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Three Horizons for Future Geoscience

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Geoscience, along with other scientific disciplines, is being increasingly challenged on how it can best confront key global challenges, such as climate change, food insecurity, biodiversity loss, human conflict and migration, and persistent poverty. But its traditional association with exploitation of the planet's natural resources for energy and materials links it with contemporary concerns around unsustainable human practices, arguably fueling a growing disenchantment that is most evident in declining enrollment in university geoscience courses in many countries. Therefore, a fresh re-framing of the geoscience's relationship to society would seem to be urgently needed. In response to this need, we introduce the "Three Horizons" concept for visualizing paradigm change in complex systems as a tool to explore how the future global geoscientific mission might be re-imagined. Using this conceptual framework, we consider three parallel pathways – "business as usual" (horizon 1), "entrepreneurial" (horizon 2) and "visionary" (horizon 3)—that offer alternative narrative trajectories for how geoscience and geoscientists might serve society's grand challenges.

Keywords: sustainability, sustainable development, well-being economy, geoscience, education

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INTRODUCTION

> 'With humanity being confronted by key global challenges such as pandemic diseases, climate change, food insecurity, biodiversity loss, conflict, migration and persistent poverty, science more than ever is called upon to make a critical contribution to create a more equal, fair, and just world and to set an ambitious agenda to ensure a better future for generations to come.' (World Science Forum, 2022)

The opening statement of the Cape Town Declaration from the 2022 World Science Forum called for a new social contract between "science" and "society" that more directly tackles the long-term well-being of humanity (World Science Forum, 2022). It challenges scientific disciplines to reflect on how they can best confront pressing societal concerns. In that regard, the interdisciplinary domain of "geoscience" finds itself especially torn. For decades, geoscience (essentially rooted in the subsurface disciplines of geology and geophysics, as distinct from the broader extension of Earth science into the biosphere, hydrosphere, cryosphere and atmosphere) has prospered and flourished off the back of its exploration for and exploitation of the planet's natural resources, not least the high-carbon reserves of coal, oil and gas that energized 19th and 20th century industrialisation and the raw mineral ingredients that fed rampant post-WWII economic growth, especially in the Global North. However, that resulting "Great Acceleration" (McNeill and Engelke, 2016) in economic activity arguably lies at the root of the very concerns around unsustainable human progress and rising social inequity that motivates the Cape Town Declaration.

There are signs that geoscience's close and enduring association with the minerals and energy extractive sector may be having an unsustainable impact on the appeal of the geosciences as a career option for younger generations (Wadsworth et al., 2020). Over the last decade or so in many resource-dependent advanced economies there has been a dramatic decline in undergraduate enrollment into university geoscience programmes, notably in the UK (43% since 2014 - Geological Society of London/University Geoscience UK, 2019); Australia (40% since 2015 – Australian Geosciences Council, 2022); Canada (39% since 2015 - Council of Chairs of Canadian Earth Science Departments, 2022); and the USA (30% in the period 2015–2020 - American Geoscience Institute, 2021). The drop in student recruitment produced a cull of geoscience programmes, jobs, and even departments (Geoscience on the Chopping Block, 2021; Selway, 2021). The underlying drivers of the apparent "collapse" or "crisis" are complex and much debated, but the diminishing popular appeal of the traditional vocational heartlands of the hydrocarbon and mining industries looms large in most commentaries (Geological Society of London/University Geoscience UK, 2019; Australian Geosciences Council, 2022). Jermyn et al. (2023), for example, highlight "...the negative perception currently associated with the Earth science extraction (mining and oil and gas) sectors." In Australia, "...the problem is that many people in the more urbanised southeastern states and territories view mining as the *only* career option for someone who pursues geology studies, an industry they understand to be detrimental to the environment (Boone et al., 2021). In the UK, "...the association of geoscience with the oil-and-gas and extractive industries has (not unfairly) led to the subject being labelled as 'dirty', and few youngsters are interested in studying a subject that they perceive as having played a central role in damaging our planet" (Whitchurch, 2019).

