MONSOON ASSEMBLAGES FORUM: PRACTICES AND CURATIONS

Inside the Critical Zone

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Landscape architects use maps, schemes, diagrams, models, to describe and design territories, as conceptual and visual tools of knowledge (Yaneva 2005). But do these tools sufficiently depict the complexity of landscapes (Yaneva and Zaera-Polo 2015)? Plans and the diverse kind of maps used by landscape architects depict land surfaces and few are dealing with the depths of the Earth and its processes, i.e. the biogeochemical cycles. In the meantime, a branch of geosciences studying landscapes as Critical Zones, shift away the traditional understanding of nature as a stable background for human activities and introduce complexity (agentivity of natural entities, time, depth). However, according to these Critical Zone scientists, their object of study is not effectively visualized, limiting the scope of the concept. Therefore, the aims of the scientists and those of the landscape architects meet. This article deals with these two aspects: first, to visualize the Critical Zone, and second, to make the understanding of nature more complex for landscape architects. It is based on ethnographic observations: the careful observation of scientific practices in the Critical Zone. Finally, it suggests that visualization can also be a format of inquiry that we could explore further.

The Critical Zone (CZ) refers to the space or volume at the surface of the Earth from the deep rocks to the tree canopy that makes life possible. The CZ is the product of chemical weathering and erosion, occurring when the water transfers chemical elements through rocks that will eventually form fertile soils (see Figure 1).

Even if the Critical Zone is planetary, it's not the entire globe, but only the thin layer of a few kilometers deep inhabited and now also threatened by environmental disturbances caused by human activities. These disturbances are now widely recognized as the Anthropocene. Even if still disputed, this term challenges our apprehension of space and time, because of the conflation between the relatively short human history and much longer geological times. The Critical Zone science is a network of geoscientists aiming at collectively understand the impact of the Anthropocene by studying complex cycles at the interfaces of soils, atmosphere and rocks. They

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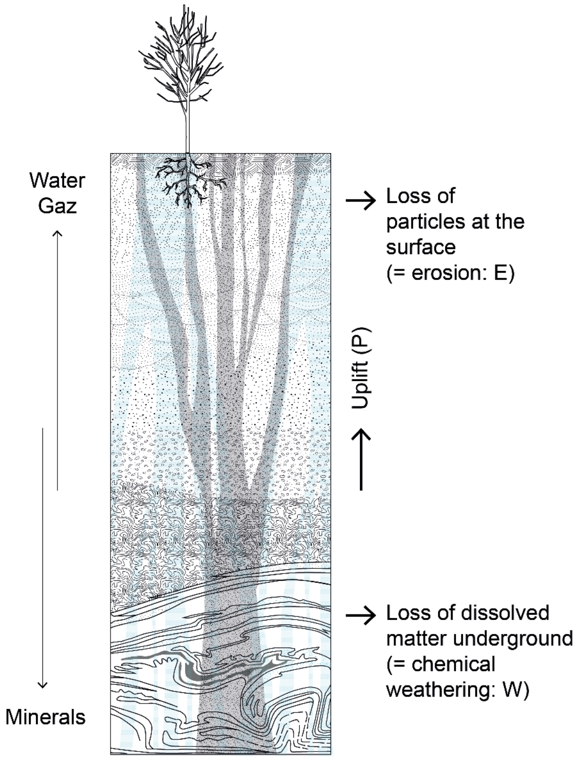
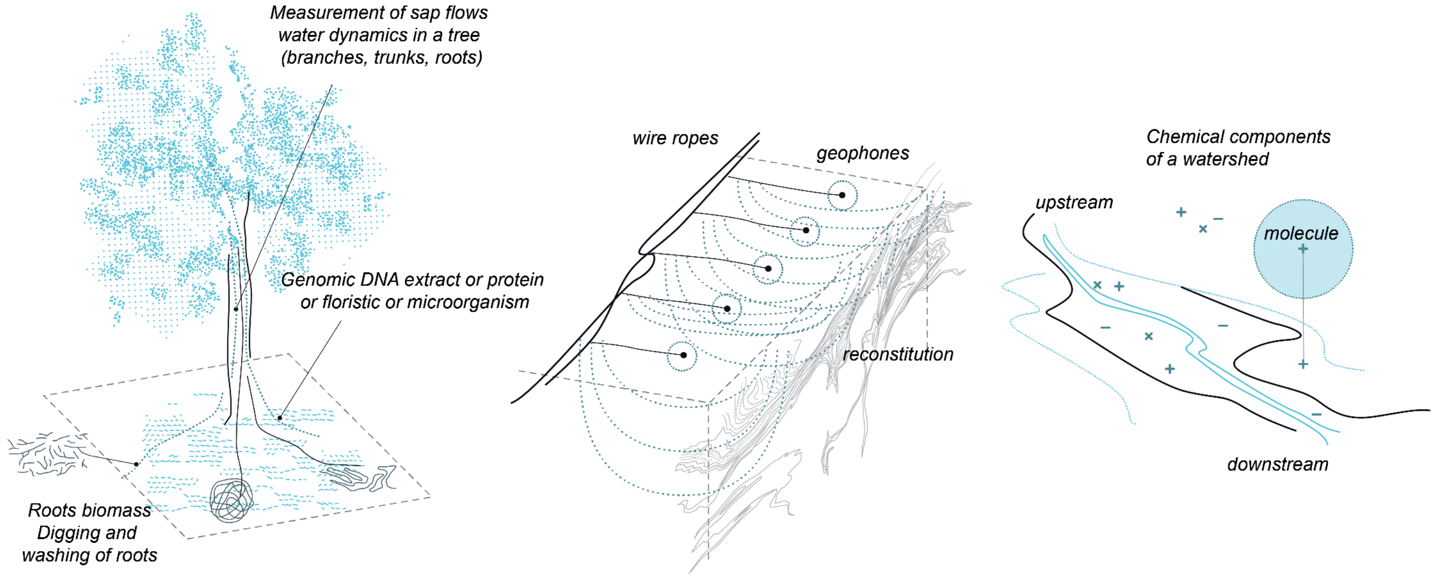


