The geoscience community's obligation to its "Last Great Hope": Do geology graduates understand human transformations of Earth systems?

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"The Last Great Hope." That is what former GSA President John Geissman called the present generation of geoscience students in his 2011 Presidential Address (Geissman, 2012). He then called for the strengthening and support of the geoscience professoriate as the instructors, mentors, and advisers of tomorrow's leaders and innovators. To those ends we argue that the geoscience community must ensure that all geology students have an understanding of the global-scale processes that are unsustainably modified or degraded by human transformations, and perhaps more importantly, help develop those students' ability to communicate that information to the general public. Furthermore, the geoscience professoriate must enable, encourage, and prepare our undergraduate geology students to speak out against misinformation delivered by a small group of individuals in science and the media who present their personal beliefs against the wealth of peer-reviewed and reproducible data that have resulted in the overwhelming scientific majority conclusion of anthropogenically induced climate change.

Students in the senior geology capstone course at the University of Southern Indiana were generally unaware and uninformed of many global-scale human modifications of Earth's processes (Table 1). Graduating geology students admitted misunderstanding that, without global lifestyle changes, the planet they have studied for the past four years would likely change dramatically during their careers, perhaps becoming *Eaarth* (McKibben, 2008), essentially a *different planet*. Textbooks (e.g., Mann and Kump, 2008), lectures, media, and museum and public land exhibits can provide everyone with accurate and timely information about global environmental change. Yet, if these approaches have not adequately informed the general populous on the fundamentals of global change, shouldn't the geoscience community at least be responsible to inform the next generation of earth scientists about climate change and other anthropogenically aggravated environmental problems?

Ignorance and misunderstandings about environmental transformations amongst geology students are not restricted to senior undergraduates in southern Indiana. Rebich and Gautier (2005) found that upper-division students specifically interested in climate change harbored misconceptions at the beginning of the course that persisted following instruction, including shortwave and longwave radiative processes, changes in temperature, and the greenhouse effect. In the allied field of engineering, Azapagic et al. (2005) found a lack of awareness on a variety of environmental issues, agencies, and sustainability practices. It was also noted that these students believed sustainability to be an issue in the future, rather than of immediate importance. Instruction in geologic thinking, considering differing hypotheses, rates, scales, and variables simultaneously, could do much to enhance understanding of global change (Dodick and Orion, 2003), but simply teaching undergraduates how to think without also introducing them to the spectrum of human transformations will leave them ignorant.

Discussions of human-driven global change, in what many are beginning to refer to as the Anthropocene (Crutzen, 2002), can and should take place in historical geology, mineralogy, petrology, structural geology, sedimentology, stratigraphy, geomorphology, hydrogeology, paleontology, and field courses (Table 1). Although there is no formal accreditation of, or standard for, an undergraduate geology curriculum, there is a generally recognized set of core and elective courses for professional geologists (Williams et al., 2004). And while we have no information about current instances of integrating "humans as geologic agents" across the curriculum, and therefore no assessment of such a curriculum revision, existing core courses can become the vehicle for such integration. Traditional historical geology and paleontology courses, which presumably cover the record of mass extinction events, can include an element investigating the causes and mapping geographical and species distributions of what is now referred to as an anthropogenically induced "sixth extinction" (Barnosky et al., 2011). A traditional sedimentology and stratigraphy course, which presumably covers sedimentation rates and yields, should incorporate an element that quantifies

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Table 1. Anthropogenic modification and degradation of global-scale geological processes, example references, and the relevant curricular elements of a traditional undergraduate geology program

Global-scale geological processes	Global-scale human transformations	Example transformation references	Relevant existing curriculum
Sedimentation	Agricultural and urban soil erosion; reservoir infilling; sediment yield to oceans; damming, dredging, and flood control of rivers; coastal erosion	Wilkinson and McElroy, 2007	Sedimentology, stratigraphy, geomorphology
Water cycle	Storm-water runoff; urban groundwater recharge; groundwater mining	Sharp, 2010	Physical geology, hydrogeology, geomorphology
Geochemical cycles	Fossil fuel emissions and climate change; fertilizer N and P application; ocean acidification; hard rock mining; REE usage; pharmaceuticals and pesticides in groundwater	Rabouille et al., 2001; Tillman et al., 2001; Vitousek et al., 1997	Mineralogy, petrology, economic geology, geochemistry, field course, hydrogeology
Landscape development	Urbanization; deforestation; desertification; mining (mountaintop removal, tar sands, etc); slope steepening and overloading; stream channel straightening; glacial melting (due to climate change)	Hooke et al., 2012	Physical geology, geomorphology, structural geology, field course
Species and habitat distribution	Exotic species introductions; anthropogenic extinctions; habitat destruction; hypoxic "dead zones"; Pacific Ocean "garbage patch"; coral bleaching	Hoegh-Guldberg and Bruno, 2010; Vitousek et al., 1997	Historical geology, paleontology, geochemistry
Earth-surface subsidence	Groundwater withdrawal; oil and gas pumping; deltaic subsidence	Syvitski et al., 2009	Physical geology, historical geology, hydrogeology, petroleum geology

human-induced changes in stream dynamics and fluvial sediment yields (Table 1). Traditional geomorphology and physical geology courses can develop lab exercises that construct spatial data displays of agricultural soil losses, desertification, and dam construction. And traditional courses in hydrogeology and aqueous geochemistry can summarize new sampling results of pharmaceuticals in groundwater, alterations to global cycling of nitrogen, and ocean acidification.

Finally, geology undergraduates need courses directly focused on anthropogenic transformations. Although there is some skepticism about the ability of an undergraduate climate change class to alter individual behavior, students in such a course do make gains in their understanding of global change (e.g., Lombardi and Sinatra, 2012). Undergraduate geology students need incentives to be in the library, in the lab, and in the field pursuing research on global environmental change and Earth processes that have been disrupted by human action. Undergraduate students need to attend and participate in conferences by GSA and other allied science organizations. They need to be reading the literature and the news and understanding the interdisciplinary complexity of global environmental issues. Most importantly, undergraduate students need to be engaging in discussions about what they read and hear. Discussions with their professors, peers, and, ultimately, with their non-expert friends and family will deepen their and the public's understanding of the problems we face.

GSA President George Davis mentioned in his address that the geoscience community is struggling to impact its future workforce (Davis, 2013). What better way to engage the future of our science than to establish a formal pedagogy about anthropogenic global change with the next generation of geologists? If they are indeed the Last Great Hope, then it is a moral obligation to make certain they understand the global effects of human transformations in Earth processes, and, by providing increased opportunities for communication skills practice, to enable them to inform the general public. We do not advocate a wholesale revision of the geology curriculum to an environmental science curriculum. Humans are now widely recognized as a dominant agent of global change across Earth's geological systems. If we teach an integrated curriculum on geology, the study of Earth, we have no option but to integrate human transformations across that curriculum.

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