Sustainability without geology? A shortsighted approach

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"There are no beautiful surfaces without a terrible depth." F.W. Nietzsche

Over the last few decades, the concept of *sustainability* has been proposed and championed as the answer to the impending challenges our society will be facing in the future. It has been a rallying opportunity for the broad earth sciences community and a good starting point for such a community to impact societal and policy decisions; however, it has been an opportunity we have largely missed thus far. We are not the first to notice that the sustainability wave has left geosciences behind. In fact, almost ten years ago, Grimm and Van der Pluijm (2012) lamented the absence of geoscientists at a National Academies Symposium aimed at "Science, Innovation, and Partnerships for Sustainable Solutions."

Sustainability theory is rooted in three interconnected domains or pillars: social, economic, and environmental sustainability. Much of the early notion stemmed from the United Nations' initiatives where the basic concepts were sharpened over the last 50 years (see Purvis et al., 2018 for a review of concepts through time). The anticipation is that the three pillars, if properly harmonized, will improve both the present and future potential to meet human needs and aspirations (https://sdgs.un.org/goals). So, it is often stated that the main drive behind sustainability—and its corollary initiatives—is to explore the capacity for the biosphere and human civilization to co-exist, in which the term (sustainability) is thrown around as the *deus ex machina* that will, if correctly implemented, save us and our planet. While it is important for humans to act upon the foreseeable changes to our planet with urgent mitigations---such as the upcoming climate crisis---we fear that the current strategies are too shortsighted and anthropocentric to produce durable solutions. This may be because sustainability education and research are taking place in the absence of geological sciences, and without deep familiarity with Earth's history and dynamism, these efforts will fall short in protecting our future.

The word *sustainability* is one of the most used words in the current scientific vocabulary (https://xkcd.com/1007/). In fact, by the end of this paper, you will have read the word another 29 times. It has been so overused (or abused) in appropriate and inappropriate ways that it has many critics who find the word vague or nonspecific. We think that the word could be appropriate in the right context but has been haphazardly applied due to a major philosophical gap in most sustainability efforts.

We can start with an etymological dig into the original meaning of the word. Sustainability derives from the Latin word *sustĭnēre*, formed by *sus*-, a variant of *sub*- meaning "under" and *tenere,* meaning "hold". Therefore, the epistemological meaning of the word is to "*hold under.*" Considering how human-centric we tend to be in our society, one interpretation of the word could be to "hold under" nature to sustain the needs of an overgrowing society. Maybe a more suitable (friendly?) interpretation would be to "hold"—*tenere*—something to a certain level, to a standard, a potentially ideal *datum* to which to aspire or regress (in the case of overgrowth).

But what is our *standard*? Our *datum*? As scientists, we feel the need to define what and how we are measuring and from which baseline. Agreements on the standard to achieve (if we use CO_2 levels) often point toward conditions just prior to the Industrial Revolution. However, because humans have been modifying the environment for the last 8000 years (Ruddiman, 2005), why not aim further back in time to the end of the Last Glacial? Or the appearance of Homo *erectus*? Our society is a mere eye-blink in geologic time; settling on a datum must reckon with this fact.

We make the point that every initiative in sustainability and any theoretical application of it should not (and cannot) be enabled without the full consideration of "deep time" that only earth scientists can bring to the table. This shares some similarities with the concept of a "deep time reckoning" introduced by Ialenti (2020) but modified to apply longer temporal perspectives or "timefulness" (Bjornerud, 2018) in using the past as an indispensable framework for the future.

Since the world's richest and most privileged people are now throwing their money behind climate engineering (maybe without fully grasping the concept), we think geologic principles should be implemented swiftly to prevent yet more ”unforeseen” consequences. One place to start is at the university level, where sustainability programs are proliferating to the exclusion of earth sciences, with a few timid exceptions.

A Historical Science: the past enlightens the present to guide our future

We are members of an observation-based historical science; this should be viewed as an advantage and a privilege—nobody can see the world as we can. Unfortunately, those with environmental policy power and market power are not necessarily asking for our advice.

Of the three theoretical pillars of sustainability, the environmental pillar seems to be the one most logically aligned with earth sciences. It makes sense that this pillar should be strongly rooted in the disciplines that study and understand Earth, its past, its climate fluctuations, and its profound transformation through time. Unfortunately, that is not always the case. Depending on the search engine and wording used in one's browsing, the results consistently suggest the lack in depth in geosciences. The top geology programs in the USA are responding differently to the external push in this direction. While some departments have added `”environmental” to their names (this has been going on for decades), the involvement of some geoscience departments with neighboring sustainability initiatives go from inaction (hence missing the opportunity) to acknowledgment (upon donors' pressure) but still hesitant impasse, to the complete surrender of their programs to the new trend. Some universities have established pathways for students to receive undergraduate and/or graduate degrees in sustainability (sometimes tagged as environmental sciences or earth systems) in juxtaposition with earth science departments or schools. But perhaps due to the Venn-like relationship between the 'three pillars' and the vagueness of the central concept, these academic programs are a maze of core and elective classes that flit around social sciences, statistics, economics, biology/chemistry, physics, and policy, depending on the chosen specialty track. The most inspired departments might graduate students in sustainability or earth systems with a requirement of one (only 1!) class in earth or natural sciences; and such a class could be a field trip or a farming experience or entirely about ecosystems. We surveyed 40 high-ranking U.S. degree programs in sustainability (or environmental science) and found that only nine required geology in at least one of their tracks, and of those only three required more than one course (Fig. 1). Geology courses are included on most elective lists, but even so, they are so swamped by other offerings that geology courses make up on average less than 10% of all electives (Fig. 1). If students are lucky (and maybe well-advised) they might be exposed to something like Global Climate Change Sciences, which some programs are far-sighted enough to include in their course list. However, Earth History, shockingly enough, is not listed as a mandatory class in many programs. It is fairly easy for students to receive a degree in policy or economics or even land use under the large umbrella of sustainability without being exposed to earth sciences.

