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Against steady state

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Abstract

Nature is never at a steady state. Natural history is generated by ever-new and ever-interacting forces that produce continuous changes. At virtually all timescales, the geological record shows that these changes do not cancel each other out and, thus, that the steady state is utopic. However, we need a state of equilibrium as a starting point for modelling Nature, and the steady-state condition is widely used as a reference in idealisations aimed at understanding natural processes. The present contribution is meant as an epistemological note of caution − from Earth scientists to Earth scientists − aimed at discouraging the use of theoretical models as true evidence instead of terms of comparison.

Key words: understanding nature, models in geology, uniformitarianism and catastrophism, data interpretation, physical models

1. Introduction

"Trust the science is the most anti science statement ever. Questioning science is how you do science!"

Linus Van Pelt, in Charles Schulz's 'Peanuts'

Science derives from the Latin verb *scio*, meaning 'I know'. However, scientists do not know, they investigate, and therefore need to imagine a starting point from which to proceed from the unknown towards the unknown. Science is a misnomer with a mythical spell, precisely what science is not.

Knowledge, from the Greek *gnosis*, is the infinite journey from nowhere to unattainable verity. At the very moment that a scientist pretends to know, he/she falls off the path of science. Our experience is limited, so we are condemned to be always wrong to some extent. Living is being wrong (Roth, 1953, chapter 1) and, following Socrates, maintaining consciousness that we are wrong represents our only knowledge and best guide.

We are, however, armed with two powerful weapons: clarity of thought and clarity of language. Although destined to be wrong, we remain stubbornly determined to reduce our degree of wrongness, and this is what science is about. Progress is what we achieve through our mistakes: hoping to be less wrong. Human frailty tends to taint systematically even what we believe to be our most rational thoughts. Our fears make us turn towards religion, because we need to be reassured and to believe into something Right and Absolute. In fact, geological debates often revolve around concepts such as the natural steady state, just like believers refer to the Garden of Eden. Ours is a plea to a strictly correct use of language and intellectual honesty in our narratives, because, in the end, narratives are all that we can achieve.

1.1.What is to be done?

"We interpret the evidence so that it fits our fanciful ideas, we eliminate difficulties by ad hoc procedures, we push them aside, or simply refuse to take them seriously."

Paul Feyerabend, Against Method, chapter 14

The philosopher of science Paul Feyerabend (1975, chapter 3) provocatively maintains that there is no decisive difference between science and witchcraft. In other words, a clear conceptual tool able to sharply distinguish between meaningful science and meaningless non-science is still lacking. Endless quarrels among epistemologists about the essential "demarcation problem" have apparently led nowhere (Popper, 1968, chapter 11; Zahar, 1983; Lakatos & Feyerabend, 1999; Resnik, 2000).

In his masterful article on the role of myth in the geosciences, Bill Dickinson (2003, p. 856) acknowledged the fact that, "distinguishing between myth and science is subtle" and that "nascent ideas in geoscience are quite commonly mythic". He also noted that, "when predictions of the extant version of a geomyth fail […] the characteristic response is to change underlying assumptions, or evaluations of constraints, in ways that keep the core of the geomyth essentially intact". Such an escape procedure is by no means peculiar to geology alone, but it characterises all scientific fields. In his "methodology of scientific research programmes", the epistemologist Imre Lakatos (1978) even maintained that this stratagem might be beneficial.

Karl Popper (1959) showed that inductivism and verifiability of theories are both myths, and Lakatos & Feyerabend (1999) concluded that falsifiability of theories is a myth as well. Inductivism has been largely criticised since Hume (1738, book 1.III.VI) and deductivism has not gone much further, but we cannot remain wavering between Wittgenstein's (1922 #7) "whereof one cannot speak, thereof one must be silent" and Feyerabend's (1975, chapter 1) "anything goes". Where can scientists start anew if not from observation? As Galileo exhorted (Galilei, 1632, Dialogue II) "Our discourses should be about the real world, not about a world of paper".

1.2. The implausibility of the steady state

"If the movement of the world really tended to reach a final state, that state would already have been reached. The only fundamental fact, however, is that it does not tend to reach a final state: and every philosophy and scientific hypothesis according to which such a final state is necessary, is refuted by this fundamental fact."

