AGAINST STEADY STATE: A QUIXOTIC CRUSADE FOR SCIENCE

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ABSTRACT

Nature is never at steady state. Natural history is generated by ever-interacting forces that produce always surprising phenomena. Negating change is negating Nature's essence, and the historical record, at both geological and human time scales, shows that steady state remains utopia. However, although unrealistic because constantly endangered, we need a state of equilibrium as a starting point for modelling Nature. The steady-state condition is thus widely used as a reference in models aimed at understanding natural processes. Models are tools useful to extract meaning from data but they do not produce data, and we are allowed to base our reasoning on fictions provided we resist the temptation to believe that our assumptions are real, thus falling into a narcissistic circular trap. We cannot avoid using fictions in our models, which however makes them limited and discourages the tendency to imagine planets sustained by elephants carried in turn by giant turtles held up by a snake.

Key Words: Understanding Nature; Geology, History, and Economics; Uniformitarianism and Catastrophism; Data interpretation; Physical models

PLAIN LANGUAGE ABSTRACT

Science derives from the Latin verb *scio* = I know. But scientists do not know, they investigate and therefore need to invent a starting point from which to proceed from the unknown toward the unknown. Science is a misnomer with a mythical spell, precisely what science is not.

Knowledge (from the Greek *gnosis* = truth obtained by means of experience) is the infinite journey from nowhere to unattainable verity. As both Socrates and Gorgias would agree, verity is not for *Homo sapiens sapiens*. In the very moment that a scientist pretends to know, he falls off the path of science.

Because our experience is limited, we are condemned to be always wrong to some extent. As sculpted in Philip Roth's quote, "*being wrong is living*" and, following Socrates, maintaining consciousness that we are wrong represents our only knowledge and best guide.

As naked apes, we are weak creatures armed with two powerful weapons: clarity of thought and clarity of language. This is our only salvation, what science should be about. Although destined to be wrong, we remain stubbornly determined to reduce our degree of wrongness. Progress is what we achieve through our mistakes: hoping to be less wrong.

We are unwilling to concede that human frailty may taint even what we believe to be our most rational thoughts. Our fear of death turns us toward religion, toward the need to believe into something Right and Absolute, and economists or geologists make no exception.

This article proves that all great economic thinkers, liberals and communists alike from Smith to Marx and Keynes, had their thoughts contaminated by their very human need to believe in Paradise on Earth.

Economists have long been convinced that all economic actors, consumers or investors, are fully rational individuals. Not naked apes, but Econs. A patent mistake, as currently underlined by behavioural economists. Only too often economic and geological debates turn around mythical concepts such as the "self-equilibrating market" or the natural "steady state", just like believers refer to God.

Steady state may reign before the beginning or after the end, but it has nothing to do with life. This article is a crusade against self-gratifying positivism, but by no means represents an attack to science. Ours is a plea to a strictly correct use of language and intellectual honesty in our narratives, because narratives are in the end all that we can achieve.

0. Prologue

> "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, ch. 14*

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

In his masterful article about the role of myth in geoscience, 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*". By no means such an escape procedure is peculiar to geology alone, but it characterizes all scientific fields, and in his "methodology of scientific research programmes" epistemologist Imre Lakatos (1978) even maintained that this stratagem may be beneficial.

Karl Popper (1959) showed that inductivism on one side and verificability of theories on the other side are both myths, and Lakatos and Feyerabend (1999) 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 ch.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. Introduction