FIGURE 1 Critical Zone sample section, process of soil formation. Drawing by the author.

ground these studies in local and outdoor observatories, which range from a few hectares to large watersheds (Brantley, Goldhaber, and Ragnarsdottir 2007; De Richter and Billings 2015; Gaillardet et al. 2018). In these landscape laboratories also called Critical Zone Observatories (CZOs), they study geomorphology, water circulation and chemical exchanges, such as the circulation of carbon, nitrates, phosphorus, Sulfur, either recycled by microorganisms and bacteria or disturbed by human activities like agriculture or industry. To grasp these processes, they set up instruments in landscapes. Some of these instruments diagrammed in Figure 2 give them an understanding of landscapes by focusing on the processes, which are invisible and moving phenomena for most of us.

METHODOLOGY: ETHNOGRAPHIC OBSERVATIONS

I follow these scientists in their various observatories for four years, grasping sciences in action (Latour 1988), in the making, through interviews and the careful recording of the practices allowing the scientists to gain knowledge on the variations of nature. The methodology for collecting qualitative data draws on STS studies that introduced the whole program and set the methodology of following scientists at work (Latour and Woolgar



Tree survey
Biological activity, soil-atmosphere gas exchanges, water transfers.

Hydrogeophysic
Mapping waters underground through the records of seismic activity

Chemical sample
Composition of water

FIGURE 2 Diagrams of some instruments used in the critical zone observatories. A classic STS argument is that through the lens of their instruments, scientists gain access to otherwise invisible worlds. Therefore, if we want to understand what knowledge on nature is brought by the critical zones, we need to study the instruments as a priority. Drawings by the author.

1979; Lynch and Woolgar 1990) mostly in their labs and a few outside (Latour 2000; Law and Lynch 1988). I also rely on Actor-Network Theory (Latour 2005) to avoid the classical distinction between the social and the physical (an artificial distinction that disappears as soon as we follow the actors' practices). These references inform my ethnographic observations, tracing not only the movements of the scientists but also all their instruments, and the various entities that compose soils, water or trees. By moving measurements, instruments, maps and graphs back and forth in the field and the lab, I witnessed how scientists trace a territory and grasp the complexity of landscapes.

In addition, I propose to contribute to ethnographic observations for landscape architecture, through a speculative gesture (De Bebaise and Stengers 2015), the development of a new "format of inquiry" (Corteel et al. 2019). This new format of inquiry through visual rather than textual tools, wishes to be a way of understanding the complexity of landscapes that we can discover when we closely follow scientific practices in the Critical Zone. As with cosmograms (Houdart 2015; Tresch 2005), my goal is to understand how scientists relate to the Critical Zone and how they compose worldviews within these relationships. Based on local sites, scientists in the Critical Zone describe nature as a much more complex assemblage than commonly thought. Indeed, they ask: what would happen if a river was not as we thought we could see, trace and measure it? And the landscape architect might add "and adapt to the design"? To go further, could these cosmograms, which are new ways of understanding nature as a "Critical Zone," be transported into the field of landscape architecture? What does this mean and how can it change the way we situate ourselves on Earth?

I will describe the first steps of the making of this tool in the second part of the article. In the first part I will describe a typical journey into the Critical Zone.

PART I. TRACKING SCIENTISTS IN THE RAIN FOREST

Each CZO (Critical Zone Observatory) has its own particularities: some are similar geographies and scales, others share climatology or geology, or also the typology of their instrumentation. To be able to understand the Critical Zone, it was necessary to immerse myself in their Observatories: to experience the science from the inside (Haraway 1988), to understand how the instruments operate and what new visions of the landscape the scientists are likely to make us discover (Daston 1992).