Friedrich Nietzsche, The Will to Power, # 708

A system attains a steady state when the variables that define its behaviour do not change. That is, present conditions were the same in the (at least recent) past and will continue to be the same in the (at least near) future. A steady state can be reached in man-regulated devices ranging from a simple bathtub to sophisticatedly engineered systems (e.g., Caianiello, 2018). But can this be true for Nature as well, where "dynamic processes arise from a multiplicity of variables", and which is "inherently complex, refuses to keep to boundary conditions, and is influenced by the pervasive variables of solid geology, climate change and life forms" (Leeder, 2011)? Can geological systems be self-regulating and thus remain durably in a steady state? Can they neutralise any potential perturbation through geological time effectively and efficiently? If so, then the present would indeed provide a powerful key long enough to unlock the secrets of the deep past (Lyell, 1830–1833). While unravelling the work of Nature, it is therefore essential to ask ourselves whether and with which limitations can homoeostatic conditions be assumed, whether is it reasonable to claim that ideal equilibrium conditions can be reached in an open natural system and next be maintained for long, resisting disruption by all kind of external forces. This is the question that the present paper investigates.

2. Steady state *vs* chaos in geological systems

"Basic physical principles need to be understood but […] detailed scenarios or predictions based upon them are best regarded as convenient fictions, worthy of discussion but not enshrinement."

David Stevenson, The nature of the Earth prior to the oldest known rock record

We may legitimately be reluctant to believe that an "invisible hand" (Smith, 1776) may lead to long-lasting stationary conditions in Nature at large. The suspicion may arise whether constant conditions are a requisite that we introduce into our reasoning to encage unpredictable Nature into a physical model that we are able to master. Such a convenient approach we can trace from the dawn of modern geological thinking (e.g., Gilbert, 1877) to the newest sophisticated orogenic model (e.g., Gerya, 2019). As we read in Ager (1993, p. xvii), "Charles Lyell had a 'steady state' view of the Earth and its life". He "even thought that all processes, including life, were cyclic, and the dinosaurs might reappear" (Gould, 1987, p. 103). Willett et al. (2001, p. 455) envisaged active compressional orogens as "damped dynamic systems" in which "the strong feedbacks between the tectonic processes that create topography and the erosion processes that destroy topography" ultimately lead to steady-state conditions reflected by stationary erosional flux, topography, geothermal gradient, and exhumation pattern (Willett & Brandon, 2002). Such ideally "mature" conditions in which all active forces are counterbalanced, and every forcing factor is effectively buffered is the opposite scenario to the one in which "one flap of seagull's wings would be enough to alter the course of the weather forever" (Lorenz, 1963, p. 431; Hilborn, 2004). On the one hand, the reassuring idealistic picture of phenomena inevitably evolving towards stability and maturity through time and, on the other, a totally unpredictable haunting world destabilised by the sudden whim of any irrelevant part of the system dislocated in any of its regions: order and chaos, two equally extreme theoretical scenarios (Ager, 1993; Orrell et al, 2001; Wolfram, 2002, p. 997).

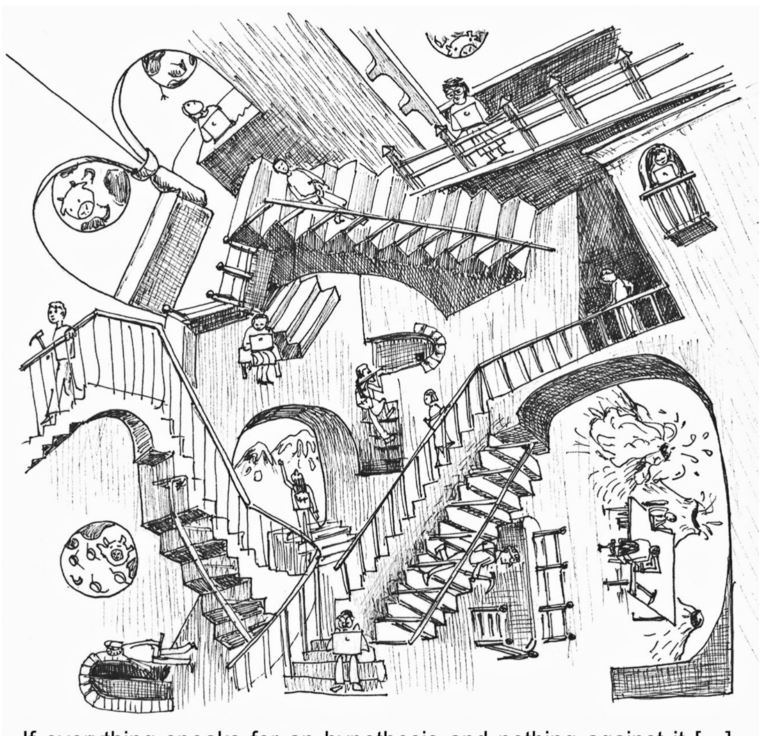
2.1. Steady state in stratigraphy

"It would be just as reasonable to take a hot water jar, such as is used in carriages, and say that that bottle has been as it is for ever."