The popular perception that geoscience is complicit in, and an enabler for, environmental damage is exacerbated by deeper difficulties that hinder the discipline's contribution to delivering the Cape Town meta-mission of "*a more equal, fair and just world*." In many of the countries with falling student recruitment the geosciences are also failing to attract students from a wide range of backgrounds. The proportion of women studying geosciences remains low and the racial and ethnic diversity of the undergraduate population is also much lower than in most other physical sciences (Geological Society of London/University Geoscience UK, 2019; Marshall and Thatcher, 2019). Others draw attention to the colonial legacy of the geosciences, in which a historical agenda to aid the growth of colonial empires' wealth via surveys and exploitation of landscapes was often done without considering the prosperity or will of the rightful owners and/or local populations (Liboiron, 2021; Scarlett, 2022). This apparent association with "dirty industries," a lack of diversity, and colonial roots led Wadsworth et al. (2020) to contend that "for geology to survive as a widely taught university subject, its reputation needs urgent rehabilitation—especially in the eyes of young people."

THE THREE HORIZONS APPROACH

That rehabilitation would seem to require a paradigm change in geoscience's relationship to society. In the wider context of environmental systems change, one way to conceptualize paradigm change has been through the "Three Horizons" approach (Sharpe, 2013; Sharpe et al., 2016; Fazey et al., 2020; Schaal et al., 2023). The approach uses a conceptual tool in which the future is viewed as emerging through three overlapping horizons (**Figure 1**):

- the first horizon, H1, represents the dominant "pattern" of behaviour, norms, and cultures within an organization or system. This horizon defines the current 'Business-As-Usual' (B-A-U) pattern, but changes in the wider landscape or context (e.g., climate change, shifting markets, or changes in digital technology) will force a decline in the dominance and undermine viability of the H1 configuration.
- the second horizon, H2, shows responses to those changes and the anticipated decline in H1. It enables emergent disruptive innovations latent in the system to gain precedence, establishing an "entrepreneurial" space that is distinct from H1. With time, these H2 innovations may be either incorporated into the H1 system to temporarily maintain BAU practices, or they may open up opportunities for far more radical ideas to become ascendent.
- the third horizon, H3, is a radical "visionary" approach that is ultimately expected to be more fully aligned with external changes, and so over time the intermediate transitional H2 state will give way as H3 behaviour, norms, and culture increasingly set the "rules" of the future system.

It is important to recognize that all three horizons co-exist in the current system. Thus, present in any organization—or, in our case, geoscience departments or programmes—is a dominance of H1 thinking, a lesser influence of H2 thinking, and a marginal expression of H3 thinking. Over time, however, their relative balance switches as initially an H2 paradigm and then an H3 paradigm gathers prominence and only essential H1 elements are retained. The Three Horizons heuristic, therefore, is a useful conceptual framework in which to storify how paradigm change might unfold. In the following section, therefore, we aim to provoke that wider discussion by offering one visual narrative of how the "B-A-U" (H1), "entrepreneurial" (H2) and "visionary" (H3) patterns might look like in the context of the geosciences (**Figure 2**).