While it is always dangerous to generalize and, of course, there are differences among schools and programs, one cannot escape the extent of the problem. Many institutions proudly tout they are graduating the future leaders in sustainability but they forget to mention that the students do not acquire the tools to really understand earth's processes and past changes. Granted, opportunities to deepen one's knowledge might be available at an individual level such that certain students can expand their geoscience experiences, but the fact that universities are focusing their sustainability training into social sciences, biological sciences, and/or engineering is shortsighted. Climate changes and their impact on our society are understood largely due to the work of geologists; seeing programs that do not keep at least Earth History and Geomorphology among their core mandatory courses is troublesome.

It is interesting to notice that European high schools and universities seems to have a more geologic-centric approach to sustainability (and geology overall), and their programs do offer courses such as Dynamic Earth and Planetary Evolution or Earth Surface Evolution (as it responds to climatic changes). As we write this, our two sons are in public middle and high school in Italy where the science curriculum includes earth science (textbook and everything!) in straight balance with chemistry, physics, and biology. This early visibility of geology—whatever the cultural forces behind it—must make it easier for university geoscience programs to be in on the sustainability conversation.

A confluence of human crises: climate change and infectious diseases

Theoretical links between climatic fluctuations and pandemics have been postulated and discussed for a long time (see Ruddiman, 2005 and its references). When the world stumbled onto SARS-CoV-2 (Severe Acute Respiratory Syndrome CoronaVirus 2) in late 2019, it should not have been such a surprise. This pandemic was a turning point and potentially the opening of Pandora's Box in that it exposes how climatic change expands the intersection between human living spaces and disease carriers, by shifting the global distribution of such carriers (e.g., Beyer et al., 2021).

The pandemic offered *per se* a daunting example with regard to crisis preparation. In the 1970s, the World Health Organization declared victory against diseases (McNeill, 1976), as it seemed the diseases that historically afflicted humans were on the retreat after decades of vaccination efforts. Unfortunately, a series of new pandemics (and a fresh new batch of viruses) swept through the world; HIV, SARS, Ebola, MERS, Ebola again and now SARS-2 are showing us how important long-term planning and prevention can be. These "new" viruses are actually "old" (if we carefully reconstruct the zoonosis) and they show we must have a historical perspective even in understanding societal diseases; a society is never immune in its interaction with an ever-changing nature especially when such society is modifying (destroying?) ecosystems at an unprecedented rate (Quammen, 2012).

McNeill's seminal work in *Plagues and People* (1976) was an important early contribution to the study of the impact of diseases throughout human history. McNeil poses that history could be read through the lens of pandemics and not necessarily through the powers and military superiority accumulated via armies and gold. His careful review poses the balance between men and diseases sharply in focus (wherein one might momentarily prevail over the other in a dynamic balance) offering an opportunity to explore history in a different way.

We surely took the uninvited opportunity given to us by viruses and their predominance on the world news to learn that viruses together with microbes and bacteria have been around for billions of years. Of course we should have known better that such a fundamental force in shaping the planet biota had to be involved with the development of early life on Earth (Krupovic et al., 2019). Without fully embracing a virocentric perspective on the evolution of life, multiple lines of evidence have been presented showing the central role of viruses in the earth's entire evolution (Koonin and Dolja , 2013). There are trillions of viruses in the modern oceans, making them the most numerous biological entities in the world's oceans, profoundly regulating the deep-sea ecosystems, and marine biologists and ecologists are only recently beginning to tackle the effects of viruses on the broader ocean ecology (Zimmer, 2005). Palaeoecologists have been looking into the effects of diseases on paleoenvironments; the example of Poinar and Poinar (2008) on dinosaurs' paleoecology is one that comes to mind. There is plenty of room to start thinking about viruses through deep time and contemplating their impact on the evolution of life on Earth, including our own species. Cesare Emiliani, in a prescient contribution from about 30 years ago, warned us*: "Indeed, both Emiliana huxley (Emiliana huxley is a species of coccolithophore) and Homo sapiens appear to be under viral attack… It is of course impossible to predict whether the attacks will be terminal, whether the responsible viruses will mutate themselves out of existence, or whether immunity will develop in one or both species, giving at least temporary reprieve."* (Emiliani, 1993).

