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GLOBAL PLANETARY CHANGE AND CATASTROPHIC EARTH-SURFACE EVOLUTION: IMPLICATIONS FOR MODERN GEOMORPHOLOGICAL RESEARCH

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Abstract: Current international programs of global planetary change research overemphasize the role of analysis as manifested in the idealized predictions of mathematical models, a strategy that contains potential flaws both scientifically and as a matter of public policy. Similar methodological problems have impeded progress in understanding the catastrophic processes that affect landforms and landscapes at various spatial scales. An increased emphasis on synthetic scientific reasoning through the use of natural indexical signs can provide a more balanced scientific approach to advancing understanding in both these areas.

Key words: global change, catastrophic processes, landscape evolution, geomorphology, modeling

INTRODUCTION

The great naturalist, Louis Agassiz, is famous for his scientific imperative to "study nature, not books." Despite what appears in textbooks and scientific articles, geomorphology and Quaternary geology are not so much bodies of knowledge about earth-surface processes and landforms as they are a way of thinking (Logos) about Earth (Gaia or Geo). This way of thinking, here defined as "geological," involves scientific inquiry directed at advancing understanding of Earth's surface and the processes that shape it over extended timescales, Quaternary time being of particular interest. Two current trends in this inquiry involve new emphases on (1) global planetary processes and how the interconnections among them (commonly viewed as "systems") are generating complex responses, some of which are critical to the habitability of the planet, and (2) processes of high intensity and impact that commonly lead to fundamental changes in the operation of processes or their complex interactions, thereby significantly reshaping landscapes.

Professor Leszek Starkel has made seminal contributions to both these aspects of modern geomorphology. He has been an innovator in conceptualizing a global approach to the science of palaeohydrology (e.g., Starkel, 1989, 1990, 2008), including leadership in the international programs that implemented that vision. He has also been a major contributor to the recognition of the role of extreme and catastrophic events in geomorphology and Quaternary geology (e.g., Starkel, 1972, 1976, 1996, 2004). The current essay will consider these themes, and extend their implications beyond earlier expositions.

GLOBAL PLANETARY CHANGE

There are two senses in which global change has become a major theme for a new kind of mega-geomorphology that treats Earth as a whole planet. The first of these themes involves the global change occurring on human timescales, such that the welfare of all humankind is potentially being placed at risk. Here the concern is with the habitability of our planet. The second theme involves changes to Earth's surface over long timescales for which the concern is with how the entire planetary surface works as a whole. Both these themes have been brought into relatively recent prominence because of technological advances that are producing spectacular new discoveries. By being driven by the discoveries made possible by new technologies, both these themes afford potential for what historian Rachel Laudan has termed "adventitious" revolutionary change in scientific thinking (Laudan, 1982). This contrasts with "stipulative" change, in which a potential revolution is advocated methodologically as a proscriptive means for doing better science.

In adventitious change methodological issues arise, not because they are the drivers for the change, but rather because the new discoveries lead to a questioning of previous assumptions about the methodologies in current practice. It is from this perspective that the present essay will treat a number of methodological issues relating to global change and catastrophic evolution.

In considering change, we are naturally led to the issue of time, which has been long considered to pose deep philosophical problems. Alternatively, time can be viewed (1) as an abstract backdrop to phenomena, quantified to precision in exactly the same way, whether moving from the past or into the future; or (2) as a duration in which we are all embedded such that there is a profound asymmetry between past and the future. For science the second viewpoint has immense implications for the concept of causation, which is central to any scientific inquiry.

As pointed out by philosopher Carol Cleland (2001, 2002, 2011), historical sciences that deal with past causes, like Quaternary geology and many aspects of geomorphology, differ methodologically from experimental sciences, like physics and chemistry. The historical sciences cannot perform controlled experiments. Nevertheless, there is a pervasive feature of nature, the time asymmetry of causation, that insures that historical methodologies are as no less valid scientifically than are experimental methodologies, and they may even be superior in some circumstances. This philosophical point runs counter to conventional wisdom among many scientists, and it is critical to advancing the sciences of both global planetary change and catastrophic Earth-surface evolution, so it is something to which I will return in the discussions to follow.

