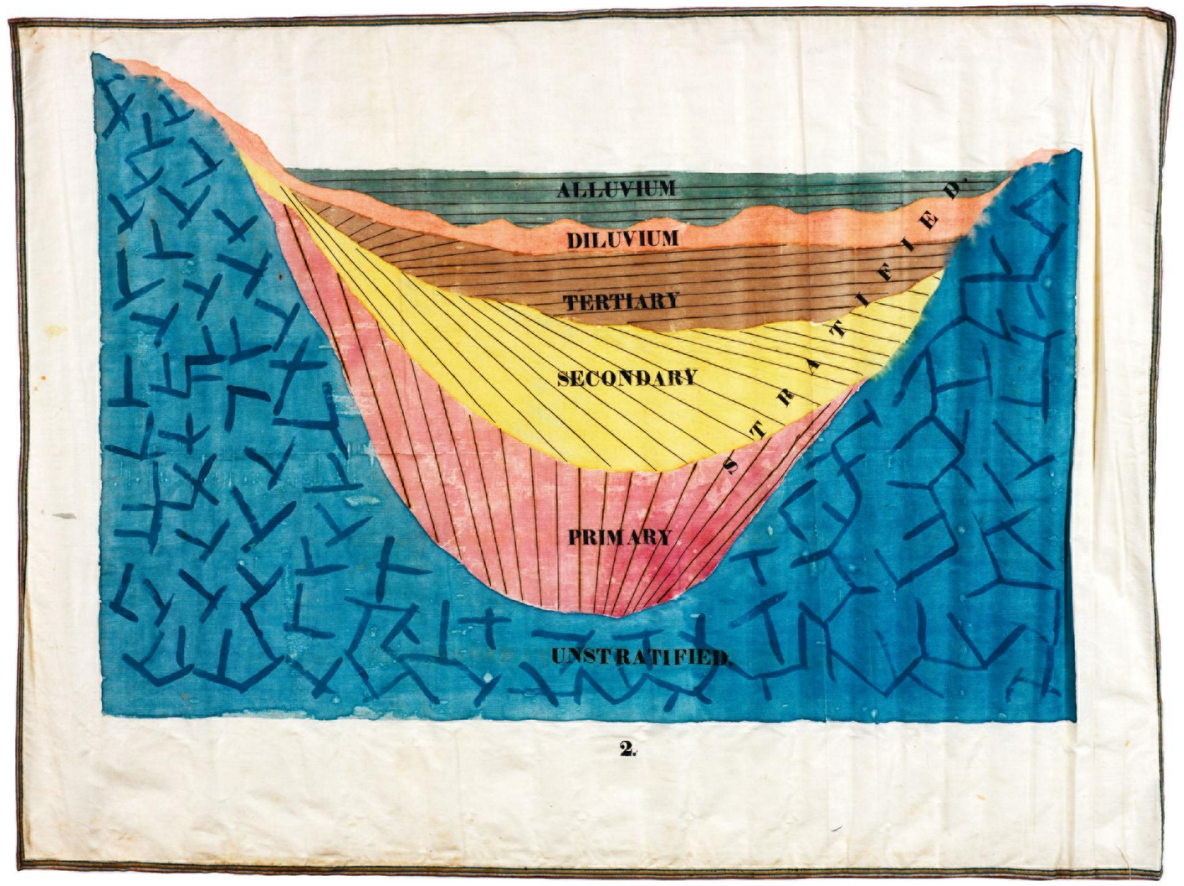


Orra White Hitchcock, Drawing of slate, Devonshire, England, 1828–40. Pen and ink on linen, 22 × 69 cm.

DISORIENTATION

Fear might be the best way to begin this section. This is at least the suggestion of Dipesh Chakrabarty in his interview: "I grew up in a place where fear was very much still a part of my life. Something about that reverence has to be brought back to supplement our very Aristotelian sense of wonderment …"

Chakrabarty has been one of the first to convince historians — meaning historians of *human* adventures — to pay attention to the disorientation induced by the introduction of coal and gas into the rhythm of social and world history. Everything happens as if the global — what modernity was supposed to deliver on the surface of the planet — is entering into conflict with what Chakrabarty calls the "planetary" — that is, the same planet once dreamed of, except now it appears concrete, material, reacting to human actions, and above all, *limiting* global development.