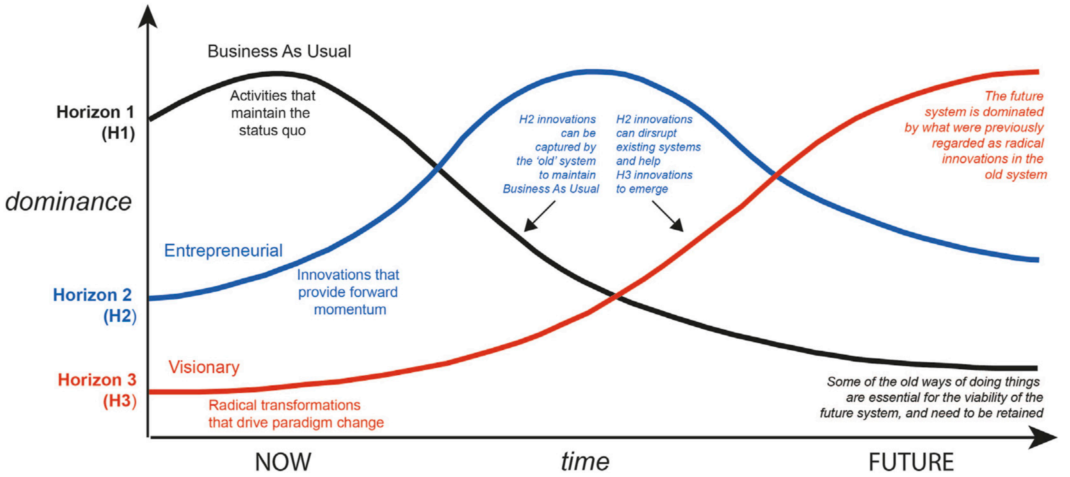

FIGURE 1 | The Three Horizons conceptual framework is a collaborative solution space for identifying, mapping and visualising possible transformation pathways for whole-system (paradigm) change. The first horizon (H1) pathway depicts the "business-as-usual" pathway, dominated by well-embedded and enduring practices, some of which are considered now ill-matched to changing external conditions. In response to emerging challenges and external threats, the second horizon (H2) depicts an entrepreneurial pathway of transitional activities in which a suite of fresh ideas, interventions and innovations provide forward momentum for change. The third horizon (H3) is the visionary pathway of "radical," "out of the box" thinking—ideas that seem peripheral or unrealistic in the present context but which, if they work, will completely transform the system. All three horizons co-exist in the current system but it is H3 that is envisaged to ultimately emerge as the long-term successor to the present paradigm (by contrast, H2 is envisaged to provide intermediary innovations that can either temporarily maintain business-as-usual practices or open up the space for more radical ideas to move to the mainstream).

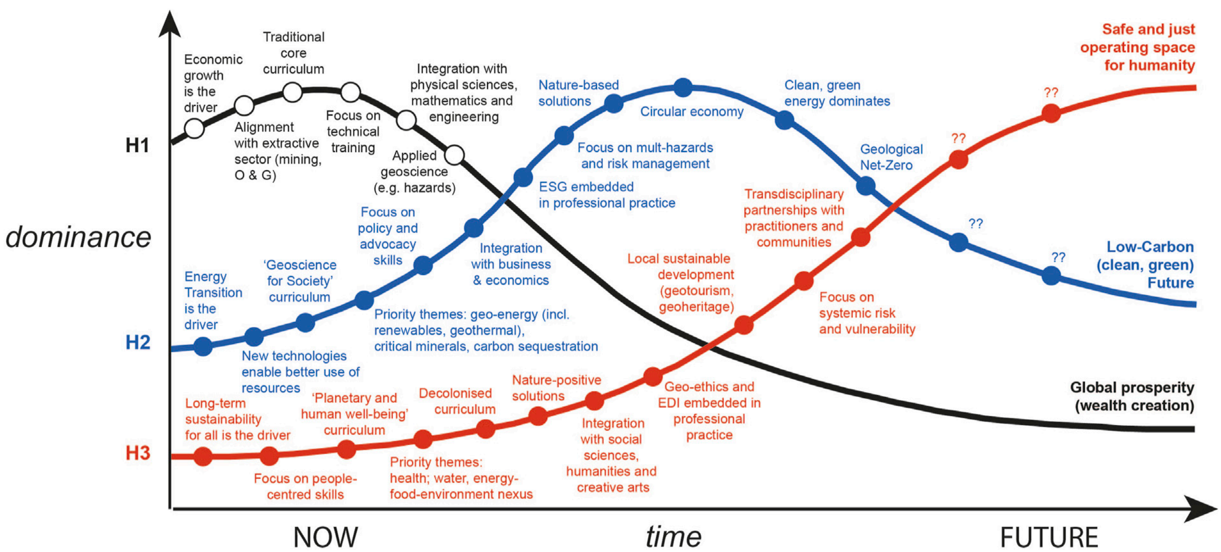

FIGURE 2 | An example of a "three horizons" narrative for geoscience in which the current business-as-usual (H1) activities and practices aligned with high economic growth, material consumption and carbon emission is increasingly challenged by emergent entrepreneurial (H2) activities and practices around the energy transition, decarbonisation and the clean, green economy, whilst latent visionary (H3) activities and practices advance a more radical social geoscience agenda centred on fundamental planetary and human well-being and advocating for a "safe and operating space for humanity."