In May 2019, I followed the scientists in their work during a short but intense data collecting. The campaign was hold in a watershed located in Guadeloupe (France) and called Bras-David (see Figure 3). The CZO of Guadeloupe (ObsErA: Observatory of Water and Erosion in the Antilles) is part of the French CZ network set up in 2011 to study tropical zones that are particularly sensitive to environmental changes. Nothing is stable in the Antilles; everything goes very fast: the cycles are rapid, the alteration goes wild, the plants decompose in a few days. The climatic events are extreme too, flooding occurs in a few minutes and may be dramatic. The overall research question is to better understand what makes up the Critical Zone here in order to understand how forests and soils will react to climate change and what drives their responses to disturbances such as storms. During the campaign that I followed in this CZO, the scientists collated data to understand the water chemistry at depth because when water circulates, it transports nutrients from rocks to the surface that are captured by the biomass and the soils.

FIGURE 3 Photography of the river studied in the Guadeloupe CZO, taken during the author's fieldwork.

Let us now follow the scientists! We moved at high speed in the mud, on slippery rocks, in wet weather, among mosquitoes. Geoscientists were difficult to follow, literally, through the forest. Indeed, it is easier to follow them in their labs than in the field! Lin, a geochemist, measures uranium in the river. He uses an experimental measurement device directly in the stream that he let for 15 days. Samples are also collected. Scientists fill up bottles with the water from the river caught at several points along its path. They will look at whether or not the composition of the water changes, looking at the chemical signatures of the Earth here. As it has never been done here before, we have to go down, up the river, follow it, and sometimes slide over the wet rocks smoothed by the water. Water alters rocks, makes soil, because chemistry transforms it by hosting water molecules. At the interfluve, piezometers have been installed. They "measure the sponge in which we are traveling," says Jérôme, the scientific leader of the mission, with an explorer look. Figure 4 illustrates some scenes from these ethnographic observations.

Here the weathering is very fast. However, despite high decomposition (by the heat, humidity and high biomass), deep weathering is still slow. Why? I learn that it is because the top soil is dense and thick (40 meters!), so the water can't pass through soils to reach the rocks. Likewise, roots come out of the soil because this one is saturated in water. They call it the "floating" forest (see Figure 5 for a view of this landscape). Therefore, scientists start to suspect that nutrients come mainly from the canopy, not from bedrocks: Sahara dusts is what allows the forest here to be there! Sahara is thus a major nutrient supply that scientists have found by tracing isotopes.

According to Tsing and Bubandt: "we moderns see ourselves making the world but forget that other organisms are constantly reworking our works" (2018). Indeed, as I learned, trees have developed different strategies to make their ground. Jane, an American scientist, told me other extraordinary stories about trees and their resilience to hurricanes. Palm trees are like umbrellas: only half of the rain falls on the ground because the leaves protect them and prevent nutrients (their food) from dissolving; they keep them under their umbrella! Trees slow down erosion, which is why it is so strange that a tropical climate does not have so much erosion: "trees make their own landscape, they play such an important role," she told me. Trees maintain thick soil so that rocks going up from below slow their rise to the surface and have time to be gently altered, become small stones and eventually sand. The trees breathe noisily around us, we are in their heavy and humid exhalation, absorbing and releasing CO_2. This space has nothing to do with the map the scientists showed me to explore this part of the island (see Figure 6). Even the clouds above have several thicknesses. We are clearly not on a surface, we evolve in layers more or less traversable by our bodies. Sometimes even our feet penetrate the ground. Nothing is flat, we go up, down, slide in. There is no surface, no faces, no interfaces. There is a volume, a vertical zone whose boundaries are blurring: this is what they rightly call the "Critical Zone."

PART II. DRAWING A MODEL

Situation of the Problem

What we learn from this brief story of the fieldwork is that soil is deeper than what we take into account in landscape design. We also learn that each part of the Earth is connected to another.

FIGURE 4 Tracking scientists at work. From left to right: measure of conductivity, Sylvain's geoseismic line, the forest, Bill's biochemistry sampling, Lin's chemical sampling. CZO Guadeloupe, ethnographic observations.

FIGURE 5 The "floating forest," Guadeloupe.