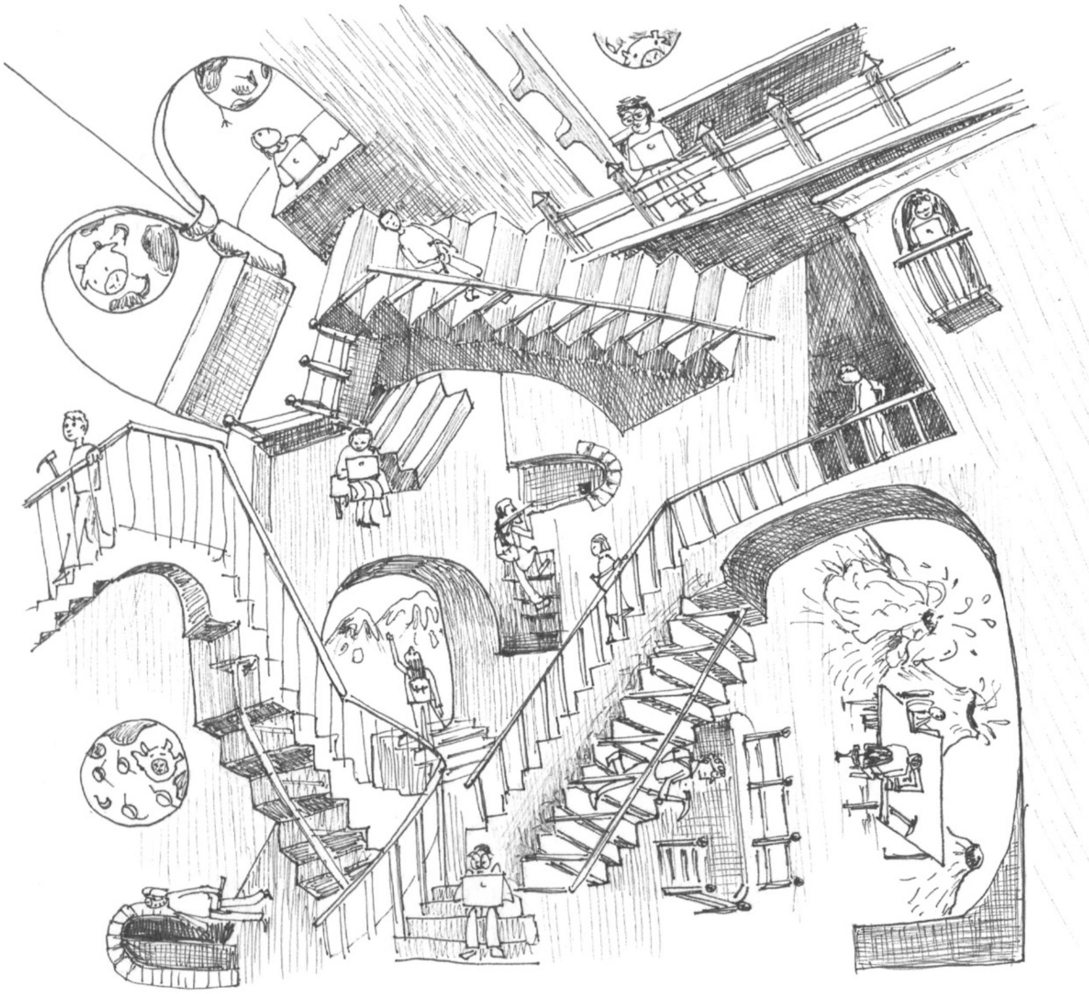
> "If the movement of the world really tended to reach a final state, that state would already have been reached. The only fundamental fact, however, is that it does not tend to reach a final state: and every philosophy and scientific hypothesis according to which such a final state is necessary, is refuted by this fundamental fact."
> *Friedrich Nietzsche, The Will to Power, # 708*

A system has attained steady state when the variables that define its behavior are not changing. The present conditions were the same in the (at least recent) past, and will continue to be the same in the (at least near) future. Steady state can be reached in man-regulated devices ranging from a simple bathtub with no bottom plug and the tap open 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-regulated and thus remain durably in steady state? Can they neutralize effectively and efficiently any potential perturbation through geological time? If so, then the present indeed provides a powerful key long enough to unlock the secrets of the deep past (Lyell, 1830). While unravelling the work of Nature, it is therefore essential to ask ourselves whether and with which limitations homeostatic conditions can be assumed (Handy et al., 2001; Willett et al., 2001; Willett and Brandon, 2002). 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 this article investigates. In a rather unorthodox way, we shall start from our present period of time, the Anthropocene (Crutzen, 2002), and from the peculiar aspect of Nature that we know best, ourselves and our society (Zeldin, 1994).