William Thomson (Lord Kelvin), On geological time, #25

The exploration of time is one of the greatest scientific challenges, and the daunting task of stratigraphy is to read the fascinating stories encrypted bed-by-bed in thick successions of sedimentary strata. While descending in deep time, the stratigrapher uses all available tools to identify, catalogue and date objects, and under the dim light provided by uncertain knowledge and intuition tries to give meaning to observations and to interpret the relationships they hold. The path is fraught with difficulties and there are always huge gaps that need to be filled with imagination, because rocks speak slowly, and their voice is barely audible because it comes from a remote past (Currie, 2018). Criteria and ideas that guide us towards understanding are inevitably intertwined with prejudice, which exposes us to the insidious pitfall of circularity whenever we feel we are moving forwards (Fig. 1). By the syllogism that men are political creatures guided by feelings and beliefs, and that scientists are men, we conclude that scientific theories are not aseptic, but rather inevitably influenced to a degree – either consciously or more often unconsciously – by a range of factors that include personal opportunities and risks, compatibility with our culture and personal creed, and with the rules and conventions of our social and working environment (e.g., Bartholomew, 1973; final remarks in Hallam, 1998, p. 136).

Whenever we fall into the teleological trap and see scientific achievements as acquired steadily along a straight luminous path, we had better recall the words of Thomas Kuhn (1962, chapter IX) that, "science does not tend toward the ideal that our



If everything speaks for an hypothesis and nothing against it […] does it certainly agree with reality, with the facts? With this question you are already going round in a circle. *L.Wittgenstein OC #191*

Fig. 1. A pictorial representation of the steady state as an idyllic community attending their ordinary perpetual business in a world without gravity (painting "Relativity" by M.C. Escher, 1953, redrawn by Laura Medina).

image of its cumulativeness has suggested", or the more poetic ones by Rose Macaulay (1956, chapter 21) that, "exploration tends to be patchy, and we can never sit back and say, we have the Truth, this is it, for discovering the truth, if it ever is discovered, means a long journey through a difficult jungle, with clearings every now and then, and paths that have to be hacked out as one walks". As envisaged by Thomas Kuhn (1962, chapters I and VI), we, as science's employees, must admit that most of our time is spent striving in a rather ant-like - if you wish steady-state (Fig. 1) - puzzle-solving activity, while at the same time waiting and fearing for the next change of paradigm that will radically revolutionise the field in which we felt competent.

2.2. Placid uniformitarianism *vs* episodic catastrophism

"Substantive uniformitarianism (uniformities of kind, degree, rate, and state), which claims how the Earth is supposed to be, is logically flawed, in that it states a priori part of what our scientific inquiries are meant to discover."

Victor Baker (2014), Uniformitarianism, Earth system science, and geology

The discovery of deep time may well be credited to James Hutton. Looking at rocks as the product of continuing natural processes, and not of biblical events as was the vogue of the time (e.g., Lehmann, 1756; Werner, 1787; Buffon, 1785; Buckland, 1823), Hutton understood the vast implication of angular unconformities such as the one separating Silurian slates from the Devonian Old Red Sandstone at Siccar Point (Scotland). The famous close of his 'Theory of the Earth' (Hutton, 1788, p. 304), i.e., "The result, therefore, of our present enquiry is that we find no vestige of a beginning, no prospect of an end", resonates with the same sense of awe and revelation traditionally associated with Archimede's *eureka* or Newton's fallen apple.

The nineteenth century that followed was pervaded by a fierce fight, largely influenced by political and religious feelings, between the catastrophists, who saw geological history as punctuated and dominated by sudden and discontinuous extreme events, and the uniformitarians, who saw the geological record as produced by forces acting continuously and regularly through time (Whewell, 1832). The former vision appears indeed as disagreeably frightening, whereas the latter has the advantage to sound pleasantly reassuring.

In his simplistically acute and provocative style, Derek Ager (1981, pp. 44–45) places the scientific dispute within the frame of the philosophical and political situation of the time, thus relating catastrophists with the Tories and the Church, who "supported the idea of monarchy as the natural state of things" with "God, the divine monarch, controlling the day-to-day happenings on Earth, geological as well as human". Instead, uniformitarians were the liberal democrats, who were generally linked with anti-religion, opposed to supernatural explanations of phenomena and in favour of gradual change. Partisans of the liberal side were "most of the scientists, thinkers and poets of the day", an eminent one being Wolfgang Goethe, "a keen amateur geologist who liked the gradual peaceful processes preached by the uniformitarians". As Aldous Huxley (1928) put it, "it is fear of the labyrinthine flux and complexity of phenomena that has driven men to philosophy, to science, to theology – fear of the complex reality driving them to invent a simpler, more manageable, and, therefore, consoling fiction." For instance, the idyllic utopia of a steady-state economy, requiring a stable population and stable consumption levels, has been idealised in different ways through the last two and a half centuries by liberal (e.g., Smith, 1776, book IV.II; Mill, 1885, book IV.IV), Marxist (Marx, 1875, part I.3), Keynesian (Keynes, 1930), and ecological (Daly, 1991; Kerschner, 2010) economists alike.

