need both.

How to speak of space and time? Neither space nor time exist in itself, but they are based on the phenomena of the world as we saw above. Let us imagine a landscape with mountains, some of them displaying folded strata. Space: some benchmarks borne by the mountains, as geographical markers that are planted there, as a set of points connected by the GPS network. Time as the sun going across the sky, or as the clouds, or as a cart: their movement allows us to classify, to sequence the events: when the cart was here, I did this, when it was there, I did that. Or, another landscape, another vision of time and space: a volcano allows to build space; ocean waves allow to build time: their progress serves me as a clock.

In what we do, we can look at space without needing to look at time. But this is not the case, and this is the heart of my discourse: time and space are not only related to the world, but also relative to, or in relationship with each other.

For a proof, a change of scale is necessary. With geologists, let us think through tens, hundreds of millions of years. The geological folds, or stone waves, are then strictly identical to the ocean waves we imagined a short while ago: they move like them and can serve us to measure time. Which served us to define space now serves us to define time.

But conversely, if we live at the scale of nanoseconds, the sand in the hourglass does not move for the duration of our entire life; the ratio of the nanosecond to the second is the same as that of the second to the century. The grains of sand may serve us as a distance gauge. What was used to set time is now used to set space.

[1] This thought experiment has been reported in several other places, e.g. in French, in Guy (2018).

Over short time scales, the ripples of a river and its swirls are similar to a landscape, we can pinpoint its irregularities to locate us.

One will say it is a beautiful allegory, but at some point, we will be able to stop and say: here is space, here is time. Well, no, in this infinite transhumance that in a way transforms time into space and space into time, we cannot stop; we are inside the world and we cannot bring rulers and clocks from outside the world to measure it. We can only compare phenomena with phenomena and, from this comparison, build space and time.

So, if we stop, it is not that we would have found a pure time, a pure space, with words defined in advance, as waiting to be used; but this is because we are tired. We stop at a scale relevant to the phenomena that we want, or that we can, study, and make a provisional sharing, between what does not move too much, we build space on it, and what is defined by comparison, and that moves more, and we call it time; but we are not sure of the ultimate meaning of the very words we use to talk about them.

4- Consequences

4.1- General consequences

All this would need longer developments. Here are some first general consequences. Time and space are of the same nature (*movement*); they are separated thanks to the multiplicity of relationships, and the sharing of them in two classes defined in opposition to each other. Space is based on invariable, or less variable relations than those on which time is defined. The limit between space and time is arbitrary (subject to free will). We use a relation-based thinking that needs to be stabilized by a decision: that of a judgment by which we choose, within the same thought, a declared constant immobility (spatial frame), in composition with a declared, also constant, mobility (the standard movement, whether human or offered by the physical world), on which our knowledge builds and loops: the postulates of relativity theory are there. In order to define measurements, we need a standard mobile in a reference frame. There are hidden conceptual loops in this process (in a way we need movement to define movement) and endless regressions.

We define speed by comparing two movements, one of which is selected as a standard. There are no longer rulers nor clocks but only a standard movement. So today we should not talk about the speed of light because light defines both the standards of space and time; or we can say that its speed is unity or rather say that light is the standard of movement. Initially, times are plural, as are spaces, supported by the multiplicity of local movements. We deal with one time, once the standard mobile is chosen. As a recipe: *social common time refers to the position of a mobile in 3D* space (think of the position of the sun or, nowadays, that of a photon in an atomic clock). All is not solved, the mystery of time is moved, but we have new keys to reread many issues, from humanities and social sciences to physics.

4.2- Epistemological consequences in geology

We may make some reference to the consequences in geology. The concepts in pairs, that we find in the history of geology, must be discussed and understood together (and not chosen separately). Processes versus fixity; cyclic time versus sagittal time (cyclic time, as well as rhythms, are allowed by space: Guy, 2020); uniformitarism versus catastrophism, etc.; one should not try to argue how to choose one over the other. These concepts are defined in opposition / relation to each other and the boundary between them is a matter of convention / choice depending on the spatio-temporal scales, on what we are able to measure/see, and what we are interested in (choose what to keep constantly variable as compared with what is constant). We cannot do it in any other way and it is interesting to put the finger on the point where we have made the convention. We find the same approach in physics. What link can we see between geological uniformity and physical uniformity? The hypothesis of light constancy is transported to geology within the physical laws and is another way to speak of the same time rating for mineral dissolution, heat diffusion, etc., in geological processes.

We may stress the increasing part in the vocabulary of geology, on processes that always associate space and time This is found in all fields.

- Metamorphism: (p, T) paths, propagation of metamorphic zones / facies…
- Metasomatism: propagation of metasomatic fronts; contrasted velocities of fronts; replacement; epigenesis…

- Magmatism: fusion, solidification, assimilation, differentiation, …
- Tectonics: shortening, subduction, extension, rising, thickening…
- Sedimentology: progradation, transgression, erosion, flooding… This expresses a link between stratigraphy (vertical vision) and large-scale processes (horizontal). The names of rocks such as limestone, sandstone, claystone etc. now come together with names of processes.

We should discuss names of rocks and other geological vocabulary within a space-time relational understanding. A dynamic, non-ontological vocabulary is a matter of scale. A rock name is at first substantial; a cut has been made between space and time on our human scale. On longer scales, a piece of granite is transient, between the solidification of a magma and the weathering at the surface of the earth. This joins the considerations of French writer Roger Caillois (1980) and others on the use of geological symbols in philosophy or in poetry. We must see the movement hidden in the rocks, whereas in standard philosophy, the stone is the symbol of fixity.

4.3- Consequences in prehistory/paleontology

In Prehistory, authors have discussed the spatial dynamics of territories, the waves of progression of archeological evidence in space and time (cut / polished stone, arrows, domestication of animals, agriculture, pottery, ceramics, etc.). Michel Rasse (2015) studied the propagation of Neolithization in Europe. Space and time themselves may be defined by archeological evidence. Prehistoric waves do not stop everywhere at the same time: there are superposition, succession, competition of waves. The input of our present studies may be to bring some epistemological and lexical insights, and to discuss the place where some conventions are made, that sustain our choices to describe the history of ancient man.

We may end with a few quotes by a French geologist who was also paleontologist and prehistorian. Teilhard de Chardin (1957) spoke of different kind of waves:

"Let us remember the waves of stone rising interminably from the depths of the past..."

"One of the most important advances made by the human mind in the last century is to have overcome the illusion of the immobile... "

"Transformism, experimentally constructed, inclines us to think that the living groups appear, follow one another and interfere a little like waves. Each group, it seems, is born in a restricted zoological and geographical domain, from rather few individuals, arrived at a same organic stage and placed in similar conditions of environment; and, from there, it spreads with more or less success on the surface of the earth." We can speak of waves for geology as well as for living and human groups; natural and human waves may compete or work together (Guy, 2016).

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