GLOBAL CHANGE AND GLOBAL HABITABILITY

Human beings live on the land surface of planet Earth. Their existence is interwoven with and dependent upon that surface which they inhabit. It was for this reason that in 1980 the original designation for various international global science initiatives was "global habitability" (Goody, 1982). "Global habitability" was quickly superseded by names dear to climate modelers and policy makers: "earth-system science" and "global change." Nevertheless, the original term reminds us of the critical motivation for this science: a habitable planet to sustain humankind's long-term existence. I will argue that this outcome can be achieved not so much via perfected predictions for an idealized "system," but more through indexical signs (see Baker, 1999, 2000a, 2000b) of the realities that relate to critical resources needed for habitability, especially water.

Global change science became earth-system science in order to apply mathematics. Pure mathematics does not concern nature; it concerns systems that allow for the drawing of necessary conclusions. Mathematical models can be useful tools in science, but these tools will only generate the consequences that follow from how one has formulated the systems to which they applied. The question remains as to whether the assumed system formulation is one that matches nature.

It is sometimes claimed that a computer model is a kind of experiment in that its predictive output can be compared to data (evidence). If there is a match, then one has achieved a kind of test. However, as pointed out by Klemes (1997), this is a test of "the fit of the model" to that data. It is not "a test of the model." The test of the model is how well the model represents reality. Models can fit data because some combination of assumptions has allowed them to do so. The test of fitting the data does not tell you if that particular combination of assumptions is the way nature actually operates, since it is possible, and in many cases highly likely, that some other combination of assumptions would also fit the data equally well. This observation concurs with a general consideration that has been well known to philosophers for at least the last 50 years, but which persists in misunderstandings by many if not most modern scientists. This is the underdetermination of theory by data and evidence.

When predicting or explaining some future outcome, the matching of model prediction to data does not tell if the presumptions that have gone into the model are an exact match to nature because there could have been other combinations of presumptions that would also have matched the data. Neither matching the data nor failing to match the data, i.e., the falsification criterion of Popper (1963), can tell us which of the multiple possible combinations of presumptions is correct. Oreskes et al. (1994) show how this underdetermination of theory by data is fundamental problem that underlies all modeling of environmental systems.

Of course, it is considered necessary to define a system because the operations of the whole Earth are immensely complex. Ever since the seminal studies of Galileo, Descartes, and Newton, physicists have used the method of analysis to break down immensely complex problems into simpler elements that can then be symbolically represented and manipulated with mathematical certainty. The scientific advantage of mathematical models is their very great efficiency in tracing out the consequences that follow from adopting a particular hypothesis (theory) and its associated auxiliary presumptions. While this may aid in the economy of inquiry for the pursuit of truth, it by no means assures the attainment of that truth.

The alternative approach to analysis is synthesis, which seeks to combine the measured elements of reality to discover something new in their combination. Synthetic reasoning is far more complex than analytical reasoning. It involves both the classification of phenomena (induction) and the genesis of new hypotheses, or abduction (see Baker, 1996a), but these are topics too great in complexity to adequately discuss in this brief essay.

ANALYTICAL GLOBAL CLIMATE SCIENCE AND PROXIES

Nearly all the emphasis in current global change and earth-system science is on model-based prediction of the climate system. Information from the past serves this all-important prediction goal primarily as "proxy data." A proxy is something that is designated to substitute for something else. In this case, various kinds of measureable phenomena are designated as proxies for climate. Arguably, the most accurate and precise palaeoclimatic proxies come from reference sections of environmental isotopes in cores from the deep abyssal plains of the world's oceans and from ice sheets in Greenland and Antarctica. These sections could not be more remote from the localities where most people live.

Much of current paleoclimatic research is directed at presenting proxy data for aiding the development of climatological and environmental scenarios to improve the forecasting of future events. Given current programmatic opportunities, this goal is commonly invoked when trying to justify research funding. The result is that the indicators of actual environmental change are considered to be mere substitutes for what is really important in regard to environmental change: the idealized predictions of mathematical models which rely upon theory that is necessarily underdetermined by evidence.