The father of gradualistic uniformitarian thinking was Charles Lyell (1830–1833), who clung to his belief in the steady-state development of the organic world, i.e., "to the notion that the Earth, together with its complete flora and fauna, had always been essentially as it is now" (Ager, 1981, p. 44; Hallam, 1998, p. 135). A belief that Archibald Geikie (1905, p. 299) would later immortalise in the aphorism "The present is the key to the past". Such a uniformitarian attitude was shared by Charles Darwin (1856), who inferred that evolution by natural selection had operated in the past from what he was seeing happening. Darwin set sail on the Beagle in December 1831, a year after the first volume of Lyell's 'Principles of Geology' was published, and he read the book so extensively that the ship's carpenter had to rebind it in wood.

Stephen Jay Gould (1965) distinguished between methodological uniformitarianism, which simply assumes the invariance of natural laws and axiomatically applies not to geology only but to science in general (Goodman, 1967, p. 94; Baker, 2014), and substantive uniformitarianism, which falsely presumes uniform rates or conditions as well. By confusing uniformity of processes with uniformity of rates, Lyell - who had been trained as a lawyer and started to enjoy geology as a hobby - managed to confuse geologists for over a century (Prothero, 1990, pp. 10–11). His meritorious battle against untestable supernatural explanations such as Noah's Flood led him to reject all catastrophic ideas about the Earth, ending up fostering a gradualistic bias so strong that led geologists to deny even clear evidence for extreme natural events, and to invariably favour slow, steady, gradual cumulative change over terrific processes such as meteorite impacts, giant landslides, glacial-lake outburst floods, hurricanes, or tsunamis.

Although "the early uniformitarians were the theoreticians and the catastrophists were the careful field observers", eventually "the uniformitarian cause won because it provided a general theory that was at once logical and seemingly 'scientific', whereas catastrophism became a joke, and no geologist would dare postulate anything that might have been linked with a lunatic fringe of fundamentalists". In this way, "geology got into the hands of the theoreticians who were conditioned by the social and political history of their day more than by observations in the field" (Ager, 1981, pp. 67–70).

2.3. The non-graduality of natural processes

"The history of any one part of the Earth, like the life of the soldier, consists of long periods of boredom and short periods of terror."

Derek Ager, The Nature of the Stratigraphical Record, chapter 8

The assumption of a steady state in many geological models recalls the tranquillising 'substantive uniformitarianism' of neo-Lyellian inspiration. The belief that everything happened in the past as it is happening today betrays the desire that we men have to protect ourselves from the dreadsome unpredictability of powerful natural agents, and our aspiration to see Nature tamed and idyllic. The necessity of such a comforting illusion transpires from the statements of the Comte de Buffon (1785, volume I), who definitely anticipated Lyell in several passages, including the one underlined here: "I speak not there of causes removed beyond the sphere of our knowledge, of those convulsions of nature, the slightest throe of which would be fatal to the globe. I reject these vain speculations: they depend upon mere possibilities, which, if called into action, necessarily imply such a devastation in the universe, that our globe, like a fugitive particle of matter, escapes our observation, and is no longer worthy of attention. But, to give consistency to our ideas, we must take the Earth as it is, examine its different parts with minuteness, and, by induction, judge of the future, from what at present exists. We ought not to be affected by causes which seldom act, and whose action is always sudden and violent. These have no place in the ordinary course of nature. But operations uniformly repeated, motions which succeed one another without interruption, are the causes which alone ought to be the foundation of our reasoning."

Exemplary in this regard is Lyell's idea that geological history is cyclical. Even extinctions were considered as temporary with the possibility of a future return, a reassuring promise typical of popular credence, myth, and religion. Dinosaurs were thus expected to reappear sooner or later – "The huge iguanodon might reappear in the woods, and the ichthyosaur in the sea, while the pterodactyl might flit again through the umbrageous groves of tree ferns" (Lyell, 1830, vol. I.VII) - which spurred the irony of colleagues (e.g., Rudwick, 1998, fig. 2).