Everybody nowadays is aware of the name geologists have given to this disorientation: the *Anthropocene*. Nobody has done more to make the discipline of stratigraphy known to the general public than Jan Zalasiewicz. The study group that he has assembled and guided has provided a scale for measuring the magnitude of human intervention into geological history that had not been realized before. And, indeed, "in the Anthropocene, almost everything becomes geology" (Jan Zalasiewicz). Hence the sad beauty of Zalasiewicz's summary of this human intervention, a picture achieved by reducing some of the geological data to a one-meter measure. How odd to realize that the biomass, according to this metric, is just five kilos per square meter, whereas the stuff humans have been able to produce — rubble, ruins, soil and all — weighs as much as fifty kilos! We knew "man was the measure of all things," but we did not know the surprising length of that measuring stick. And to learn that the collective pressure of human activity is comparable only to asteroids at the end of Cretaceous or giant volcanoes at the end of the Permian, does not make the measure any less distressing.

After all, volcanoes too have been dragged into our culture, as Karen Holmberg argues, but it's not reassuring that humans have become volcanoes themselves, especially as their kind of industrial eruption works 24 hours a day, 365 days a year.

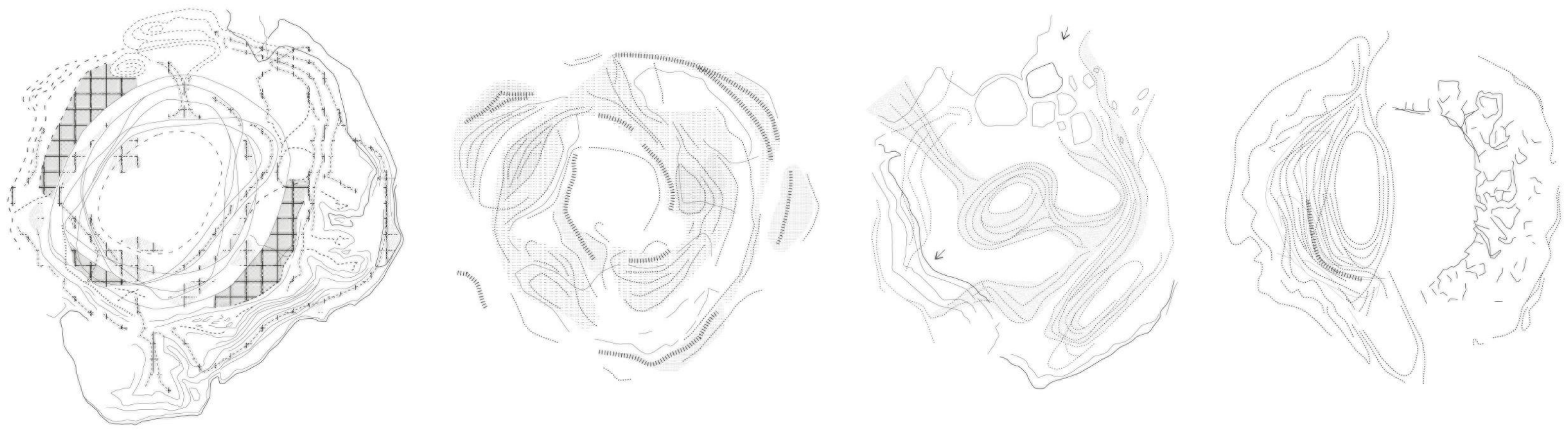
No wonder that the word Anthropocene has metastasized to the point that Clémence Hallé and Anne-Sophie Milon can refer to "the Infinity of the Anthropocene." The news is so disorienting that every discipline, every interest group offers an alternative term, insisting on this or that other variable, in order to cope with the maelstrom. That's actually the good thing about this new geological label: it has spread everywhere and yet it is impossible to settle quietly "in" the historical period it designates.

