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Viewpoint

Limitations of uniformitarianism in the Anthropocene

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ABSTRACT

For many decades, studies in physical geography, geomorphology, sedimentology and stratigraphy have used uniformitarianism as a guiding principle by which to interpret environmental and land surface changes over different spatial and temporal scales. In this paper we argue that, as the Anthropocene proceeds and Earth systems increasingly move away from the mix of geomorphological processes typical of interglacial periods, significant limitations arise regarding the use of uniformitarianism as a principle by which to interpret Earth surface systems of the present and future. We argue that looking to changes in linked climate and land-surface processes of past interglacial periods is increasingly inappropriate in evaluating the impacts of ongoing climate change on Earth surface processes of the Anthropocene in which complex human-induced land surface feedbacks are increasingly important. We argue that all geoscientists need to critically reconsider whether the long-held assumptions of uniformitarianism are useful in the Anthropocene era.

Introduction

Uniformitarianism as an approach to the interpretation of geologic evidence for past Earth events and processes has been a fundamental guiding principle in many areas of geoscience (Oldroyd and Grapes, 2008) (Table 1). The origins of this approach and its relevance to the history of research in geography and geology are described in detail (Chorley et al., 1984) and critiqued elsewhere (e.g., Shea, 1982), but this approach is derived from Hutton's Theory of the Earth (1795) which argued that observation and measurement of present-day Earth surface processes and their products can be used to explain the formation of similar products by similar processes that operated in the past, through the application of 'natural laws'. This reasoning means that geology (e.g. stratigraphy) is therefore similar to cosmology, in which observations are made on the outcomes of processes, rather than the processes themselves (Balashov, 1994). Lyell (1830–1833) expanded upon Hutton's thesis, including statements on the rate and steady-state nature of geologic processes (Camardi, 1999). Gould (1965) classified these components into substantive uniformitarianism (whereby theories of uniform conditions or rates of change (i.e., natural laws) can be tested) and methodological uniformitarianism (whereby these natural laws apply over a range of spatial and temporal scales). Conflation of different components within Lyell's viewpoint of uniformitarianism, into the single Principle of Uniformitarianism (or Actualism), is a motivation to reject the notion of uniformitarianism in geography and geology (Gould, 1965; Shea, 1982; Baker, 1999). This also arises because of the recognition of the role of extreme (catastrophic) events in geography and geology (Huggett, 1990; Baker, 1998; Marriner et al., 2010). However, many geologists have argued from the perspective of their own subdiscipline that uniformitarian approaches are relevant and that 'the present is the key to the past' (e.g., Windley, 1993; Retallack, 1998; Racki and Cordey, 2000). A more nuanced view is that 'the basic physical laws appear to apply to all of geologic time as well as the present' (Garner, 1974, pp. 41–42). As such, it is useful to distinguish between 'strong' and 'weak' interpretations of uniformitarianism (Balashov, 1994). 'Strong' uniformitarianism refers to the application of the classical Principle of Uniformitarianism, as outlined above (see Table 1). 'Weak' uniformitarianism (lowercase letter u) refers to the methodological and interpretive approach undertaken in many studies in physical geography, geomorphology, sedimentology and stratigraphy, whereby understanding of processes and environments in the past (or present) are informed by those of the present (or past). Such disconnected, circular reasoning is common in all types of palaeo studies (Edwards et al., 2007), and is the context in which we consider uniformitarianism in this paper. The changing dynamics of Earth systems in the Anthropocene, and

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Table 1
Working definitions of some key terms used in this paper, and key source derivations. Note that there is disagreement on the definition and scope of many of these and other philosophical terms that may be used in different contexts, and thus we acknowledge that readers may disagree with the (working) definitions used herein. Note the difference between 'uniformitarianism' (lowercase) and the 'Principle of Uniformitarianism' (uppercase).