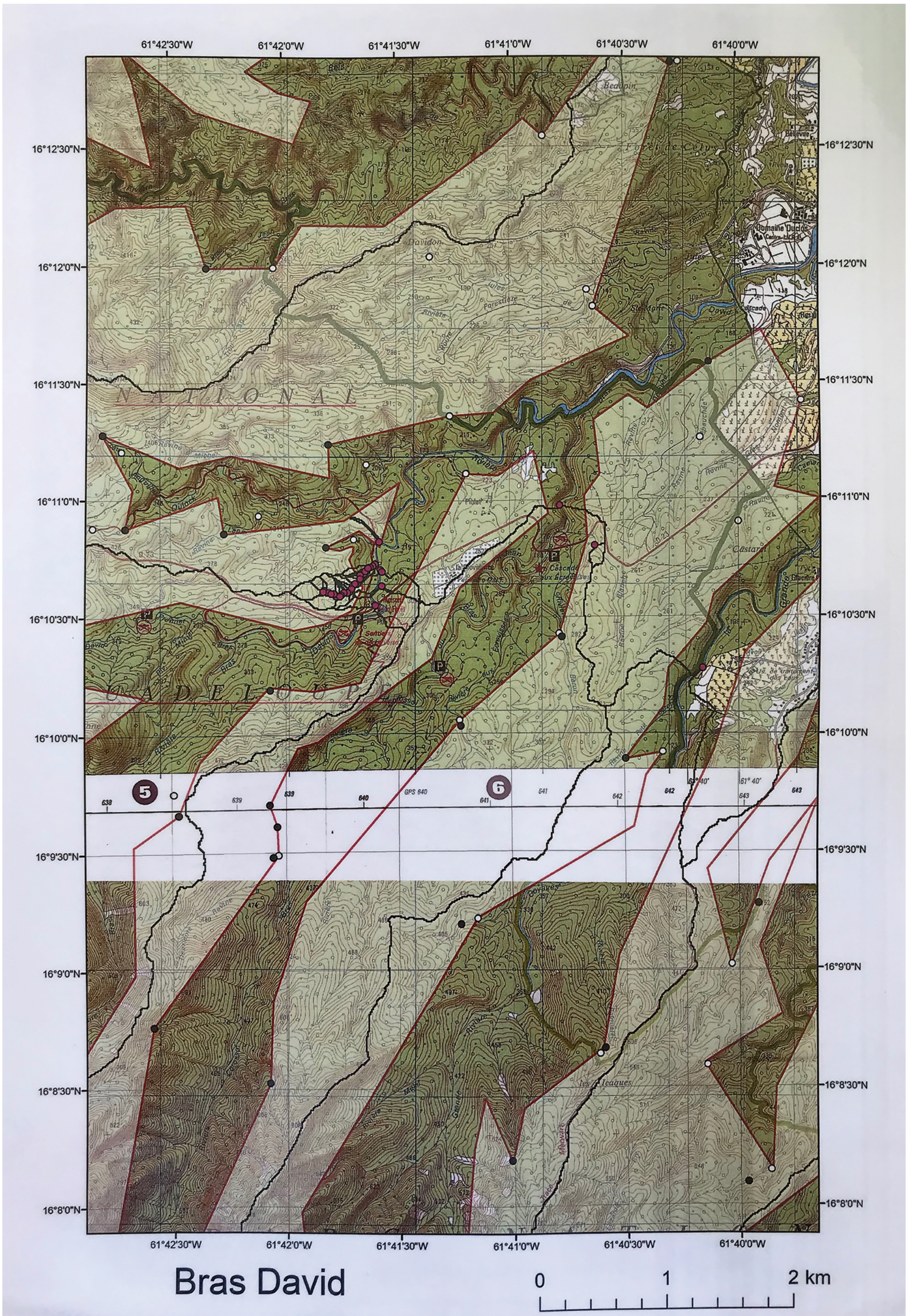


FIGURE 6 The map used by the scientists to explore the streams of this part of the island: they are looking for new places to monitor the water at "knickpoints" (where there is a change in topography, where water from the subsoil gushes to the surface: there are interesting chemical samples to take here because the water is loaded with minerals from the subsoil rocks).

Finally, we witness here the agentivity of natural entities that we once considered as background: they are actually the ones that make up the environment.

Thus, by equipping the landscape with instruments, the scientists visualize the precise internal movements of landscapes: chemical flows, air turbulence, temperature changes, actions of microorganisms, seismic movements, chemical transport of pollutants in different parts of the Earth, chemical transport of tree molecules by leaves, wind speed and much more. The CZ changes our perspective: we are inside a dynamic process of terrestrial cycles where humans and non-humans are included in the same vortex of things.

However, this complex understanding of nature disappears on the flat surface of a map which uses latitude/longitude system to locate a place. What we need to know now, as Sylvain (a scientist in charge of modeling the critical zone) told me, is not "where are we" but "where are we at this moment, into which cycles"? This is a different type of localization. As Dilip Da Cunha (2018) argues in his book *The Invention of Rivers*, the problem with traditional cartography is that it freezes landscape features into a single state and excludes their changing states, like the water cycle. He argues, with others such as Italian Limes (Ferrari, Pasqual, and Bagnato 2018), Monsoon Assemblage (Bremner 2020) or Forensic Architecture (Duncan and Levidis 2020), that the river, as well as the borders as such are cartographic inventions made by drawing a boundary between two "milieu," soil and water in the case of river, with an abstract line. Borders, frontiers and lines are not enough to describe landscapes at a time when we need to visualize environmental changes: the melting of ice, the flooding water or the atmospheric pollutants scattering everywhere. The historian of philosophy Helmut Müller-Sievers (2000) explains that cartography based on the Cartesian grid ignores depth, growth and time. He argues that we can look to chemistry for a representation of space that includes time because it is the science of becoming, attraction, and growth. As he writes:

> Chemical processes build up the content of the earth from its inner core outward and thus regulate the qualitative distribution of matter upon its surface. Chemism provides the dimension of depth that is inaccessible to any geography based on the geometry of surfaces. This is not only the third dimension of physical space but the dimension of manifest time, of geological history.