SYNTHETIC GLOBAL SCIENCE AND INDEXICAL SIGNS

I think there is a much more scientifically effective way in which to consider paleoenvironmental data. This is to treat such data as indexical signs, which are signs that directly connect to real phenomena through causation. They are thus distinguished from symbolic representation, including the mathematical formulations of predictive models, in that the latter connect to phenomena through convention and representation. Examples of indexical signs include the paleostage indicators and slackwater deposits that are used in paleoflood hydrology (Baker 2008a).

In contrast to symbolic formulations, syntheses of indexical signs do not provide precise predictions. Rather, indexical signs are directed at the goal of understanding realities, the past being the only reality to which we have reliable access. The indexical view of paleoenvironmental data thus contrasts with the current practice of symbolically ordering past phenomena as "proxies," so organized as to facilitate the testing climate models, the output of which, filtered through policy/political middlemen, serves as the sole connection to issues of habitability.

PREDICTION AND PUBLIC POLICY

The relationship of science to decision makers, policy, and society is anything but scientific. The world of the scientist involves objective facts, proof, rational methods, measurements, and incremental progress. The world of the policy maker involves subjective values, beliefs, emotional concerns, perceptions, and deadlines or crises. Wise action does not immediately follow from providing the best possible technical information. The culture of policy-making must include societal factors, especially subjective values, as a contrasting input to the objective facts of science.

Arguably, the influence of authoritative predictions of a few degrees global temperature change on people will have far less impact on public perception than will the natural variability of water supply, severe floods, droughts, and other hydrological changes. I think it appropriate for science to draw attention to the latter issues directly, via the natural indices of real phenomena, not as the implications of idealized model predictions. People base their actions mainly on concrete particulars that they can understand in commonsensical terms. They are instinctively suspicious of the idealized pronouncements of "experts."

I believe that the global environmental science program needs to be balanced by a synthetic approach that begins with local understanding of real (that is, past) paleoclimatic and paleohydrological change in relation to local needs and concerns. This largely empirical local science should be synthesized across regions for comparison to the global analytical approach. The advantages to this strategy are both political and scientific. Politically, the emphasis on local, real-world problems will have a strong appeal to the beliefs, values and perceptions that underpin societal action. Scientifically, the synthesis of local and regional paleoclimatological and paleohydrological science can be viewed as a source of discoveries, requiring completely new models for their explanation.

CATASTROPHIC EARTH-SURFACE EVOLUTION

CATASTROPHIC EVENTS IN GEOMORPHOLOGY AND THEIR SIGNS

Both practical and conceptual issues have retarded progress in the understanding the role of cataclysmic events in landscape evolution. On the conceptual side, progress was long hindered by adherence to a totally flawed conception of the role of uniformitarianism in scientific inquiry (Baker, 1998). The prolonged debate over the origin of the Channeled Scabland as a result of megaflooding illustrates the importance of this issue for much of the last century (Baker, 2008b).

Catastrophic events are rare. To understand them as a practical matter, one must either await their rare occurrence or study the preserved effects of their past manifestations. Of course, as with global change, one can make assumptions and then mathematically follow the consequences of those assumptions. However, this poses problems noted by Pilgrim (1986, p. 169S): *In comparison with analytical studies using the computer, the uncertainties of field research…provide a considerable disincentive. In addition, there is a tendency among researchers to regard research involving complex mathematical procedures as having greater prestige than field-based research*.

Field-based historical investigations of the indexical signs of past events, which are termed "traces" by Cleland (2001), provide the critical means of understanding cataclysmic processes. These indexical signs can be assembled into a common cause explanation, in which seemingly improbable correlations or similarities among the past events or states represented by the indexical signs are best explained by reference to a shared common cause (Cleland, 2011). The power of the common cause explanation derives from the thesis of overdetermination, which asserts that all events are causally connected in time in an asymmetric manner (Lewis, 1979). As argued by Cleland (2001, 2002), this means that localized events overdetermine their past causes through the immense number of diverse and rich effects (indexical signs) that are preserved from the operations of those causes.