Key term	Definition	Source or indicative reference
Anthropocene	The current epoch in which humans and our societies have become a global geophysical force	Steffen et al. (2007)
Bifurcation	A change in the dynamical behaviour of a system when a parameter is varied	Turcotte (1992)
Deterministic chaos	Physical systems whose time dependence is deterministic but which also displays sensitivity to initial conditions, resulting in nonlinear and chaotic behaviour	Schuster and Just (2005)
Disequilibrium	An open system that is not in a state of balance between opposing forces. It may possess the properties of dynamic instability and multiple modes of adjustment and divergence	Phillips (1999)
Earth surface systems	The totality of systems operating at the Earth's surface. These include geomorphological, ecological, hydrological and pedological systems	Knight and Harrison (2013a)
Emergence	A characteristic of systems where scale-dependent properties exist and whose behaviour is not amenable to reductionist analysis	Harrison (2001)
Equifinality	A concept of general systems theory indicating the same final state may be achieved from different initial conditions and in different ways	Whittow (2000)
Feedback	A process by which the results of one operation of a system are used as input to the next operation	Whittow (2000)
Geomorphological sensitivity	(1) The equilibrium response to doubled carbon dioxide of specific 'types' of Earth surface system such as glaciers or rivers (2) The equilibrium response of all those Earth surface systems that are present in one geographical area, as can be demarcated by a watershed	Knight and Harrison (2013a)
Hysteresis	Where the equilibrium state of a system after a forcing event is not the same as before the event	After Krasnoselskii and Pokrovskii (1989)
Landscape palimpsest	A land surface that bears superimposed evidence for geological or geomorphological events of different ages in the past	After Whittow (2000)
Nonlinearity	A characteristic of a system where the principle of mathematical superposition does not apply	After Manson (2001)
Phase space	A coordinate space defined by the state variables of a dynamical system	Turcotte (1992)
Post-normal science	Scientific activities and discourse in which there is high uncertainty in scientific knowledge, the dynamics of systems, and scientific decision-making based thereon	After Funtowicz and Ravetz (1993, 1994)
Predictability	The extent to which the dynamics or outcomes of a system can be forecast into the future based on our understanding of its previous behaviour	After Sarewitz et al. (2000)
Principle of Uniformitarianism	The 'strong' principle or doctrine, developed by Hutton and later by Lyell, that the same natural processes and laws that operate today have operated universally and throughout geologic time	Camardi (1999)
Quasi-equilibrium	A state of near equilibrium as a system moves towards a steady state, but which is never actually achieved due to a changing energy environment	Whittow (2000)
uniformitarianism	The 'weak' viewpoint that observations of those processes currently operating upon the Earth can be used to interpret processes and products of the geological past, and vice versa	This paper

the explicit involvement of human activity in Earth system processes and feedbacks in ways that have not been experienced throughout Earth's previous history, mean that the applicability of the viewpoint that 'the present is the key to the past' should now be reviewed. The Anthropocene is now an era of post-normal science (Funtowicz and Ravetz, 1993, 1994), in which scientific uncertainty has increased and traditional modes of scientific reasoning have become increasing limited in their capacity to interpret the past based on observations from the present, and vice versa. In this paper we argue that geographic and geologic viewpoints of the Anthropocene cannot be seen through the lens of past behaviour(s) of Earth systems. Instead, the Anthropocene probably has no analogue in Earth's geological past and thus neither the 'natural laws' expounded by Principle of Uniformitarianism nor reference to high-CO_2 periods of the past can be used as guides to Earth system behaviour in the Anthropocene.

Uniformitarianism and Earth systems

Earth system behaviour can be measured as the functional relationship between forcing and response, including the magnitude of response relative to forcing, the time lag(s) involved, and any other associated system feedbacks. This relationship is described by the concept of geomorphological sensitivity, which is the equilibrium Earth system response to climate forcing (Knight and Harrison, 2013a). Geomorphological sensitivity is of relevance to evaluating the Principle of Uniformitarianism because it is a representation of the different ways in which the land surface responds to climate forcing. For example, nonlinearity and time lag effects mean that the processes driving land surface change, and the products of these processes, are disproportional and are in disequilibrium, respectively (Phillips, 2009). The result is that the physical attributes of land surface systems more closely reflect unspecified past rather than present conditions, and that the present state of these systems cannot be easily matched with prevailing climate. In a uniformitarian context, this means that evaluations of system state under present conditions of climatic or environmental forcing cannot be used as a guide to estimate the spatial/temporal patterns or magnitude of past forcing. The logic of this approach is clearly demonstrated in landscapes where cosmogenic dating has been applied to exposed rock surfaces that have been subject to subaerial weathering over long time periods (e.g., Bierman and Caffee, 2001; Portenga and Bierman, 2011). The dates obtained from this approach span a range of ages showing that, across a single region, land surface weathering does not take place at a uniform rate or affect all parts of the landscape equally. The result is a mosaic of landscape palimpsests (Bailey, 2007) in which some landscape elements reflect present-day forcing, whereas others are relict and reflect climatic controls of the past (Stroeven et al., 2002; Knight and Harrison, 2013b). This shows both the spatial and temporal contingency of geomorphological sensitivity, and that uniformitarian principles fail to account for the formation of landscape palimpsests, even in the same location and under the same conditions of forcing. Uniformitarianism also cannot account for the feedbacks associated with system behaviour. For example, over time as ecosystems become established on a sloping land surface, soil thickness increases and hillslope angle decreases due to soil creep. This means that slope systems' dynamical processes operate at slower rates over time as they converge towards quasi-equilibrium (Phillips, 2009). As a consequence, in this example, system sensitivity to forcing decreases over time, which is a notion opposed to the steady state and steady rate of change argued through uniformitarianism.