This type of temporal cosmogram is very much in line with the way scientists in the Critical Zone approach landscapes, as they use extended time scales: from geological time to high-frequency monitoring. Like any architect who thinks with visual tools, I began compulsively drawing diagrams to restitute the "space" of the Critical Zone that seems to unfold through the observation of scientists' practices. This space does not share much in common with the Cartesian space. I therefore found it useful to translate these findings into a tool halfway between science and landscape architecture: a transitional tool to situate ourselves in this fragile skin of the Earth that is the Critical Zone. This "abacus" or model (I'm still struggling to give it a name) is not intended to compete with cartography. Rather, it is a complementary and questioning tool on how we understand our environment based on what I have observed in the field. In the last part, we will discuss how it changes our spatial coordinates and perhaps allows us to better understand the landscapes in which we are intertwined with many other invisible entities.

A Model according to Geochemical Cycles

As we saw in the field, geochemists of the Critical Zone follow the traces of elements to detect the chemical processes that impact landscapes: these are the biogeochemical cycles passing through the compartments of the CZ, i.e. atmosphere, biomass, soil, rocks, when they alter or erode matter and let different chemical signatures in landscapes. Related to what we have known from the fieldwork (deep soil/connectedness of phenomena/agentivity of entities), the model aims to tackle three questions: I. how to give depth to the surface and to the thickness of the soil that urban planning takes as a surface to build upon? II. How to pass from the traditional spatial localization (longitude/latitude) to temporal localization in cycles (kinetics)? III. how to convey human impact?

Drawing on ethnographic observations and months of interactions with the scientists in different CZOs, I produce a template to collect the geochemical signatures. This diagram, template, abacus or conceptual model represented in Figure 7, uses a visual grammar to map cycles. These cycles are the result of the association, dissociation, combination, or transformation of the dynamic natural entities, hence the name "gaia-graphy" (Arènes, Latour and Gaillardet et al. 2018), after Lovelock and Margulis theory of the Earth (Latour and Lenton 2019; Lovelock 1979; Margulis 1998).

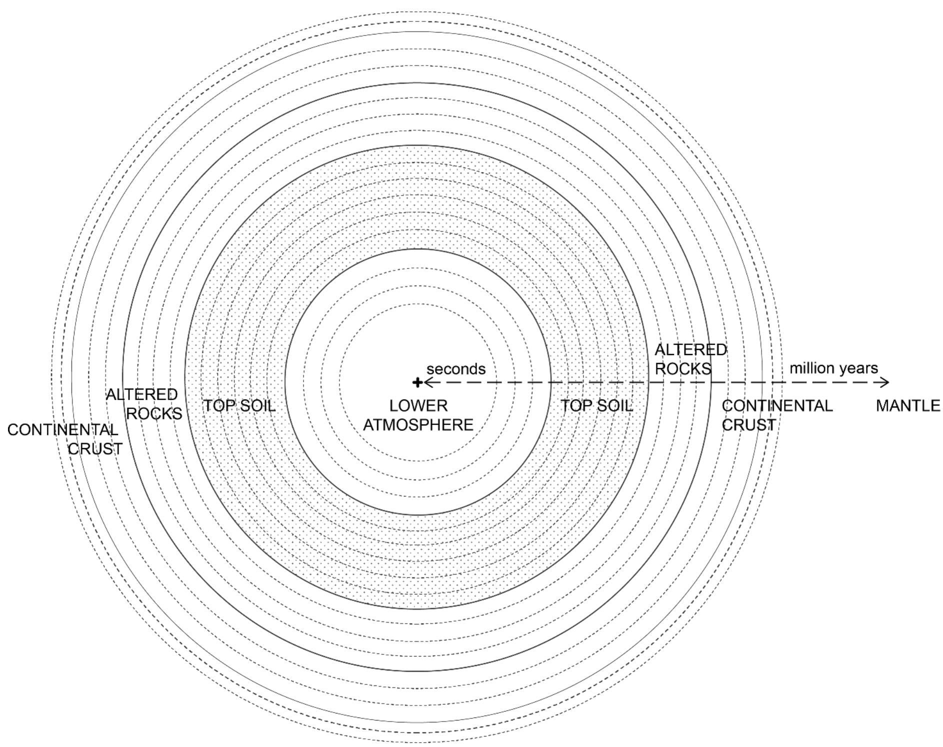


FIGURE 7 The model is a new format of inquiry that I use in my fieldwork with scientists to visualize the Critical Zone. Drawing by the author.

