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Short communication

Uniformitarianism, earth system science, and geology

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ABSTRACT

If logic is viewed as a normative science of right reasoning, then various forms of uniformitarianism introduced in the late 18th and 19th centuries were logically flawed at their inception. As noted by William Whewell in 1833, a priori metaphysical assertions about nature are always highly suspect parts of scientific reasoning. Thus, the extension of such presumptions to predictive Earth systems science is not a defect in regard to the general scientific use of the present in regard to analogical reasoning about the past, or the past in regard to analogical reasoning about the future. Rather, there is a defect in regard to the logical role of both strong and substantive forms of uniformitarianism when applied to all science. However, when properly understood, there is great scientific merit in analogical reasoning that uses the immense reservoir of Earth's past operations to see how the full complexity of that planet's present and future operations combine to produce patterns of process operation that evolve into a future that is increasingly being dominated by human influences. Such reasoning is abductive (or retroductive), and it is both a methodologically useful and scientifically fruitful component for generating understanding that can be further elucidated by the deductive and inductive methods of Earth systems science.

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Introduction

No metaphysical notion is more commonly and uncritically presumed to be fundamental to the Earth sciences, and to geology in particular, than that of uniformitarianism. Given that this regulative principle privileges knowledge about the present in regard to inferences about the past, it is ironic that its introduction in the late 18th and early 19th centuries coincided approximately with the time when the Industrial Revolution was initiating a great acceleration in carbon dioxide emissions and when human population growth was greatly increasing many geomorphological process activities on portions of Earth's surface. These are changes that are most commonly proposed to mark the beginning of the Anthropocene, though some human-induced environmental changes were very important even earlier in Earth history (Foley et al., 2013). If the present is a time of immense change of a type (human-induced) never before experienced on the planet, how can it inform us about other periods in time, past or future (Knight and Harrison, 2014)?

As pointed out by Stephen Jay Gould in his first published paper (Gould, 1965), uniformitarianism conflates two different classes of concepts. One, which Gould designated as "substantive," makes ontological claims about the world, in that presumptions are made about how nature actually is, e.g., its processes change relatively slowly and are uniform over time and space. The other class of claims is methodological, in that injunctions or suggestions are made, based on present-day observations, to apply that present-day process understanding to conditions in the past (or future).

In their recent paper Knight and Harrison (2014) observe that substantive uniformitarianism, which they define as "the Principle of Uniformitarianism" or as "the 'strong' principle or doctrine developed by Hutton and later by Lyell" (Camandi, 1999), has been largely discredited by Gould (1965) and others. They note that the many previous criticisms of uniformitarianism have focused on the research approach rather than on the research object. They define the latter as "Earth's physical systems," and they claim that this, "...cannot be meaningfully investigated using a uniformitarian approach..."

Uniformitarianism and systems

Because uniformitarianism was formulated prior to the understanding of Earth in "systems" terms, it is well to be clear in what is meant by the latter. A "system" is a structured set of objects and relationships among those objects. Is Earth the exact same thing as "Earth systems" (e.g., Baker, 1996a)? Earth systems involve those structures that scientists deem to represent what is important for being monitored, modeled, etc. in order to generate predictions. Earth itself has much more complexity (with humans

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or without) to be studied in its complete totality without some simplification into what its human interpreters designate as its "systems." Physical scientists do not measure everything because such a task would be impossible. Physicists, in particular, measure what they deem to be critical for achieving a system-based understanding. The deductions that can be made (they are loosely termed "predictions") from this understanding (physical theory) are only possible because assumptions have been made so that results can then be deduced from those assumptions. These assumptions include whatever gets chosen to constitute the "system" to be monitored, modeled, etc.

Defining the methodological form of uniformitarianism as "the weak viewpoint that observations of those processes operating upon the Earth can be used to interpret processes and products of the geological past, and vice versa," Knight and Harrison (2014) offer the following reasons to reject uniformitarianism (with systems-related terms highlighted in bold):

1. "...it does not account for the dominant role of human activity in substantively changing the behavior of **all Earth systems**, and the significant and very rapid rates of change under anthropogenic **climate forcing**." Indeed, "...**Earth systems** are now operating in ways that are substantially different to how they are believed to have operated in previous geological periods."
2. "...it cannot account for the **properties and dynamics of all systems** that are known to be characterized by **nonlinear feedbacks**, time lags and other **system properties**; spatial and temporal variability of these properties; and where climate and **Earth system feedback** are amplified."