It is actually one of the characteristics of the present that this disorientation can be observed in many different sites and at very different scales — which is what the layout for this volume allows. Witness the care with which an artist like Sonia Levy follows the work of oceanographers and biologists as they accompany and maybe preserve (or at least learn as many lessons as possible from) the threatened corals gathered in the basement of a Museum in London. It is every component of the former nature that has to be taken care of.

The same puzzlement has moved Robert Boschman to explore the archeology of our only real predecessors, those hunter-gatherers living 12,000 years ago, who within only a few generations had to adjust to massive climate change. The Young Dryas episodes narrated by Boschman offer a meditation on how to cope with a massive disorientation in the order of the universe. Except our European ancestors might have been nimbler in shifting their ways of life than we modern humans are; prisoners of our mammoth technosphere.

To order the universe is precisely what becomes difficult in a time such as ours. According to John Tresch, "cosmograms" are objects, stories, images, and narratives that capture the spirit of a time or a new situation for which there is no received name. Just what we need when the whole machinery of time is getting out of joint. Cosmograms order the world just at the moment when there is no order. "What do they *do* — how do they propose, institute, challenge, satirize, critique, prop up, or quietly reinforce an order of the universe?" When Tresch quotes Elisée Reclus's "Humanity is nature becoming aware of itself," we take stock of the distance between the optimism of geography in the nineteenth century and this more recent slogan of the activists in France today: "We're not defending nature, we *are* nature defending itself." Human consciousness is what seems to be in short supply today.

In times of uncertainty the crucial question is to decide whether we are able to tell the right story, and this time not to build a world of fiction but to have an imagination realistic enough to follow what the real world is made of and how; that is, what's the story the world itself tells. A problem that Richard Powers, the great American novelist, has done more than anyone else to solve practically, by writing stories *as they are*: "And like it or not, the man and his measurements and the mountain and the neighbors and the forest and all that story's readers are all a part of it."



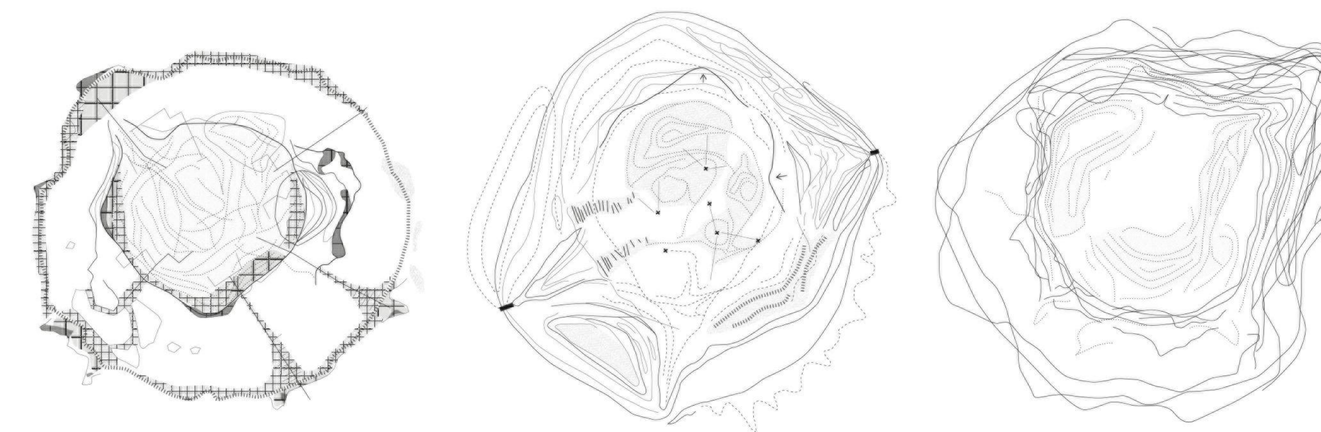


Fig. 6: Alexandra Arènes, Series of terraforming processes: chemical and physical weathering and erosion, solar radiation, melting of ice and sea currents, droughts and floods, carbon extraction and emission, sediment accumulation, plate tectonics and volcanism, 2019. Visualization.