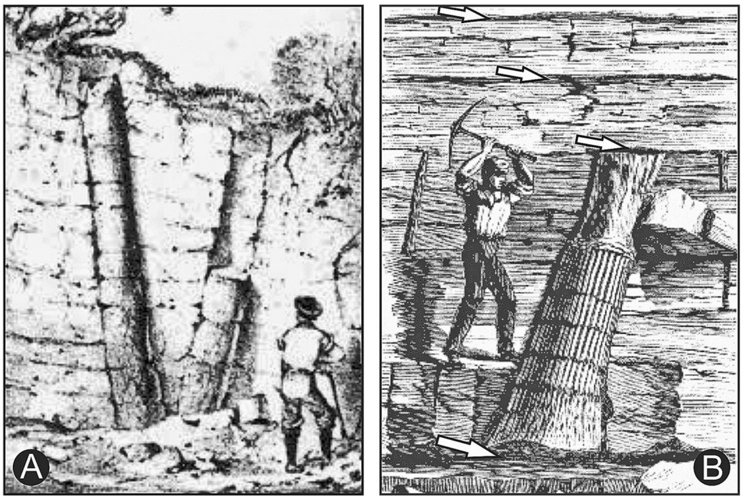
The belief that presently acting processes represent in both kind and degree those that acted in the past led Lyell to deny any overall directional trend in the history of the Earth, which must therefore be in a steady-state condition (Rudwick, 1970, p. 8). Such a nondirectional steady-state theory was doomed to meet with a plausibility collapse in the face of gathering stratigraphical and palaeontological evidence (Bartholomew, 1976). Underlying Lyell's commitment to an anti-evolutionary view was his refusal to accept that men could have evolved from the apes as implied by Darwin's theory, his repugnance to see humanity placed "among the brutes" (Lyell, 1830, vol. I.IX; Bartholomew, 1973). Moreover, the idea of extinction conflicted with a deity envisaged as caring and all-providing, and Lyell took the drama out of it. Influenced by Giovanni-Battista Brocchi's (1814) study and interpretation of Cenozoic faunas of the Apennines, he considered faunal turnover as regular and monotonous as the ticking of the clock, so that piecemeal extinctions could be used like radioactive decay as a measure of geological time (Rudwick, 1978, fig. 1).

In palaeontology, the process of speciation was traditionally envisaged as 'phyletic gradualism', with new species emerging progressively from the slow, steady transformation of entire populations. Darwin's (1856, XIII.4) observation of the great divergence of species of birds in the Galápagos Islands, however, suggested that new species originated rapidly in small local groups isolated from their ancestors. This led Eldredge & Gould (1972, p. 84) to formulate their theory of 'punctuated equilibria' and to consider that "the history of evolution is not one of stately unfolding, but a story of homeostatic equilibria disturbed only rarely […] by rapid events of speciation". Derek Ager (1981, p. 21) concurred that, "most evolution proceeds by sudden short steps or quanta", which parallels Thomas Kuhn's (1962, p. 208) idea of "scientific development as a succession of tradition-bound periods punctuated by non-cumulative breaks".

In stratigraphy, the uniformitarian belief is patently contradicted by paradoxical observations such as that of forest trees of up to more than 10 metres in height fossilised in growth position, as observed worldwide and typically in the Carboniferous Coal Measures (Fig. 2). Such 'polystrate' fossils, well known since the nineteenth century and widely cited by creationists as alleged proof of the Biblical Flood, document indeed very rapid fluvial or tidal sedimentation in floodplains and coastal swamps at time scales ranging from days to years (Gastaldo et al., 2004; DiMichele and Falcon-Lang, 2011). Because at these rates (i.e., >> 1 m *per annum*) a sediment pile thicker than the entire lithosphere would be produced in 10^5 years, such local episodes of rapid accumulation must be brief and compensated for by long periods of non-deposition concealed in multiple elusive discontinuities ("the breaks of smaller time interval are still more numerous and may add up to equally large measures of time unrecorded by sedimentation"; Barrell, 1917, p. 748; Dott, 1982) (Fig. 2B).

The extrapolation of such ultra-high, punctual sedimentation rates to the entire Coal Measures highlights a discrepancy of several orders of magnitude, which leads to the inescapable conclusion that sediment accumulation in a single place is highly discontinuous and anything but at a steady state (Ager, 1981, chapter 3). Similar discrepancies characterise tidal environments, where monthly series of daily ebb and flood tides can be preserved and entire hyper-high-frequency lunar cycles materialised in sigmoidal cross bedding (Mutti et al., 1985). Such a continuous accumulation can be evidently maintained only for a very limited time window at each site, otherwise we would need a sedimentary basin of a depth equalling the Earth's radius to preserve the registration of all tides occurring in one million years.