1.1. Steady state in human affairs

> “The man who takes historic fact seriously must suspect that science does not tend toward the ideal that our image of its cumulativeness has suggested. Perhaps it is another sort of enterprise.”
>
> *Thomas Kuhn, The Structure of Scientific Revolutions ch. IX*

The idyllic utopia of steady-state economy, requiring a stable population and stable consumption levels, has been idealized in different ways through the last two and a half centuries by liberal, marxist, and ecological economists alike. Adam Smith (1776 book IV.II), the founder of classic liberal economics, theorised that an invisible hand will ensure that the enlightened self-interest of individuals will contribute to the prosperity of society as a whole, and as a consequence any national economy would eventually reach a stationary state. John Stuart Mill (1885 book IV.IV) similarly believed in an ideal society were all individuals could pursue their own good free from any interference from others or government, and that a stationary state was inevitable, imminent, and desirable. On a different political front, Karl Marx (1875 part I.3) embodied the concept of a stationary state in his vision of a prosperous communist society where every man could receive “*according to his needs*”. More recently, John Maynard Keynes (1930) distrusted the magical power of free market and invoked active state intervention to eventually attain economic equilibrium and free the people from pressing economic cares, avarice, and "*love of money*". Leading ecological economist Herman Daly (1991) considered that the Earth's limited mineral resources cannot sustain endless economic growth, and thus recommended immediate political action to impose restrictions on all resource use in order to establish a steady-state economy. Steady-state economy, as well as the more radical version de-growth economy, are however explicitly recognized as "*unattainable goals*" and socio-political utopias (Latouche, 2006; Blühdorn, 2007; Kerschner, 2010). In the same way, Adam Smith (1776 book I.VIII and I.IX) failed to provide examples of a society that could settle in stationarity after having reached "*its full complement of riches*". Mill (1885 book IV.IV.§3) wrote "*this ultimate goal is at all times near enough to be fully in view; ... we are always on the verge of it, and ... if we have not reached it long ago, it is because the goal itself flies before us"*. And history has taken on the job to blatantly contradict Marx's historicistic prophecy of peaceful wealthy communism (Walicki, 1995). The argument may be closed by citing aphorism #*1064* in Nietzsche (1885): "*that a state of equilibrium is never reached proves that it is not possible*".



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*

Figure 1. A paradoxical configuration of steady state as an idyllic community attending their ordinary perpetual business in a gravityless world (from Escher, 1953, redrawn by Laura Medina).

1.2. Steady state 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*

Having established that both free market and deliberate political action have grossly failed to bring us any nearer to ideal social and economic equilibrium throughout the last centuries, we may legitimately be reluctant to believe that an "*invisible hand*" may lead to long-lasting stationary conditions in Nature at large. The suspect may rise that constant conditions are the requisite that we need to introduce in our reasoning to encage unpredictable Nature into a physical model that we are able to master. A reassuring tendency that 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, where cyclic, and the dinosaurs might reappear"* (Gould, 1987 p.103). Willett et al. (2001 p.455) envisage 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 and Brandon, 2002). Such ideally "mature" conditions in which all active forces are counter-balanced and every forcing factor is effectively buffered is the opposite scenario as 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 side the reassuring idealistic picture of phenomena inevitably evolving toward stability and maturity through time, on the other side a totally unpredictable haunting world destabilized by the sudden whim of any irrelevant part of the system dislocated in any of its regions. Order and chaos, two equally theoretical extreme scenarios (Ager, 1993; Orrell et al, 2001; Wolfram, 2002 p.997).

2. 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*

Science is a very sophisticated, open and dynamic conceptual system that – not much differently from myth and religion – may be envisaged as born out of our fear and urgent basic need to decipher Nature's laws firstly for protection and survival, and next to manipulate matter to our advantage. 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 the available tools to catalogue, identify, 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 big 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. Criteria and ideas that guide us toward understanding are inevitably intertwined with prejudice, which exposes us to the insidious pitfall of circularity whenever we feel we are moving forward (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, consciously and 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 teleologic trap and see scientific achievements as acquired steadily along a straight luminous path, we had better recall the words of T. Kuhn (1962 ch.IX) "*science does not tend toward the ideal that our image of its cumulativeness has suggested*" or the more poetic ones by Rose Macaulay (1956 ch.21) : "*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*".

Following Thomas Kuhn (1962 ch.I and VI), we can ironically envisage most of us as science's employees who spend most of the time striving in a rather ant-like – if you wish steady-state (Fig. 1) – puzzle-solving activity, while at the same time fearing and waiting for the next change of paradigm that will radically revolutionize the field in which we feel competent.