The Terra Incognita under Our Feet

Despite the importance of the Critical Zone for humanity, major questions are still unanswered. First of all, the Critical Zone is a "terra incognita" whose architecture is poorly understood. Beyond the conventional layered textbook representations defining the soil, the regolith,[7] the ecosystem, the water table, the river, and so on, we lack conceptual representations showing the interconnections between these compartments which the different disciplines have erected and frozen as objects of study. Numerical models that tend to reproduce and predict the behavior of the Critical Zone are hampered by this lack of knowledge of its boundaries, and of the spatial and temporal connections of the object that sustains human activities and feeds us.

Very simple questions arise: What is the depth of the Critical Zone? What are its lower (towards the center of the Earth) and higher (towards Earth's upper atmosphere) limits? What are the living organisms that populate it, to what depth do they live, and where do they find their energy? What are the essential interfaces and main water flow paths? How does geologic legacy determine the shape and functioning of the Critical Zone over thousands to millions of years of topographic change, rock fracturing, and controls on the nature of rocks? Conversely, over time, does the Critical Zone "learn" to no longer depend on geologic and climatic initial conditions, but to strike out along trajectories controlled by and for life, as Lovelock suggests? What is the inventory of the processes that animate the Critical Zone? What do we know about the multiplicity of coupling mechanisms in this "functional biogeodiversity" of the Critical Zone which, by connecting the different compartments — soil, water, minerals, air, living organisms — are responsible for the ways in which it responds to perturbations of variable amplitude and temporalities? It is known that trees communicate with each other, so what about all the other agents in the critical soils — water, bacteria, clays, and carbon dioxide? How does a soil destroyed, for example, by the action of too intensive agriculture "remember" how to implement chemical reactions that can restore it? What is the rate of formation of a cultivable soil and what controls it? How long does the rainwater that infiltrates and the pollutants that humans introduce reside in the Critical Zone? These are the questions, both academic and operational, that remain unanswered, but which should condition the way we coexist with this object, which is also our habitat (*see fig. 6*).

Critical Zone Observatories

To meet these challenges, scientists are getting organized. Following the initiative of the United States of America, Critical Zone Observatories (CZOs, or networks of Critical Zone Observatories) have been set up in various countries. A global network is being developed. These observatories are well-chosen sites, locations that are heavily instrumented and monitored over sufficiently long periods of time so that processes and fluxes in the Critical Zone can be identified, described, and incorporated into numerical models. Only observation over long time periods makes it possible to capture the different kinetics — temporalities — of the Critical Zone, of extreme events as well as slow trends. CZOs are agrosystems, cultivated or relatively preserved forests, cities, high mountain catchments, instrumented wells, or glaciers. The measurements made in CZOs, either in situ (in the field) or on samples analyzed in the laboratory, are adapted to the processes that are locally best expressed. The instruments are often very sophisticated, whether they are installed directly in the field or in the research laboratories attached to these CZOs. For example, the use of isotopic ratios to track the route of chemical elements in the Critical Zone and the processes in which they are involved (clay precipitation, evaporation, uptake of nutrients by roots, etc.), or the deployment of passive or induced geophysical methods, such as the seismic imaging of gravels transported at the bottom of streams, are widely used by Critical Zone scientists.

Each CZO is a place, a plot, a hillslope, a catchment, characterized by a unique, simply formulated scientific question, which is often of societal interest and for which the place has been chosen as representative. There is *a Critical Zone*, perceived as a new scientific object, but there are *Critical Zone Observatories*, all different in their combination of different parameters: geology, climate, topography, soil, living organisms, human activities, its history, or the conflicts of land use.

For example, a CZO can be designated to understand the response of the Critical Zone to the increasing (or decreasing) acidity of rain, the generation of destructive flood events, the response time of an agrosystem to changes in agricultural practices, the retreat of a glacier, or the role of climate change in Amazon floods. The main characteristic of a CZO is that it is site-specific; that is, determined by local conditions, and chosen to exemplify a particular type of mechanism to be understood at a particular scale. Elementary processes are discernible at the scale of a small river basin. At the scale of a region, such as the drainage area of the entire Amazon River, other processes emerge that require observations and modelling tools different from those required at the scale of a small river or a parcel of land.