An example of the thesis of overdetermination of past events by data or evidence is the phenomenon of cataclysmic paleoflooding. Inference as to the nature of immense megaflooding, such as the cataclysmic events that created the Channeled Scabland, is supported by an immense amount of indexical signs in the form of the well-preserved effects of that ancient flooding (Baker, 2009). In contrast, the prediction of a future cataclysmic flood is immensely underdetermined through the lack of available evidence.

CATASTROPHIC EVOLUTION

Evolution implies a developmental process of formation or growth. In biology the meaning of evolution has come to be rather restricted to a particular kind of growth process, intrinsic to living organisms, and involving genetics, inherited traits, and long-term adaptation. Evolution includes a much broader range of phenomena than what is usually portrayed by the contrast between Darwin's theory of descent by natural selection and Lamarck's theory of inheritance of acquired traits. A theory of evolution through catastrophic events was proposed by geologist Clarence King (1877), who became the first director of the U.S. Geological Survey. The role of chance, extreme events in evolution was later introduced to biology by Eldridge and Gould (1972), who envisioned species development by a process of long periods of stasis, interrupted by rare and rapid periods of extremely rapid speciation.

As with the role of cataclysmic events, the role of evolution in geomorphology has encountered conceptual and practical impediments. Evolutionary thinking achieved a major emphasis in geomorphology during the late 1800s and early 1900s through the influence of William Morris Davis. Davis (1899) developed a grand synthesis to explain whole landscapes. Unfortunately, the available tools for evaluating the temporal and spatial relationships for whole landscapes were not up to the task of effectively evaluating this scheme.

Today an adventitious revolution is underway to answer many of the questions raised by Davis and his contemporaries. Terrestrial cosmogenic nuclides are being applied to achieve a geochronology of surface features. Amounts of uplift and erosion can be specified over long time scales with thermochronology. High-resolution, hyperspectral remote sensing and digital topographic representation can now be applied to very large regions, combining various data sets with GIS technology. The latter tools are being applied to newly discovered landscapes on the ocean floor and on the rocky surfaces of extraterrestrial planets, moons, and asteroids in the solar system. Of course, there will be issues of how to interpret the new data, including how one can compare landscapes that form in very different environments, but these are all exciting questions associated with discovery.

The failings of the Davisian system led in the later 20th century to geomorphological work that focused on smaller temporal and spatial scales, particularly in the measurement of active landscape processes. The "new geomorphology" even developed into a kind of stipulative revolution, asserting that the quantitative measurement of processes constituted a more effective scientific approach than the explanatory description of whole landscapes. However, this process-based agenda had the partly unintended consequence that the temporal and spatial scales of geomorphological inquiry were diminished, simply because the time scales for measurement of active processes are limited to human scales, and large regions involve complex assemblages of processes.

A Cartesian reductionistic metaphysics presumes that, having effectively analyzed the fine scale of things, one can then simply sum the fine-scaled components to generate what occurs at much larger scales of time and space. But presumption is not science, and it is now obvious that one cannot simply extrapolate the process measurements from fine scales of time and space. Landscapes, not unlike living organisms, display complexities of organization at large scales that are not simply constituent of their finer scaled parts.

Among the conceptual criticisms leveled at Davis's scheme was that it invoked a presumably unscientific teleology in its developmental schemes directed toward particular outcomes (e.g., the peneplain). Of course, a strong teleology that invokes a final purpose or end that results from intentional acts, such as the so-called "argument from design," leads one into areas that more philosophical than scientific. But there is also a weak form of teleology that involves natural tendencies for processes to work toward certain end conditions. Mayr (1988) recognizes a scientifically valid form of weak teleology in biology: teleomatic processes, which are seemingly goal-directed processes that arise from physical laws.