2.1. Placid uniformitarianism versus 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, Uniformitarianism, earth system science, and geology*

The discovery of deep time may well be credited to James Hutton, a gentleman farmer who belonged to the same circle of eminent Scottish thinkers that included the economist Adam Smith. 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), James Hutton understood the vast implication of angular unconformities such as the one separating Silurian slates from the Devonian Old Red Sandstone at Siccar Point. The famous close of his *Theory of the Earth* (Hutton, 1788 p.304) – "*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 sounds pleasantly reassuring.

In his simplistically acute and provocative style, Derek Ager (1981 p.44-45) sets the scientific dispute in 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*". Uniformitarians were instead 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.*"

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) will immortalize 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 1832, the same year the second 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 without nurturing an excessive interest in rocks by themselves – managed to confuse geologists for over a century (Prothero, 1990 p.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 to foster 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 p.67-70).

2.2. 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, ch. 8*

The assumption of steady state in many geological models is nothing more that tranquillizing *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 in order to protect ourselves from the dreadsome unpredictability of powerful natural agents, 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 vol.I), who definitely anticipated Lyell in several passages, including the one underlined: "*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 at this regard is Lyell's idea that geological history is cyclical, with every event repeating through time. Even extinctions were considered as temporary with the guarantee of a future return, a reassurring 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 (fig.2 in Rudwick, 1998).

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 face a plausibility collapse in the face of gathering stratigraphic and paleontological evidence (Bartholomew 1976). Underlying Lyell's dogged 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 persistent 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 (fig.1 in Rudwick, 1978).

In paleontology, 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 Galapagos Islands, however, suggested that new species may originate rapidly in small local groups isolated from their ancestors. This led Eldredge and 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 up to more than 10 m-high fossilized in growth position, as observed worldwide and typically in Carboniferous Coal Measures (Fig. 2). Such "polystrate" fossils, well known since the Nineteenth Century and widely cited by creationists as an 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-Land, 2011). Because at these rates (e.g., >> 1 m/a) a sediment pile thicker than the entire lithosphere would be produced in 10^4 - 10^5 years, such episodes of rapid accumulation must be brief and compensated 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).

The extrapolation of such ultra-high, punctual sedimentation rates to the entire Coal Measures highlights a discrepancy of several orders of magnitude, which makes inescapable the conclusion that sediment accumulation is highly discontinuous and anything but steady state (Ager, 1981 ch.3). Similar discrepancies characterize tidal environments, where weekly series of daily ebb and flood tides can be preserved and entire hyper-high-frequency lunar cycles materialized in sigmoidal cross bedding (Mutti et al., 1985). Such a continuous accumulation can be evidently maintained only for a very limited window of time in each site, otherwise we would need a sedimentary basin at least as thick as the Earth's radius to preserve the registration of all tides occurring in 1 Ma.