In CZOs or networks of CZOs, ideally scientists from different backgrounds and speaking different languages work together to understand the object in an integrated way. They do it by sharing instruments, data, and numerical models. The beauty of this integration has allowed some CZOs to attract scientists from the human and social sciences, while some are working more and more with local stakeholders, users, and citizens. One of the hopes of the global network of CZOs is to develop a set of common metrics that can be applied everywhere according to the scale of observation to build standardized and interoperable common databases informed by common metadata. These data will describe characteristic processes at each scale, and will inform numerical models that will improve our ability to predict the evolution of the Critical Zone in response to climatic, anthropogenic, or geologic forcing.

Thus to study the Critical Zone, scientists study critical places, as Alexander von Humboldt had already understood when he wrote in his famous book *Cosmos* (1845–62) that "every where, in every separate portion of the earth, nature is indeed only a reflex of the whole."[8] Every corner of the globe, every CZO, is an instrumented natural laboratory, in which the processes and pulsations that characterize the Critical Zone are identified.

The conceptual view that describes CZOs not as static objects structured into different subentities, but as animated by biogeochemical cycles is particularly new and relevant: CZOs manifest the water cycle, the carbon cycle, the phosphorus cycle, or the cycle of rare earth elements, and are offering a new perspective on habitats. In the same way that the CZOs provide information to paint the picture of the Critical Zone, each chemical element or molecule provides its own systemic image of the Critical Zone without caring about the divisions between subcompartments. In this biogeochemical approach, the biological nature of the organism is less central than the chemical or physical reactions that they render possible. There is a significant difference here between the concepts of a Critical Zone introduced by Earth scientists and that of ecosystem, introduced by ecologists — at least in the historical meaning of the term "ecosystem." Living organisms participate in the formation and evolution of a biogeochemical system that we must learn to name and represent better. Their biodiversity is important because it conditions the physical, chemical, and biological reactions in the Critical Zone (*see figs. 7 and 8*).

Our Territories Are "Critical Zones"

The concept of a Critical Zone does not set up an opposition between humans and nature or between living and nonliving states. It refers to a system, which we still have difficulty naming and representing that is anchored locally, and orchestrated by biogeochemical cycles in which living organisms including humans are agents, among others. The sun's energy animates these cycles, but they would not exist without the action

7 See Clifford S. Riebe, W. Jesse Hahm, and Susan L. Brantley, "Controls on deep critical zone architecture: A historical review and four testable hypotheses," *Earth Surface Processes and Landforms* 42, no. 1 (2017): 128–56.

8 Alexander von Humboldt, *Cosmos: A Sketch of a Physical Description of the World*, vol. 2, trans. Elise C. Otté (New York: Harper & Brothers, 1866), 95. Originally published in German as *Kosmos: Entwurf einer physischen Weltbeschreibung*, vol. 2 (Stuttgart: J. Cotta, 1847).

A

B

C

D

FIGS.: A — Biosphere 2, north of Tucson, Arizona, the largest laboratory for global ecology ever built. B — The crew of four men and four women. C — The half-acre farm of Biosphere 2. D — The underground tunnel between the lung and the main part of Biosphere 2 during construction.

Life in a Bubble: The Failure of Biosphere 2 as a Total System

Bettina Korintenberg

A MAN-MADE Garden of Eden, Noah's Ark for Mars — so the headlines ran in 1991, with the inauguration of Biosphere 2.[1] The project undertook to reconstruct, on a smaller scale, the Earth's own biosphere as a closed, total system.[2] The media reports' metaphorical repertoire give an indication of the social context of the 1980s within which this extraordinary experiment began taking shape. At its core lies a relationship among three distinct aspects: on the one hand, there was the utopian dream of space colonization and meanwhile, on the other, a nascent yet growing consciousness of the planet's limits in terms of overpopulation and environmental problems. Third, in the image of the man-made Garden of Eden, the human being as governing power and creator of an ideal realm comes into play. This idea is also found in the predominant concept in that decade of cybernetics as the science of governance of closed systems.[3]