The highly fragmentary character of the stratigraphical record ("a lot of holes tied together with sediment"; Ager, 1981, p. 35) produces utterly er-



If a child asked me whether the Earth was already there before my birth, I should answer him that the Earth [...] existed long, long before. And I should have the feeling of saying something funny. *L. Wittgenstein OC #231*

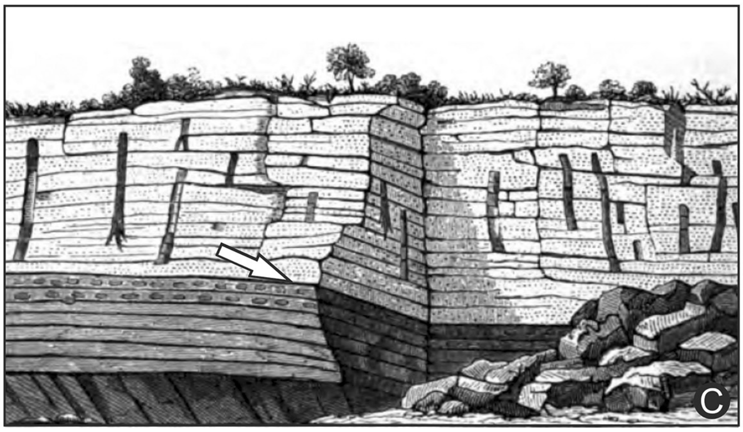


Fig. 2. An illustration of the incommensurability of geological and human time scales: Upper Carboniferous trees buried in growth position. These 'polystrate' fossils document rapid local sediment accumulation at the scale of days to years that cannot be maintained through any geologically significant length of time, and thus must be compensated for by long periods of non-deposition concealed in a series of subtle discontinuities such as those indicated by arrows. **A –** Nant Lech, Swansea Valley, South Wales (source: the National Library of Wales, reprinted in Ager 1993, fig. 4.5); **B –** Joggins, Nova Scotia (Dawson, 1868, fig. 35); **C –** St. Étienne, France (Credner, 1906, fig. 310).

ratic relationships between rock thickness and corresponding time span, and thus fundamental distortions in our perception (Sadler, 1981; van Andel, 1981). Wherever an ample availability of accommodation space makes it possible to approach quasi-continuous registration, a sedimentary succession may appear as repetitively monotonous and comprehensive as an Andy Warhol film (Joseph, 2005; Haladyn, 2011; Walsh, 2014). Conversely, wherever subsidence or sediment supply repeatedly stops, proceeding by hiccups as an ill-working recorder, a sedimentary succession may appear as an accelerated sequence of condensed spasmodic events, like a Hollywood film (Bordwell, 2002; King, 2013).

In most continental to shelf environments, a limited tectonic subsidence forces sediment to move around under the action of tractive currents rather than build up. Ager (1981, p. 50) observed that, in three millennia, a site in the Gulf of Mexico had a 95% probability to see a hurricane fully able to resuspend and redeposit all the ≤ 30 cm of sediment accumulated during that time. The storm bed generated during that geologically instantaneous single episode will be the only sediment left as a testimony of those three millennia, provided it will not itself undergo subsequent reworking. Such a view legitimates a comparison between the event stratigraphy of sedimentary and volcanic successions (Ager, 1993, chapter 11).

Going further, a parallel may be drawn between the geological record and the tale of human history, which is punctuated by crises, wars, and revolutions, whereas our daily life, that stack of enjoyable dull moments when nothing momentous happens, is confined to complete irrelevance. Although we have all rights to blame both geological and human history for having a morbid inclination towards moments of horror and an equally unjust repugnance for trivial day-by-day routine, the truth is that to reduce natural or human events to a regularly repetitive linear flux is as plausible as the improbable image of a spherical or cylindrical cow (Harte, 1988, 2001). A steady state does exist in Nature but only as the *status quo*, the garbage time between events that matter (Califano, 1977).

3. The steady state in geological modelling

"The reasonable man adapts himself to the world: the unreasonable one persists in trying to adapt the world to himself. Therefore, all progress depends on the unreasonable man."