Horizon 1—Business as Usual (B-A-U)

"It can be said, without exaggeration, that the development of geosciences goes hand in hand with industrial growth. In other words, industry can never expand fast enough to promote the economy of human society without sophisticated geosciences and relevant technology" (Xun et al., 1997, p.84, p.84)

Although the geosciences span a broad endeavour to understand the history of the planet and how it works, the application of that knowledge has been extensively applied in the search for and the extraction of Earth's natural resources. Modern geology has arguably advanced in lockstep with, first the Industrial revolution, and then more rapidly with the 20th century demand for energy and materials. The enabling geoscientific toolkit comprises traditional building blocks—mineralogy, petrology, stratigraphy, paleontology, sedimentology, structural geology, tectonics, geophysics, geochemistry—that have been honed over decades and tend to be common from university to university and country to country. It is a global curriculum that largely prioritises core technical laboratory, field and analytical skills, and draws on exchanges with the other physical sciences, mathematics and engineering. Grafted onto this traditional core are applied sub-disciplines that more directly serve society: geological hazards, hydrogeology, engineering geology, environmental geology, economic geology, petroleum geology. Business-as-usual (H1) activity in the geosciences is built around maintaining this long-standing curriculum and serving its traditional vocational pathways into the mining and energy sector, but it is in this sector that key entrepreneurial (H2) innovations are emerging.

Horizon 2—Entrepreneurial Transitions

Although there are important developments in the geosciences (such as "big data," machine learning and the new digital revolution), arguably the main impetus for reframing traditional geoscience is the societal shift from a high-carbon past to a sustainable, carbon-neutral future. That shift tends to be framed in terms of addressing key ambitions within the UN Sustainable Development Goals (SDGs), notably SDG 7 (Affordable and Clean Energy), SDG 8 (Decent Work and Economic Growth) and SDG9 (Industry, Innovation & Infrastructure) and SDG 12 (Responsible Consumption and Production). A response to the UK geoscience enrollment "crisis," for example, highlights the vital importance of the geosciences "…to meeting net zero targets, addressing the UN SDGs and leading the UK through the energy transition and underpinning "clean and green growth" (Geological Society of London/University Geoscience UK, 2019). Across the world, many geoscience programmes are adjusting their curricula, recasting petroleum geoscience as "geo-energy," rebadging minerals and mining as resource management, re-tuning exploration geophysics for groundwater and remote sensing studies, and turning the attention of geochemistry from hydrocarbons to water and soil remediation. Technical knowledge gleaned from many decades of surface and subsurface exploration is being repurposed for the assessment and development of geothermal energy, wind energy and solar arrays, and the exploration and management of critical minerals to support those renewable technology developments. Growing sustainability concerns mean that society is demanding from the extractive sector the responsible sourcing of materials, nature-positive mining solutions, efficient emissions monitoring and lower carbon footprints, and authentic stakeholder and community engagement to ensure that mining operations deliver long-term social as well as economic benefits (Gloaguen et al., 2022). The geological subsurface also promises to be the frontier for future energy storage (hydrogen) and the permanent disposal of radioactive waste and carbon dioxide, with Carbon Capture and Storage (CCS) widely regarded by geoscientists as a viable and effective long-term solution to secure permanent (i.e., geological) "Net Zero," and thereby addressing Climate Action (SDG 13). Decarbonising the traditional economy, supporting a new circular economy, and ensuring resource sustainability require the expansion of the academic geoscience mission through closer partnerships with industry, liaisons with policymakers, and interdisciplinary alliances with university business schools and with the social sciences, especially economics, law, and political science.

These Horizon 2 innovations might seem to offer the lure for driving disruptive change within the geosciences, but such is the gravitational pull of business-as-usual thinking that such innovations are equally likely to be co-opted into Horizon 1 mindsets, yielding only incremental adaptations that temporarily serve to sustain the *status quo*. On their own, the Horizon 2 adaptations described above cannot propel truly transformative, whole-system change because they deal primarily with one part of the well-being system, namely a resource-driven focus on prosperity through clean, green economic growth. In a Horizon 2 mindset, wider concerns of social equity, diversity and inclusion remain secondary and the well-being roots underpinning the broader demands for an "equal, fair and just world" are not directly addressed, or not addressed with a timeline fast enough to solve them.

Horizon 3—Radical Visions

A more radical H3 vision for geoscience emerges from a holistic integration of planetary and human well-being. In response to geoscientists identifying physical limits in the Earth system—planetary boundaries and tipping points—that ought not to be exceeded if wholesale system change is to be avoided, social scientists have highlighted minimum social limits that ought not to be dropped below if human well-being is to be maintained. Between this "ecological ceiling" and "social basement" lies the "safe and just operating space for humanity" (Rockström et al., 2009; Dearing et al., 2014). At the same time, economists rejecting 'growth' as the global imperative for delivering human well-being are promoting an alternative meta-economic paradigm, the Well-being Economy, which not only seeks to measure the level of economic activity, but also material living conditions, quality of life outcomes and various other sustainability implications (Fioramonti, 2017; Costanza et al., 2018). A well-being economy is one that: stays within planetary boundaries; meets all fundamental human needs; maintains a fair distribution and efficient allocation of resources, income, and wealth; and creates governance systems that are fair, responsive, just and accountable. It is a holistic framework that has been adopted by some advanced economies (notably Finland, Iceland, New Zealand, Canada, Wales and Scotland) as a more comprehensive way to judge national progress, and it seems likely that more and more governments and corporations will measure themselves against this broader set of economic, social and environmental metrics.