Step I. Giving Depth: From the Surface to the Thickness of the Soil

The template doesn't aim to visualize the surface of the land but rather the vertical layers of the Critical Zone, from the rocks to the atmosphere. We start by opening up the globe to see what is inside. In doing so, we realize that the Earth's core is taking too much place whereas the soil is invisible. Yet the core is the most remote place for us as we are soil earth bounded creatures. So, we imagine doing a simple gesture: to turn the skin of the Earth as a glove. Figure 8 illustrates the steps to build this view.

In this view, the atmosphere is at the center and the core at the periphery. Topologically this is convenient for us, since the chemical elements, including pollutants, are trapped in a space that did not previously exist on the map (the atmosphere layer). Even if traveling, pollution remains into the air we breathe, as shown in Figure 9. Similarly, the rocks that we did not see before actually surround us and make us sensitive again to the ground and of what compose it, including buried anthropic wastes. Moreover, it gives more space to the top soil as it was previously invisible at the global scale where it did not even appear as a thin film at the surface of the planet. Yet, we have seen previously the thickness of the soil may vary enormously, from 40 meters thick in tropical environment, to only 5 meters thick in Europe.

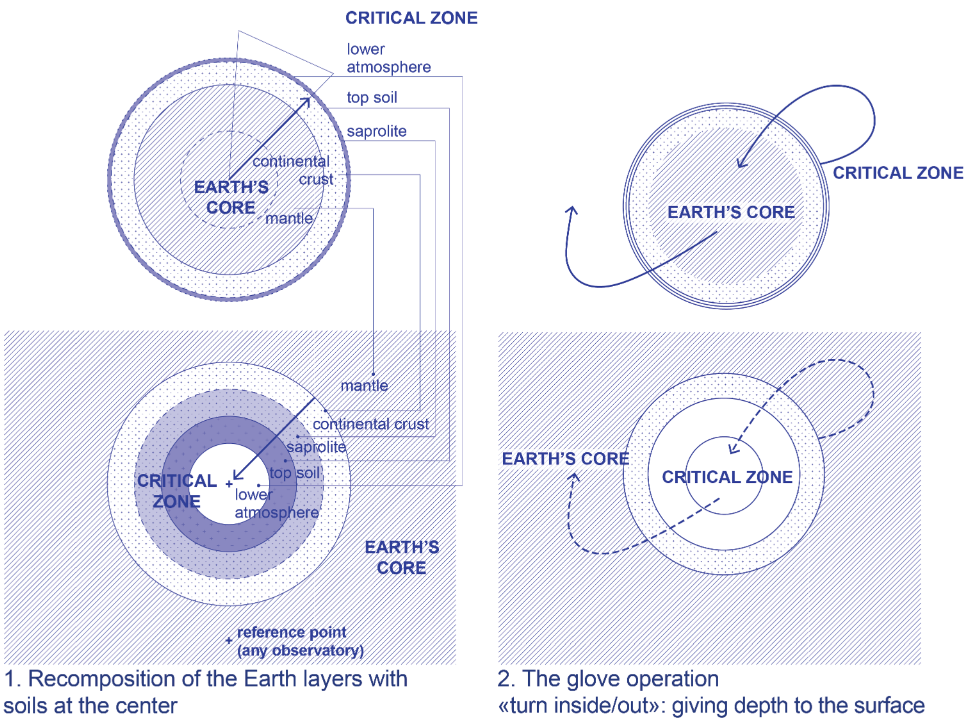
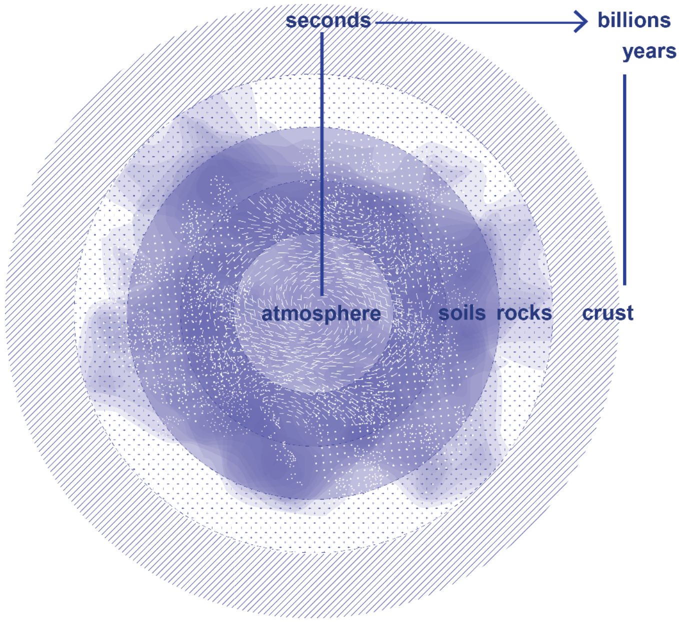


FIGURE 8 First steps of the construction of the template: reversing the Earth's skin in order to give more space to the soils, this thin layer which is invisible at the planetary scale and yet primordial for life. Focusing on a specific place, on an observatory, we can measure precisely the depths of each vertical layer (lower atmosphere, canopy, soil, weathered rocks). A visualization of a CZO in the Vosges forest using this template model can be visible in the exhibition "Critical Zone observatories" at the ZKM Karlsruhe (2020). Drawings by the author.