The engineer, systems ecologist, and author John P. Allen, along with businessman Perry Bass, who was engaged in the environmental protection movement, wanted to turn utopia into a reality by duplicating the biosphere. Between 1987 and 1991, a gigantic glass-and-steel facility was constructed in the Arizona desert; the structure's design, made of domes and pyramids, evoked a sort of sacred architecture of the future. Seven biomes — savanna, ocean, tropical rainforest, mangrove swamp, desert, an intensively farmed agricultural area, and living space for the crew — were meant to represent Earth's biospheres and therefore supposed to function as a completely closed and self-contained ecosystem. The goal of the enterprise was to bring about a better understanding of the functioning of the biosphere, to develop technologies to aid in environmental problems such as air pollution, and to acquire foundational knowledge for future space colonies.[4] For this reason, the project was monitored by NASA.

In September 26, 1991, eight Biospherians dressed in overalls as if about to embark on a space expedition were sealed inside Biosphere 2. The experiment was planned to last for many years, but after only a short time, the system began reacting differently than had been expected and the crew left Bioshere 2 after two years on September 26, 1993. The space quickly became life-threatening for the humans and many of the life forms introduced into it. This result occurred despite the almost unlimited energy and technological resources that were available and the enormous efforts made by the Biospherians to keep the ecosystem running. Oxygen levels dropped so low that oxygen had to be artificially introduced from outside. The majority of insects died: no pollinators survived, leading to the proliferation of ants, roaches, and crickets. The human inhabitants suffered from malnutrition.[5] It was impossible to sustain life inside this biosphere created by humans. Biosphere 2 therefore became, not long after its inauguration, a locus of harsh scientific and media controversy.

James Lovelock's description of Gaia — a concept he coined with Lynn Margulis to name Earth's ever-changing biofilm, produced and maintained by the activities of all its life forms — is central to understanding the failure of Biosphere 2: "Gaia is an evolving system, a system made up from all living things and their surface environment, the oceans, the atmosphere, and crustal rocks, the two parts tightly coupled and indivisible. It is an 'emergent domain' — a system that has emerged from the reciprocal evolution of organisms and their environment over the eons of life on Earth. … Self-regulation emerges as the system evolves. No foresight, planning or teleology … are involved."[6]

According to Vladimir Vernadsky, the biosphere may be defined as a space in which all life is materially integrated — an explanation that comes close to the understanding of Gaia. The biosphere has an open, processually self-evolving, emergent system that can't be calculated in advance, nor assembled from component parts or adjusted to scale. Biosphere 2 was itself too small to generate its own changes in weather[7] or movement in its "ocean"; nor was it able to regulate changes in temperature and chemical composition across vast water and land surfaces. And it wasn't just the scaling that proved problematic, but also the selection of animal, plant, and geological cohabitants. The respective experts in charge of each biome assembled the selection of life forms that would be settled into the quasi miniature versions of, for instance, savanna or rain forest. In so doing, they tended to focus on animals and plants that had a presumed utility for human beings.[8] Accordingly, the selection was in fact centered on human life and its survival. This selective extraction of biotic and abiotic components and their calculated assembly will never be able to adequately reconstruct or simulate the temporal dimension of the biosphere's development as an open system which has been evolving over millions of years.

The problem with this centering of the human being was most remarkably evident in the increase of CO_2 in the space and, in this case in particular, in the context of the life forms that inhabited its soil. The soils of Biosphere 2 were heavily enriched with nutrient-rich compost and dung, as the planners wanted to take advantage of the opportunity to provide the inhabitants with as many nutrients as possible to supply them. But the high number of bacteria and mushrooms that thrived in this enriched soil caused CO_2 levels to rise sharply, as a result of their own metabolic and respiratory processes.[9]

The failure of the Biosphere 2 experiment demonstrates the error in the idea that human beings could serve as engineers of the Earth system, composing a whole from parts[10] — an error that risks the extinction of the human species and the life forms that exist alongside it. In the context of acute environmental crises and their consequences for life on Earth, this failure implies our chance to gain awareness of the Earth's uniqueness as a living environment, with its fragility and incalculability, and to develop a different attitude toward and new modes of entanglement with all forms of terrestrial life.