It is interesting that one of the leaders in the refocusing of geomorphology to process-based studies, Luna Leopold, was led by his work to invoke what I have here termed "weak teleology." Leopold (1994) describes his long-standing project of uniting the relation of physical laws, the influence of chance, and tendencies toward consistent forms and relationships associated with fluvial forms and processes in geomorphology. Following ideas from Mayr, Leopold (1994) concludes that some of teleology arising from chance and physical laws may have some relevance in fluvial geomorphology. An example is the concept that random fluctuations in nature trend about a most probable state of least work, and that this can be opposed by a tendency toward the uniform distribution of work, thereby resulting in the ideal form of a river's longitudinal profile.

CATACLYSMIC PLANETARY EVOLUTION

In thinking of Earth-surface evolution one is considering temporal and spatial scales much greater than those of the landforms and landscapes that are the usual subject matter of geomorphology. Indeed the scale is so great that one encounters the issue of possible uniqueness. While there are multiple examples of moraines, levees, yardangs and barrier islands that can be compared and set into their respective contexts of nearby landforms and associated controlling process variables, there is only one Earth surface. Can one do science on a single, isolated object?

The problem here is no different than any other in geomorphology. When we go to study a particular moraine in Ohio, we do not solely consider its unique properties. Rather, we also make comparisons to many other moraines, including those that may be better preserved, younger in age, etc. The analogies that are made to the other landforms are not perfect; each moraine has its own unique properties. Nevertheless, employing a kind of analogical reasoning, the geological investigator can use the similarities to advance understanding of moraines in general.

Where does one find the Earth-like surfaces for comparison to the sample of one that we presumably know so well? There are at least 10 billion stars in our moderate-sized Milky Way galaxy (one of at least 200 billion galaxies in the known universe). A high proportion of these stars have orbiting planets, and recent discoveries have identified (measured) more than 550 planets outside our own solar system. Although the rapidly accelerating pace of exoplanet discovery was initially biased toward finding huge, gas-ball objects (so-called "hot Jupiters"), orbiting close to their respective stars, future missions will be more focused on the discovery of earthlike planets. Given that our own solar system has 4 rocky planets with earthlike attributes (Mercury, Venus, Earth, and Mars), prospects from other star systems foretell an astronomical expansion in the sample size from which to develop a generalized understanding of earthlike landscapes, i.e., the science of geomorphology.

Though it may be many decades before adequate resolution is achieved to analyze surface details on the immense number of potential planets on which to pursue future geomorphology, the science of earthlike planetary surfaces (Baker, 2008c) will continue to be focused on Earth's surface and that of nearby neighbors, particularly Mars. Its scientific scope will involve both the range of landscape phenomena to be studied and also the range of approaches that will be taken in that study. Of course, these two elements are interwoven, in that the chosen methods of study can limit the range of phenomena deemed to be of interest, and vice-versa.

What we find when we look at the available sampling of long-term evolution of planetary surfaces is that cataclysmic events dominate. Venus was almost completely resurfaced about 500 million years ago. Mercury and Mars have surfaces dominated by the scars of past impact events, and the largest and most dominant craters derive from an impact cataclysm about 3.9 billion years ago. Over the long spatial and temporal scales of the universe, it is processes that are cataclysmic from our human perspective that dominate.

EVOLUTION IN THOUGHT

Science involves both what we can say about nature and what nature can say to us. The former style of science ("what we can say about nature") is best exemplified by physics and by the application of mathematics. There is no question that spectacular advances have been made in the sciences that make elegant statements about nature. However, for an effective science of Earth's surface, and particularly for the continued habitability of that surface we need to make similar advances in the sciences that deal with what nature is saying to us.

Generations of physics students are exhorted to study mathematics by the authority of a selective quote from the writings of Galileo Galilei: that to read the book of nature one must know the language in which it is written, that language being mathematics. It is thus ironic that physicists do not really read the mathematics from the world. Instead they theorize in mathematical terms and then see if that mathematical theorizing matches the outcomes of a carefully controlled experiment. The alternative view is that the book of nature is indeed written in a language, but that language is not in the symbolic notations of mathematics. No, the language of nature is signs, specifically indexical signs that directly represent causative processes. These signs exist in a semiosis that invites the scientist to their interpretation.