In short, methodological uniformitarianism is considered to be a flawed concept, whether used in reasoning about the past (e.g., "the present is the key to the past") or in the making of predictions about future states of the "earth system." These conclusions involve claims about the nature and role of uniformitarianism in the Earth sciences, particularly geology (cf., Baker, 1998), and claims about the proper role of systems thinking in the Earth sciences.

Original meaning(s) of uniformitarianism

Obviously any application of uniformitarianism to systems thinking is a recent development, since the uniformitarian concepts arose about 200 years ago in regard to thinking about the Earth, and not for more modern concerns about earth systems. William Whewell introduced the concept in his 1832 review of Volume 2 of Charles Lyell's book *Principles of Geology*. He defined it in the context of the early 19th century debate between catastrophists; who called upon extreme cataclysms in Earth history to explain mountain ranges, river valleys, etc.; and uniformitarians, like Lyell, who believed that Earth's features could (and should) all be explained by the prolonged and gradual action of the relatively low-magnitude processes that can commonly be observed by scientist of the present day. By invoking this principle Lyell believed that he was placing geological investigation in the same status as the physical experimentation of Sir Isaac Newton (Baker, 1998). The latter had noted in his methodological pronouncements that inductive science (as he understood the meaning of "inductive") needed to assume *vera causae* ("true causes"). However, as Lyell reasoned, the only way for geologists to know that a causative process could be absolutely true (i.e., "real" in the nominalistic sense) was to observe directly that process in operation today. Thus, uniformitarianism for Lyell was about an assumption that was presumed to be necessary for attaining absolute (true) knowledge about past causes using inductive inference. Uniformitarianism was not (though some naïve, uninformed misrepresentations of it many be) about predicting (deducing) phenomena that could then be subjected to controlled direct measurement and experimental testing (the latter being impossible for the most of the past phenomena of interest to geologists).

The term "uniformitarianism" includes numerous propositions that have been mixed together, selectively invoked, and/or generally misunderstood by multiple authors. Hooykaas (1963) and Gould (1978) provide rather intensive dissections of the various forms of uniformitarianism in their historical context. The following is a brief listing of the many notions that have come to be under the umbrella of "uniformitarianism":

- Uniformity of Law (UL) – That the laws of nature are uniform across time and space. This view applies to what Smolin (2013) terms the "Newtonian paradigm."
- Uniformity of Methodology (UM) – Also known as Uniformity of Process (UP) – Weak form: present-day processes are most appropriate for explaining the geological past (also known as "actualism"). Strong form – the geological past must be explained by invoking processes that can be presently observed today. This form of uniformitarianism sometimes gets summarized in the maxim that was first stated by Sir Archibald Geike (1905, p. 299): "The present is the key to the past." If a past phenomenon can be understood as the result of a process now acting in time and space, one should not invent an extinct or unknown cause as its explanation. This latter view is closely related to parsimony (Occam's Razor), as was pointed out more than 40 years ago by philosopher of science Goodman (1967).
- Uniformity of Kind (UK) – past and present causes are of the same kind, same energy, and produce the same effects.
- Uniformity of Degree (UD) – geological circumstances have remained the same over time.
- Uniformity of Rate (UR) – gradualism – that change across space and time is typically gradual, steady, and slow.
- Uniformity of State (US) – steady-stateism – that change across space and time is equally distributed throughout space and time. Earth is in balance, in a dynamic steady state.

Uniformities of Law (UL) and of Methodology (or Process) have been considered to be "methodological" and related not to geology alone, but to the possibility of doing any kind of science at all. They are also epistemological, in that they seem appropriate or useful to invoke in some form in order to have any chance at all for achieving knowledge. It is for these reasons that the highly respected analytical philosopher Goodman (1967, p. 93) concluded, 'The Principle of Uniformity dissolves into a principle of simplicity that is not peculiar to geology but pervades all science and even daily life." For example, one must assume UL in order to land a spacecraft at a future time at a particular spot on Mars, i.e., one assumes that the laws of physics apply to more than just the actual time and place of this instant. Physicists also assume a kind of parsimony by invoking weak forms UM and UP when making simplifying assumptions about the systems that they choose to model, generating conclusions by deductions from these assumptions combined with physical laws. In contrast, the other forms of uniformitarianism (UK, UD, UR, and US) are all substantive, or ontological, in that they claim a priori how nature is supposed to be. As William Whewell pointed out in his 1832 critique of Lyell's *Principles*, it is not appropriate for the scientist to conclude how nature is supposed to be in advance of any inquiry into the matter. Instead, it is the role of the scientist to interpret nature (Whewell is talking about geology here, not about either physics or "systems"), and science for Whewell is about getting to the correct interpretation.

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