We think an incredible opportunity is in front of our inherently historical science; a science that tracks changes by studying the sedimentary record. If history could be read through the lens of disease (as suggested by McNeil 1976) and extinctions could have a viral (or microbial) component to them (Emiliani, 1993), our skills as geoscientists would be helpful to the conversations about how to prepare for the future. An historical "habit of mind" is advisable for every action we undertake.

A grounded embrace of our planet's "dynamic disequilibrium"

"The higher we soar, the smaller we appear to those who cannot fly." F. W. Nietzsche

Economists, philosophers, physicists, and engineers got involved early on in the debate about the future of our society and have been active in decision-making processes. They pushed the sustainability 'boat' straight to the highly theoretical level of system (and complex) thinking—hence fundamentally soaring it off the very *terra firma* to which complex thinking should be anchored: Earth. Sustainability should walk on foot!

With the theorists of the three pillars heavily weighted toward the economic and social sciences, the environmental pillar is left behind to be mostly an engineer's afterthought.

Firstly, we need to position earth sciences as the core of the environmental pillar. To do this, we suggest emphasizing the importance of the biosphere as it is linked to the geosphere. This is not a petty fight between sciences but a philosophical need solely pointing to the exposition of a fundamental fact. Biosphere and geosphere have constantly 'danced' together to shape the environment we live in (as elegantly explained by Knoll, 2003). Life's evolution through its long history influenced earth's surface more than one might think and, overall, the central role of plate tectonics – arguably among the most influential revolutions of the last century – has never been fully appreciated by the general public. The role of oxygenic photosynthesis (and the appearance of large quantities of the "poisonous" oxygen in the atmosphere; see Lane, 2002) and the coupled atmosphere and ocean interactions through time illustrate the complex relationship between evolution and environmental changes.

In addition to a more balanced treatment of the biosphere and geosphere, we think geomorphology is underrepresented in environmental and sustainability science training. Global landscape evolution through space and time interacts with the atmosphere and hydrosphere, reacting to any dictation of climate and its changes through time. The sedimentary record is the outcome of such interactions. How can a graduate of a sustainability program become suitably aware of landscape change without taking classes in earth history and geology? And then how will this graduate help mitigate the distress of coastal communities related to sea-level rise, or understand the full range of possibilities in terms of flood patterns or erosion rates?

The notion that the planet's habitability, as it is nowadays, which fostered the rise of our species, was somehow given to humans as our perfectly designed "living place" is plain wrong. As earth scientists know, the evolution of Earth from its early days has been a winding path, a long great adventure of which we are sorting out the details thanks to the incredible amount of work done by many colleagues over the last few centuries. Fundamental understanding of critical geological phenomena on Earth must be used to solve scientific, engineering, and societal challenges around our future survival. Furthermore, the resilience of global landscapes during a time of rapid perturbations appears to be the one major control on anything we do to mitigate the changes to come. There is the unsettling feeling that many of the "corrective means" brought up by sustainability studies are more short-term engineering mitigations rather than long-term solutions. Some brute force attempts to control our climate (e.g., carbon removal) bear unpredictable risks via poorly understood feedbacks within the oceans and biosphere. Most of us are aware that the engineering of nature comes with unintended consequences, high costs, and even higher stakes for the society directly impacted (See The Control of Nature, McPhee, 1989).

The Opportunity:

Our planet is in a constant *dynamic disequilibrium* and within such a state we need to learn how to coexist. This fundamental concept should shape the leadership of the future so that mitigation attempts are not fragile engineering maneuvers pushed upon nature (or editorial stunts by big personalities) but instead are durable solutions that can adapt to forecasted feedbacks and out-of-normal events. Maybe the sustainability camp has been clever at advertising their cause, and maybe geologists have not done such a good job at enticing the public opinion, but we think that attracting well-meaning students into career paths that do not have adequate grounding in earth sciences could be unfortunate for our society (and for the future of such students). For this reason, earth science must be promoted and presented as a core value in the sustainability programs that are now growing across universities.

To us, this is an ethical call. We cannot let our society move forward with energy and economic plans without understanding the behavior and limits of the environment we are trying to sustain. Our unique and hard-earned understanding of the past must educate global decisions about climate and energy, and so we have to speak up.

"Faber est suae quisque fortunae." Appio Claudio Cieco

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Figure 1. The number of required geoscience courses, and the percent geoscience electives, in 40 sustainability or environmental science undergraduate programs in the U.S. These programs typically offer multiple tracks; the data here represent the curricula from the most geoscience-relevant track in each program. Where given a choice, we surveyed the Bachelor of Science degree program. The programs represent a wide geographic range of public, private, and small- and large-population colleges and universities and were listed as top-ranking environmental or sustainability programs at: universities.com, usnews.com, bestvalueschools.com, or environmentalscience.org. The three schools requiring more than one geoscience course include the University of Vermont, University of South Dakota, and Stanford University.

Geology absence from high-ranked sustainability degrees (U.S.)