1 For media resonance, see Rebecca Reider, *Dreaming the Biosphere: The Theater of All Possibilities* (Albuquerque: University of New Mexico Press, 2009), 90f.
2 The term "biosphere" was coined by Austrian geologist Eduard Suess in *The Face of the Earth*, 5 vols., trans. Hertha B. C. Sollas (Oxford: Clarendon Press, 1904–24). Originally published in German as *Das Antlitz der Erde*, 5 vols. (1883–1909). The Russian mineralogist and geochemist Vladimir Vernadsky later took up the term and expanded it conceptually to include an understanding of life as a geological force perpetually transforming the Earth, in *The Biosphere* [1926] (New York: Springer, 1997).
3 See Tega Brain, "The Environment Is Not a System," *APRJA* 7, no. 1 (2018): 4.
4 See John P. Allen and Mark Nelson, "Biospherics and Biosphere 2, Mission One (1991–1993)," *Ecological Engineering* 13 (1998): 15–29, here 16.
5 Joel E. Cohen and David Tilman, "Biosphere 2 and Biodiversity: The Lesson So Far," *Science* 274 (November 1996): 1150f.
6 James Lovelock, *Gaia: The Practical Science of Planetary Medicine* (London: Gaia Books, 1991), 11.
7 Paul S. Cohen and Brenda H. Cohen, "Biosphere 2," *Journal of College Science Teaching* 21, no. 3 (1991): 174f.
8 See, in this regard, Reider, *Dreaming the Biosphere*, 94–101.
9 Jordan Fisher Smith, "Life Under the Bubble," *Discover Magazine*, December 20, 2010, https://www.discovermagazine.com/environment/life-under-the-bubble.
10 See, in this regard, Bruno Latour, "Some Advantages of the Notion of 'Critical Zone' for Geopolitics," *Procedia Earth and Planetary Science* 10 (2014): 3–6, here 5.

Fig. 2: Alexander von Humboldt and Aimé Bonpland, *Geographie der Pflanzen in den Tropenländern*, in *Ideen zu einer Geographie der Planzen* [1805] (Tübingen: Cotta, 1807).

vegetation flourishes throughout the whole terrain, all the way up to the snowline. The Himalayas, Humboldt eventually conceded, were taller than the Andes, but their higher latitude causes vegetation to cease at a lower altitude. A view from their highest summits reveals mainly rocks, ice, and snow: "Scarcely is a solitary palm-tree to be found in the beautiful valleys of Kumaoun and Gahrwal [Nepal]."[7]

The range of plant life observable in the Andes mirrors the *Naturgemälde*'s synthesis of isolated impressions into a whole. The role that climate plays in the natural synthesis is the role knowledge plays in the painted one. Plants must be identified by species, and their distribution must be mapped "physiognomically," as outward symptoms of underlying processes. The purpose of the *Naturgemälde*, however, is aesthetic. The "view of Nature" (*Ansicht* in the German original) consists in "the renewal of enjoyment which ... affords to sensitive minds."[8] Humboldt wrote his books both to instruct and to entertain. Their entertainment value transcended the task of reaching a general audience. Beyond the purpose of *Bildung* [education] lay the epistemic power of *das Bild* [the picture] itself. For, if in nature everything was interwoven with everything else, then the representation of nature to humans must be interwoven with humans. The aesthetic character of nature painting is not ornamental (as illustration) or rhetorical (as mode of persuasion) but conforms to Humboldt's insight that nature, which encompasses the human, must be communicated to humans according to their sentient nature, which is to say aesthetically, in the original sense of αἰσθητικός (*aisthētikós*) as "pertaining to sense perception."