Unfortunately, much of modern philosophy of science has misled in the claim that all science must proceed from theory. There is a current fad in reviews of papers and proposals to invoke philosophical admonitions that overemphasize the testing (falsifying) of hypotheses. This fad seems to derive from blind adherence to the authority of certain philosophers. If these philosophers have any working experience in science at all it is generally in physics, in which it is indeed possible to have an experiment for an idealized "system" in which all the components are explicitly defined and controlled. For such investigations, the hypotheses serve as mere propositions that are derived from theoretical considerations, and only connect to the actual operations of the real world through corroboration via the experimental results.

In contrast, as long recognized for geological investigations, hypotheses about past phenomena do not function as mere propositions to be experimentally verified/falsified by correspondence to data measured in a controlled laboratory setting. Because geologists study a past that is inaccessible to experimentation, they employ "working hypotheses," testing for their consistency and coherence with the whole body of collected evidence. Applying modes of inquiry described by T.C. Chamberlin, G.K. Gilbert, and W.M. Davis, geologists have long used their working hypotheses to advance a path of inquiry toward the truth of the past, while avoiding the blockage of that inquiry by privileging any particular theoretical take on that past (such as by overemphasis on predetermined hypotheses, that are presumed to dominate the inquiry).

Field-oriented Earth science is a science of synthesis, not analysis. As pointed out by Gilbert (1886), the field-based geologist is an investigator, not a theorist. That is why the current fad of requiring proposals and journal articles to be organized into a rigid mode of testing predetermined hypotheses violates what has come to be known as 'The First Rule of Reason.' One formulation of that rule is "do not block the path of inquiry." T. C. Chamberlin's version of this logical error was his notion of a "ruling hypothesis" (Chamberlin, 1890).

Of course, one should enter a study with hypotheses in mind, but it is nearly always impossible to definitively verify or falsify a reasonable hypothesis when there is no possibility of a controlled experiment. Instead, it is a much more pragmatic and productive strategy to discover the more fruitful hypotheses that may evolve from the original working hypotheses, termed "regenerative hypotheses" by Chamberlin (1904). In regard to the original working hypotheses, what is important is the synthesizing of information toward the goal of seeking consistency, coherence, and consilience (not correspondence "testing" of analytical outcomes from pre-investigation propositions). It is this synthesis that generates the anomalies (recognized as such by experienced geologists) that serve as guides for formulating new hypotheses that are more productive than the original ones (Baker, 1996a).

CONCLUSIONS

Current emphases on global change and earth-system science overemphasize the methodological role of prediction from mathematical models. While such models may function appropriately as tools in a strategy to advance understanding, their overemphasis can be detrimental to such advancement when their analytical program of theorizing about nature is out of balance with a program to achieve a synthesis of what nature has to tell us through its indexical signs. This is best explored by methods of the historical sciences, which are by no means inferior to the experimental approaches of theory-oriented sciences like physics.

Too much can be made in science of the now-outdated philosophical fad of improper emphasis on testing (falsifying) hypotheses. As long recognized in geological investigations, hypotheses about past phenomena cannot function as propositions to be experimentally manipulated in a controlled laboratory setting. Because geologists study a past that is inaccessible to experimentation, they follow "working hypotheses," testing for their consistency and coherence with the whole body of collected evidence. Applying methods described by T.C. Chamberlin, G.K. Gilbert, and W.M. Davis (see Baker, 1996b), geologists have long used their working hypotheses to advance a path of inquiry toward the truth of the past, while avoiding the blockage of that inquiry by privileging any particular take on that past.

Over very large scales of time and space, Earth's surface, and the surfaces of earthlike planets, are shaped by processes that are extreme and rare, i.e. catastrophic. These processes also need to be investigated by a synthetic approach, emphasizing indexical signs, to achieve an understanding that can be incorporated into new kinds of evolutionary thinking about Earth's surface.

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