A concern with "human well-being" has long motivated geoscientists', notably in the study of natural hazards—such as earthquakes, volcanism and floods—which are a persistent impediment to sustainable development, and environmental stewardship through land and water remediation. But the rise of the "well-being agenda" allows geoscience to consider how it might more directly contribute to the deeper, more enduring social aspirations of Zero Hunger (SDG 1) and No Poverty (SDG 2), alongside ambitions for Good Health and Well-being (SDG 3) and Clean Water and Sanitation (SDG 6) as basic components of a "good life" (Stewart, 2023). Global health concerns, which span multiple SDGs, especially demand geological expertise, for alongside the adverse health impacts from anthropogenic activities, notably mining and oil and gas operations, communities around the world face serious health risks from the natural geo-environment. Similarly, access to clean water and sanitation is a limiting condition in many parts of the world, so the geoscientist's ability to locate and sustainably exploit groundwater resources is likely to become ever more critical in supporting sustainable development. At the local and regional level, viable community livelihoods can also be sustained through geoheritage and geotourism initiatives (e.g., "geoparks").

Although this "social geoscience" currently languishes on the periphery of current academic and industry thinking (Stewart and Gill, 2017), there are growing attempts to map conventional geoscientific mindsets and skillsets onto this wider set of global sustainability challenges (Capello et al., 2021; Gill and Smith, 2021). The recent UNESCO report on *Geoscience in Action: Advancing Sustainable Development* (Capello et al., 2023), for example, offers real-world examples of how inclusiveness, equity, advocacy, community mobilization and social justice can enter mainstream geoscience as core components, not peripheral distractions. It adds to an emerging progressive agenda for challenging deeply imbedded assumptions on traditional practices and power relations, for integrating "geo-ethics" into the mainstream academic curriculum (Peppoloni and Di Capua, 2017), and for building on novel transdisciplinary alliances (e.g., socio-hydrology, socio-hydrogeology). Moreover, since it will involve more direct participatory engagement, and even co-creation, with the frontline stakeholder communities that geoscientists seek to serve, H3 practices will benefit from input from the wider social sciences, humanities and creative arts, and people-centred skillsets very different from H1 technical and analytical skills and H2 business and advocacy skills.

CONCLUSION

Re-imagining how modern geoscience might better address the changing needs and demands of 21st century society is complex and contested, but the Three Horizons framework offers a simple dialogic tool to initiate that important conversation amongst the geoscience community and all the groups connected to it. As a conversation starter, the template (**Figure 1**) is a way for academics and students to map out their own versions of what constitutes "business as usual," "entrepreneurial" and "visionary" components in curricula and programmes, both in the present and projected into the future. For the industry sector, this may serve as a communication tool to raise awareness about the perception of the importance of geosciences for the future well-being economy. In that way, it is possible for the geoscience community to develop a collective sense of what the 21st century mission of the discipline ought to be. In this brief Perspective, we have envisioned one narrative provocation (**Figure 2**), in which geoscientists are viewed as key workers for planet, people, and prosperity, with a role in and responsibility for helping to ensure a shift, via the low-carbon energy transition, to a "safe and just operating space for humanity." Others may map out geoscience's three horizons very differently. However, whatever the visualised pathways, it seems likely that future geoscience will need to combine the twin ambitions of planetary and human well-being if it is to deliver on the Cape Town Declaration's grand challenge to science to create a *more equal, fair, and just world*.

DATA AVAILABILITY STATEMENT

The original contributions presented in the study are included in the article/supplementary material, further inquiries can be directed to the corresponding author.

AUTHOR CONTRIBUTIONS

IS prepared an initial draft manuscript and all authors contributed equally to its revision. All authors contributed to the article and approved the submitted version.

CONFLICT OF INTEREST

MC was employed by the company Red Tree Consulting.

The remaining authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

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