In the first volume of *Cosmos*, Humboldt "paints" a portrait of nature, starting from outer space and descending down to Earth and into the soil, where fungi flourish and dermestids feed. Then, seemingly as a codicil, he turns to the human species, concluding with a long citation from his brother Wilhelm's writings on the "idea of humanity," and how humans venture out of their own domain to the wider world only to return to themselves in the form of the study of their historical past. Accordingly, the second volume of *Cosmos* turns to past portrayals of the natural world, starting with the earliest landscape poetry and painting. Humboldt insisted that the *Naturgemälde* belongs to a history of art and that this history therefore is a resource for future representations of Earth understood as (in our times) Critical Zone. Early on in that history, at the birth in Europe of the autonomous gallery picture — *das Gemälde* — Jan van Eyck produced landscapes more capacious than any natural view. (Reportedly, this painter also created a circular representation of the world: "you may distinguish in it not only the places and the lie of the continents," wrote an observer in 1456, "but also by measurement, the distance between places.")[9] These landscapes served as backdrop to religious scenes, but van Eyck and his followers also recognized that vast vistas might fascinate at least as much as would the sacred personages portrayed as if alive in front of them, hence the conceit of establishing in a middle ground tiny viewers, depicted with their back toward us, gazing into the beautiful distance. Eventually such vistas became the specialty of entire painting workshops, especially in Antwerp, northern Europe's painting capital. In 1905, around the time that the term *Weltanschauung* was gaining popular currency, academic art historians in Germany coined the term *Weltlandschaft*[10] to characterize this historical development. Developed by Joachim Patinir and Quinten Metsys, such landscapes found their greatest expression in the art of Pieter Bruegel the Elder.

Bruegel's worldscapes are always nature-cultures (*see fig. 3*). On a ground plane rising steeply to a narrow strip of sky this artist lays out a vast terrain stretching from watery flatlands reminiscent of his native Flanders to the snowcapped Alps and beyond, and always with open ocean somewhere in view. This immensity he also defines as an arena for human activity — sometimes in the form of seasonal labor, sometimes as a variety of cultural practice: customs (e.g., carnival and Lent), play (children's games), language (vernacular proverbs), etc. Landscape dwarfs and naturalizes the human, integrating Bruegel's players into the rhythms of day and season and submitting them to the challenges of survival. This encourages a stoic viewpoint. One can gaze *sub specie aeternitatis* at the absurd undertakings of the human animal. Bruegel's visual humanism posits the world as humanly made, not naturally found, dependent, art historically, on a radically different *Weltanschauung*. Bruegel's landscapes, as well as almost all of his subjects and themes, depend on the anti-human art of Hieronymus Bosch. Working two generations before Bruegel, Bosch fashioned cosmic panoramas observed from on high. But his paintings are haunted by another viewer who, always yet higher up, sees us before we see him. At first glance, the implied beholder appears to be an art-loving, privileged, and (perhaps) pious patron who takes strange pleasure in torments and catastrophes occurring to others, especially the poor and marginal: violent death, cruel torture, deluge, devilish dominion, conquest by enemies, apocalypse, and so forth. On the other hand, the true and sovereign beholder is God, who sits in judgment above and sees us before we see him. The human — both in the painting and before

7 Humboldt, *Cosmos*, vol. 1, 29.

8 Alexander von Humboldt, *Aspects of Nature, in Different Lands and Different Climates with Scientific Elucidations*, vol. 1 (London: Longman, Brown, Green, and Longmans, with John Murray, 1849), vii. Originally published as *Ansichten der Natur mit wissenschaftlichen Erläuterungen* (Tübingen: Cotta, 1808).

9 Bartholomaeus Facius, *De viris illustribus* [1456], translated and discussed in Michael Baxandall, "Bartolomaeus Facius on Painting," *Journal of the Warburg and Courtauld Institutes* 27 (1964): 90–107, here 104.

10 Eberhard Freiherr von Bodenhausen, *Gerard David und seine Schule* (Munich: Bruckmann, 1905), 209.

Fig. 3: Pieter Bruegel the Elder, *The Gloomy Day*, 1565. Oil on wood, 118 × 163 cm.