The Need for Geologists in Sustainable Development

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The challenges facing our society to become more sustainable are large and require inter- and trans-disciplinary approaches. Although geologists possess specialized problem-solving skills that make us well-suited to help society move toward more sustainable practices, we tend to be underrepresented in relation to other disciplines in national and global debates on sustainable development. This underrepresentation calls for broad-scale educational and professional training opportunities to increase our engagement with these issues, and sustainability science, in particular, provide a means to advance the involvement of geologists in these discussions.

Societal problems related to the preservation of the environment in particular and to sustainable development in general are inherently complex. This complexity is partly due to the nonlinear response of environmental and societal systems to actions rooted in historical contexts that were precipitated by multiple groups of people who can be autonomous and adaptive (Levin, 1999). Further complexity results from lag times between the initiation of an action by these autonomous individuals and the occurrence of measurable responses by environmental and societal systems, as well as feedback mechanisms that could either amplify or dampen these responses. This complexity requires innovative approaches and solutions involving multiple disciplines in the technological, natural, and social sciences. Although some important steps have recently been taken, geologists tend not to be engaged in these discussions, despite skills and proficiencies that permit us to tackle these complex issues. One mechanism that could address this gap is the inclusion of sustainability science in geology curricula and in professional development opportunities to facilitate the emergence of a new generation of professionals well-versed in understanding and addressing sustainability issues.

Sustainability science is a fairly new field of study that started in the mid-1980s and reached consensus in terms of its goals and approaches by the early 2000s (Bettencourt and Kaurc, 2011). Some researchers initially defined it as the study of the interactions between human and environmental (earth) systems, but more recently scholars have defined it as a type of applied science, in the vein of agricultural and health sciences, that seeks societal action to preserve environmental integrity through the use and application of scientific knowledge (e.g., Kates, 2011). Rather than being characterized by distinct methodologies, approaches, or questions, what differentiates sustainability science from other academic fields is its search for solutions to sustainability issues. Consequently, sustainability science requires the use of context-specific methodologies from multiple disciplines to perform a careful examination of phenomena linked to societal and natural dimensions. It also involves the postulation of working hypotheses that explain the observed phenomena and, equally important, the development of workable solutions that could address these phenomena within human timescales.

Despite its recent emergence, sustainability science has gained considerable momentum among academic and professional institutions. For example, the U.S. National Academy, through its Board on Sustainable Development, produced an influential report on the subject (NRC, 1999), and the journal *PNAS* established a dedicated section for it in 2005. The U.S. National Science Foundation (NSF) now has a program to fund research and education on sustainability science, and a growing number of graduate programs on this subject are now in place at universities around the world, including some that have integrated geosciences and sustainability programs. Additional momentum in the international arena has resulted from the launch of the journal *Sustainability Science* in 2006 and the creation of the International Society for Sustainability Sciences in 2012. Furthermore, the number of peer-reviewed articles focusing on this new field of inquiry has been growing consistently (Bettencourt and Kaurc, 2011), thus testifying to the rapid expansion of this academic field.

A look at the different sustainability science publications, as well as the membership of the International Society for Sustainability Science, reveals a worrisome underrepresentation of geologists. However, our profession is well-suited for sustainability science, and climate change provides an example that illustrates the role that geology in particular and earth sciences in general could play in sustainable science. Geologists have provided a historical context for the climate state that has prevailed since the advent of our civilization, and we have shown the potentially catastrophic effects that rapid climate change can have on the earth system. We have also helped rule out the role of non-anthropogenic drivers on the changes in global temperature, sea level, and rainfall patterns that have been observed during the last century.

As a historical and interpretative science, geology can inform society about interactions in coupled human-environmental systems because our skills and proficiencies allow us to recognize the varying manifestations of phenomena at different spatial and temporal scales. We are also comfortable with the integration of concepts from different disciplines, albeit at present being mostly from those of other sciences. Similarly, coupled human-environmental systems render replication and the use of controlled experiments largely impractical, thus making interpretations based

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on the convergence of multiple lines of evidence the best option for understanding these systems. This approach is part of our discipline, involving the simultaneous use of multiple hypotheses, thus making us well-suited to contribute to sustainability science. Because of our approach to solving problems, we are also tolerant of complexity, knowing that simple governing equations are impractical when explaining natural systems, yet also knowing that meaningful patterns can be extracted and explained, even in complex systems, by carefully observing, comparing, and contrasting phenomena (e.g., mineral and rock types, volcano shapes, tectonic settings, depositional environments, etc.). Our skills also allow us to examine the role of non-renewable and renewable resources, thus affording us the opportunity to help society move from depending on the former and toward relying on the latter.

Our role in sustainability science can also be meaningful by virtue of our acceptance of occasional unquantifiable scientific uncertainty. Although this issue has largely been unexplored by philosophers examining the nature of geology, the extreme difficulty of conducting controlled geologic experiments, the paucity of the geologic record, the impracticality of expressing a number of geological principles numerically, and the intrinsic complexity of earth systems have made geologists more agile in interpreting phenomena, even in the face of high scientific uncertainty. In this sense, geologic reasoning complements that of other scientific fields in that it largely has abandoned classical (frequentist) statistics in favor of Bayesian reasoning. For example, geologic interpretations do not require statistical proof as determined by a less than 5% chance that the occurrence of an event is due to randomness. Instead, geologic interpretations favor statistical approximation, in which the confidence in an interpretation is constantly being updated as new evidence becomes available (Horwich, 1982). Plate tectonics illustrates this point. It was accepted not because its odds for being a random occurrence were measured and determined to be exceedingly small. Rather, it was due to the growing confidence that geologists had in this interpretation as more and more evidence supported it. The focus of inquiry in sustainability science is on informing society about actions that could improve sustainability, thus making statistical approximation a more adequate tool, particularly when replication and controlled experimentation are impossible to perform. For that reason, the ability of geologists to infer underlying processes through Bayesian reasoning is a valuable skill needed to understand coupled human-environmental interactions.

Despite the built-in advantages of geologic reasoning for sustainability science, geologists are not active participants in discussions regarding sustainability, even though these discussions include issues of geological relevancy (water, soil, mineral resources, energy, natural hazards, etc.). Although some important steps have recently been taken—such as the inclusion of geologists in the NSF's Science, Engineering, and Education for Sustainability Program, the development of policy documents by our community (AGI, 2012), and the development of key professional development initiatives (e.g., Interdisciplinary Teaching of Geoscience for a Sustainable Future)—a more systematic approach must be developed to address our underrepresentation. In this sense, the inclusion of sustainability science modules or exercises in geology courses and professional development programs could address this gap by familiarizing geologists with sustainability issues and providing opportunities for us to apply our specialized problem-solving skills to address them. The inclusion of these modules or exercises in introductory courses could also have the effect of making geology more relevant to students who are fascinated by the subject (Gilbert et al., 2010) but who do not pursue it, possibly because they see it as less salient, prestigious, or scientific than other disciplines (Hoisch and Bowie, 2010), particularly by minority students who may view geology simply as the study of rocks (e.g., Kurtis, 2009).

Although a larger involvement of geologists in sustainability issues is critical to address complex human-environmental systems, our representation is slim in relation to other scientific fields. For that reason, our professional and academic organizations should work toward the more intentional inclusion of these issues in curricula and agendas with the hope of having a new generation of geoscientists more prone to use their knowledge and skills for the development of a sustainable society.

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