George Bernard Shaw, Maxims for Revolutionists (1903) #124

Geologists, like all scientists and humans in general, seek to understand Nature, i.e., a multitude of physical and chemical processes that continuously interact, overlap, intersect, and resonate unpredictably with one another to produce an ever-changing sequence of forms. Observing Nature is the primary way we use to gather information on those processes and interactions. Observations, however, are not neutral, but depend on concepts, which in turn depend on language. What we call the interpretation of phenomena is a highly subjective process carried out by individuals and based on their specificities and prejudices. Geology is a particularly complex discipline in which observations are dispersed through multiple dimensions of space and time, and many concepts are thus only approximately defined and often intertwined with mythological thinking (Dickinson, 2003; Garzanti, 2017). Inconsistencies therefore reign, not only in founding hypotheses (often called 'models'; Ager, 1993, p. xvi) but also in language. Try to ask a hundred geologists a simple geological question (e.g., "What is continental collision?"). The information you will receive from a range of diverse and often contrasting answers will likely be incoherent, imprecise, unsatisfactory, and confusing. Does this mean that "Geology is not a science" (Sheldon Cooper in the 'Big Bang Theory') and that − because past scenarios cannot be tested by experiment and therefore are supposedly unscientific (Gee, 1999, pp. 5–8) − geologists should confine themselves to "stamp collecting" (Ernest Rutherford in Birks, 1963, p. 108)? Hardly so! Geology, akin to history, economics, and politics (Frodeman, 1995; Cleland, 2001, 2002), tries to understand what has taken place and is taking place on Earth so as to choose the best way to design our future. As Daniel Kahneman (2011) aptly stated, "we tend not to look for what we don't see and to construct the best story we can out of the evidence we have, which may be slight, partial and biased". This is what humans are condemned to do, and therefore this is what philosophers, economists and geologists do: endeavour in the heretic task to probe Nature, which is absolute, with our subjective concepts and limited intellectual and material means (Currie & Sterelny, 2017). How then to proceed?

3.1. The frozen Nature

"They will teach us that Eternity is the Standing still of the Present Time, a Nunc-stans which neither they, nor any else understand"

Thomas Hobbes, Leviathan, IV, 46

The only path we can follow is to frame observations within hypothetical scenarios (i.e., models) that best succeed in explaining them, and thus extract meaning so that phenomena can be understood and whenever possible reproduced. Newton's laws for classical mechanics, for instance, explain the motion of a body of interest under certain assumed circumstances (e.g., the geometry of the body is reduced to a point mass and its velocity is much slower than that of light). That is, if one assumes a cow of complex geometry and known mass *m* as a point mass (assumption), then the acceleration of the cow in response to a given force *F* can be assessed as F = ma (model). Although a cow is clearly not a point mass, such a preliminary assumption enables us to predict the acceleration of the cow, because, to a first approximation, its geometry is unimportant to determine the kinematic response to the applied force.

Describing a chicken or a cow as a mass point or a sphere (Stellman, 1973; Harte, 1988; Orrell, 2012) remains patent nonsense, and the steady state is similarly nonsensical, because change is the primary driver of natural processes. If changes are negated, then the concept of Nature itself is misrepresented. If changes in conditions are forbidden, then the steady state is eternal, with no way to escape. Yet, assuming a steady state enables us to freeze Nature, thereby defining an easily handled reference scenario.

3.2. Models built upon models

"People think that it is strange to have a turtle ten thousand miles long and an elephant more than two thousand miles tall, which just shows that the human brain is ill-adapted for thinking"

Terry Pratchett (2001), The Last Hero

The steady state is a paradoxical stratagem used to isolate a physical portion of Nature from a continuum constantly subject to change in space and time. In this way we create a functional laboratory with simple and well-defined initial conditions (Paola, 2011). As the sphericitization of the cow, this operation disrespects the origin and character of geological features and processes, which are invariably influenced by pre-existing lithologies, structures and events that change both in time and from place to place. This makes each natural object distinct

Fig. 3. Human knowledge, geological knowledge being no exception, is based on assumptions that have no firm base (painting "Le Château des Pyrénées" by R.F.G. Magritte, 1959, redrawn by Laura Medina). While modelling natural phenomena, the risk is to interpret the results as facts and not as a derivation of the assumed premises.