3. Soil-atmosphere coupling: pollution is kept inside

FIGURE 9 This template makes it possible to visualize the concentrated and cyclic pollution in the atmosphere. Each circle (layer) also corresponds to temporal phenomena: in the atmosphere, the circulation of chemical elements takes a short time, whereas in deep rocks, the cycle takes longer to complete. Drawings by the author.

Equally important, it gives a time scale to the Anthropocene. Indeed, thanks to these processes, we can capture vertiginous scales of time and space—from seconds to millions of years and from meters to thousands of kilometers: the scale is defined according to the phenomenon, the cycle.

Step II. Passing from Spatial Localization to Temporal Localization in Cycles

Water movements are, as we have seen, what scientists follow through the jungle, taking samples, analyzing its chemistry, because it gives information on how the earth is reacting. These bio and hydro movements put the elements into motion, in cycles, and thus terraform the landscapes: it shows where we are in the Earth evolution and not where we are on a surface not reacting to us. The cycles cross the strata of the CZ from top to bottom or bottom to top, losing or gaining speed with each transfer, and also losing or gaining chemical element quantity. Thus, we had to foresee in our coding the direction of the cycle, its speed and its quantity. As illustrated in Figure 10, two opposite directions help to trace its trajectory: centrifugal (from the center to the periphery, therefore from the atmosphere to the rocks) or centripetal (from the periphery to the center, therefore from the rocks to the atmosphere).

The quantity is simply visualized through the thickness of the lines. The angle of the spiral defines the time it takes for a phenomenon to occur and so for an element to change its form: the more the angle is flat the more it takes time for change whereas an acute angle means that the element is rapidly transforming (see Figure 11).

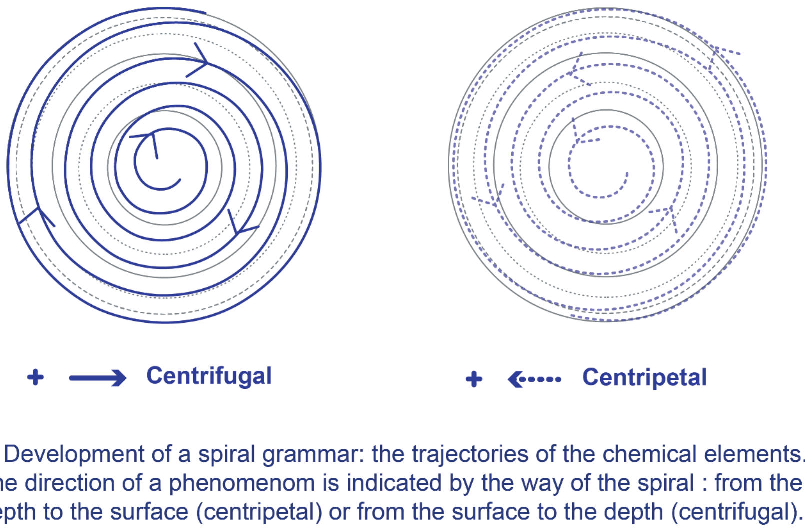


FIGURE 10 The cycles are represented by spirals originating from the atmosphere or from deep rocks: they move in one direction or the other, from the surface downwards or the other way around. The first movement is centrifugal (the elements are dispersed in the rocks and leave the observatory boundaries) and the second is centripetal (the elements rising to the surface concentrate in the atmosphere where they are captured by soils and biomass). Drawings by the author.

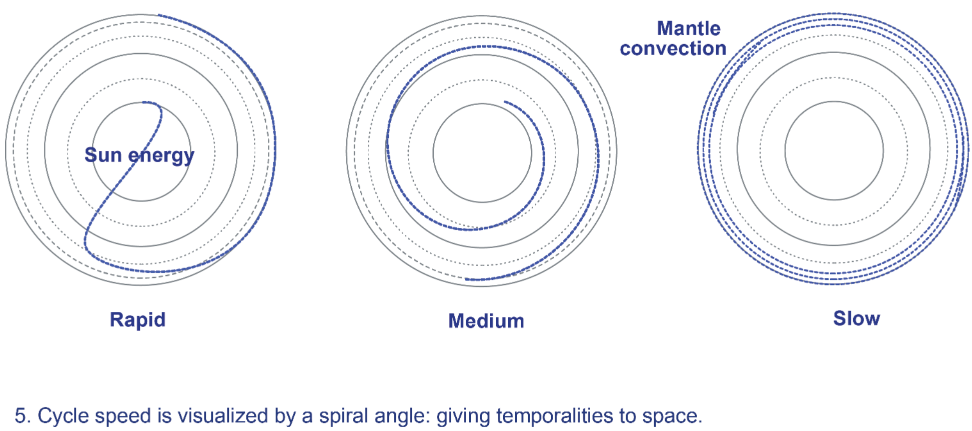


FIGURE 11 The cycles move at different speeds. Thus, we give a speed to the angle of the spiral, ranging from flat (slower movement, almost always influenced by the mantle cycle) to rapid (faster movement, almost always related to the components that rotate in the atmosphere). Drawings by the author.