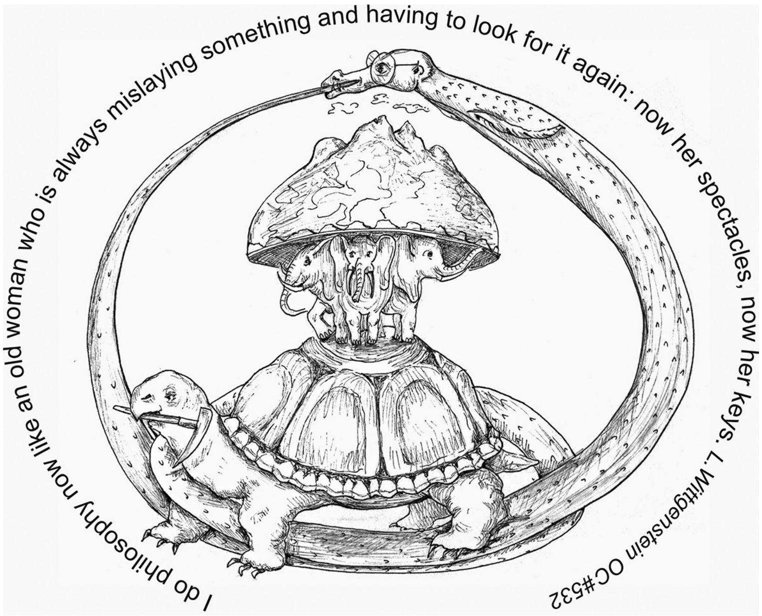


Fig. 4. The world turtle (also referred to as the cosmic turtle or the world-bearing turtle; drawing by Laura Medina) is a mytheme of a giant turtle (or tortoise) supporting or containing the world. The mytheme, which is similar to that of the world elephant and world serpent, occurs in Hindu mythology, Chinese mythology, and the mythologies of indigenous peoples of the Americas (after Wikipedia).

and unique, and therefore unmodellable ("there can be no general theory, only the effects of competing causes"; Leeder, 2011). If we need to move on, then we must find expedients, and simplify. For instance, orogenic belts, representing the most complex product of geodynamic processes, are often implicitly or explicitly represented as quasi-cylindrical, either in space (e.g., Gansser, 1964; DeCelles et al., 2016) or in time (e.g., Bernet et al., 2001).

In geological models, the steady state is generally assumed to be temporary. If the history of the Earth is envisaged as long periods of boredom interrupted by moments of terror (de Beaumont, 1829; Ager 1981, pp. 106–107), then a long period of boredom may allow a system of interest to recover from the preceding moment of terror and to equilibrate to a given set of conditions. In this perspective, the periods of boredom may even become the important part of the story, whereas the moments of terror are considered annoying events which the system has to recover from (Whipple, 2001).

Convenient misrepresentations of Nature may be used in turn as axiomatic assumptions upon which further, second-order models are built. However, this procedure is not exempt from risk (Fig. 3). For instance, to assume that a landscape is at a steady state (basic assumption) allows us to use the stream power law (first level, model 1) to reconstruct vanished landscapes (Sternai et al., 2012) and investigate the transitory effect of a sea level fall or of a pulse of tectonic uplift or water discharge (Whipple & Tucker, 1999; Willett, 2010; Romans et al., 2016). Or, to assume that laboratory-derived empirical relationships can be extrapolated to natural temperatures, pressures, and strain rates (basic assumption) allows us to use steady-state creep flow laws (first level, model 1) to infer rock rheology at inaccessible depths, thereby reproducing lithospheric structures that develop at timescales far longer than our lives (Ranalli, 1995; Handy et al., 2001). Thirdly, to assume that the geothermal gradient is at a steady state (basic assumption) allows us to use the heat-transfer equation (first level, model 1) to estimate the closure temperature/depth of geochronometers and, by means of further physical relationships (second level, model 2), the rock exhumation history at any given place on Earth (Braun et al., 2006; Malusà & Fitzgerald, 2019).

Explaining Nature in this way may recall the myth about the Earth being held up by an elephant, held up by a tortoise, held up by a snake (Fig. 4) (Tylor, 1865). The risk is that, in the exciting up-and-down course of such a complex 'matryoshka' modelling procedure, we lose track of the level we are in. Consequently, we may confuse hypotheses - or even hypotheses based on other hypotheses - with observations, ending up in considering them as data (e.g., slab breakoff on a tomographic image of the Earth's mantle; Foulger et al., 2015; Garzanti et al., 2018).

4. Conclusions

"It's getting them wrong which is living, getting them wrong, and wrong, and wrong, and then, on careful reconsideration, getting them wrong again. That's how we know we are alive, we are wrong!"

Philip Roth, American Pastoral, chapter 1

In any scientific investigation we need to start from simplistic, often groundless assumptions (Wittgenstein, 1974, OC#166). In geodynamics, we typically assume that the crust is homogeneous and undeformed, and many geomorphological and tectonic models of orogenic belts are bidimensional, thus implicitly assuming cylindricity in space. Although based on fiction (cows as point masses, orogens as cylinders), a physical model can, within limits, be robust (e.g., F = ma). A model is a tool, a simplistic substitute for reality useful as an interpretative frame for data; it should not be taken as evidence. If we believe that our models are evidence, then we are kept in circular auto-confirmation. Scientific research ends in the moment when our primary motivation ceases to be the curiosity to understand and becomes the desire to affirm our views.

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