Step III. Conveying Human Impact

Let's now draw a cycle. The carbon cycle described in Figure 12 is one of the most important on Earth, for both organic and inorganic materials. Each time the line bifurcates, that is, takes another angle while spiraling, means that the element traced, here the carbon, is transforming. If it is transforming through long period of time, like in subduction (process 8), the angle of the bifurcation is flat. On the contrary, when the transformation occurs in a short period of time, in days for example with the respiration (process 2), then the angle is steep.

By doing this exercise with the carbon cycle and decomposing its transformations (or bifurcations through the layers) step by step, we have drawn a line that goes down, and rises regularly, that balances in both directions and loops. Except at one stage: when the carbon stored in the deep strata is extracted and brought to the surface very quickly by human industries (process 7). This line cuts the "natural" spiral, not allowing the elements to be slowly transform and digest by the earth processes: the cutting line, the sharp extraction,

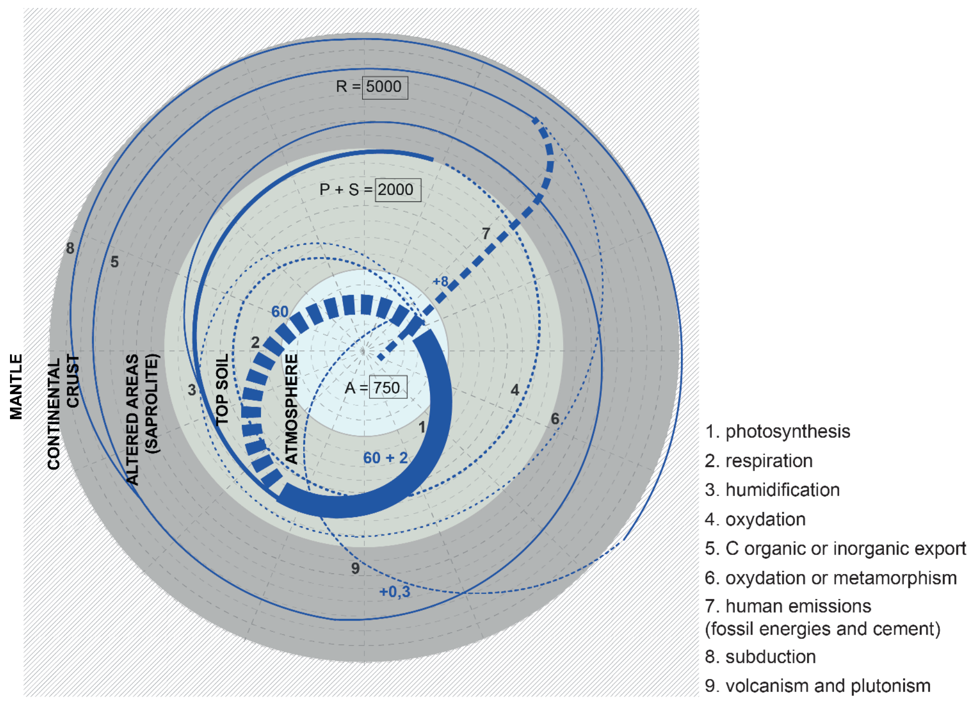


FIGURE 12 The terrestrial carbon cycle in the Critical Zone, carried out with the help of IPGP (Institut de Physique du Globe in Paris) scientists. The figures correspond to the amount of carbon in each reservoir in gigatonnes (Gt) for the atmosphere, soil, and rocks. The spirals describe the trajectories of the carbon in each layer and their thickness the amount of carbon lost or gained during the transfer. Drawings by the author.

shortens distances in space and time, and does not loop. It remains suspended in the atmosphere. It therefore shows that the human signature is a shortcut through the earth layers, disturbing the carbon cycle. As we know, human industry is an accelerator of CO_2 circulation. In this visualization of the CZ, humans appear as a trace, a perturbation of the biogeochemical signal at the time of the Anthropocene.

CONCLUSION

The Critical Zone extends the scope and the scale of what can be seen in landscapes. Combined with ethnographic observations, landscape architects can use their tools to go further in exploring the Critical Zone, by modeling, drawing and visualizing it. In the first part of the article, I extracted some reports of my field work in CZOs to show how the actors I followed generate new knowledge on nature. In the second part, I focused on the issue of mapping and tracing landscapes. As we acquire a new understanding of nature by following scientists who themselves trace biogeochemical cycles, we need a new *graphy*, a tool for tracing the Earth's moves. This is this visual experiment that I am currently conducting with the help of scientists: to trace the times and depths of the Anthropocene, a gaia-graphy of the Critical Zone.

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