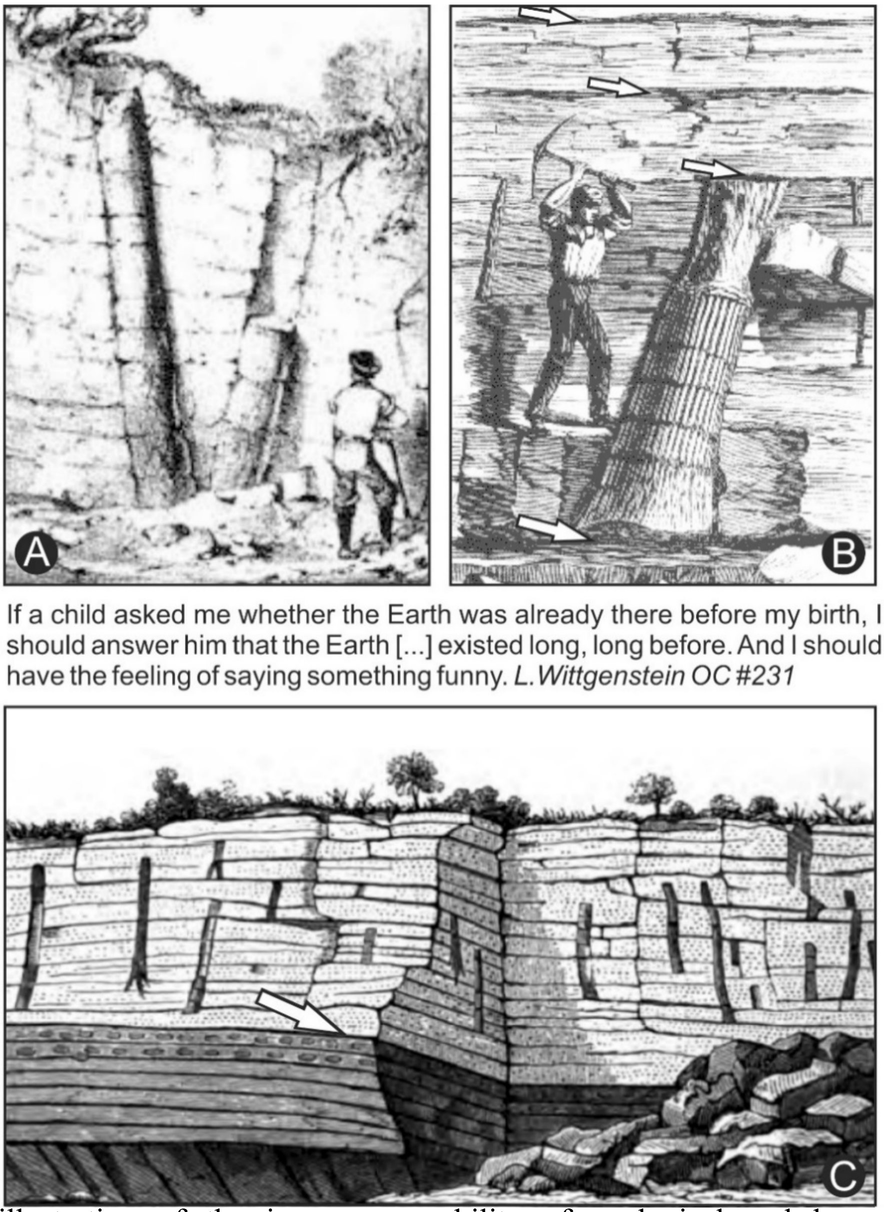


Figure 2. An illustration of the incommensurability of geological and human time scales: Pennsylvanian trees buried in position of growth. These "polystrate" fossils document rapid sediment accumulation at the scale of days to years that cannot be maintained through any geologically significant length of time, and thus must be compensated 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 (fig.4.5 in Ager 1993); **B**) Joggins, Nova Scotia (fig.35 in Dawson, 1868); **C**) St. Étienne, France (fig.310 in Credner, 1906).

The highly fragmentary character of the stratigraphical record (“*a lot of holes tied together with sediment”*; Ager, 1981 p.35) produces utterly erratic relationships between rock thickness and corresponding time span, and thus fundamental distortions at different scales in our perception (Sadler, 1981; van Andel, 1981). A sedimentary succession may appear as repetitively monotonous and comprehensive as an Andy Warhol’s film (Joseph, 2005; Haladyn, 2011; Walsh, 2014) wherever an ample availability of accommodation space makes it possible to approach quasi-continuous registration. Or, instead, as an accelerated sequence of condensed spasmodic events as an Hollywood film (Bordwell, 2002; King, 2013) wherever subsidence or sediment supply nearly stops or proceeds by hiccups as an ill-working recorder.

In most continental to shelfal environments, a limited tectonic subsidence forces sediment to move to-and-fro under the action of tractive currents rather than building up. Ager (1981 p.50) observes that in three millennia a site in the Gulf of Mexico has 95% probability to see a hurricane fully able to resuspend and redeposit all the ≤ 30 cm of sediment that could accumulate during that time. The storm bed generated during that geologically-instanteneous 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 event-stratigraphies of sedimentary and volcanic sequences (Ager, 1993 ch.11).

Going farther beyond, 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, the stack of the 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, truth is that to reduce natural, economic, 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). Steady state does exist in Nature but only as the *status quo*, the garbage time between events that matter (Califano, 1977).

3. 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, as 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. The final aim of a full understanding of Nature, i.e., the knowledge of the whole, is the same as understanding God, is being God. Observing Nature, which is what is reserved to humans, is the 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 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 approximatively defined and intertwined with mythological thinking (Dickinson, 2003; Garzanti, 2017). Inconsistencies therefore reign, not only in founding hypotheses (often pretentiously called "models"; Ager, 1993 p.xvi) but also in language. Try to ask a hundred geologists a geological question. The information you will receive from a range of different and even contrasting answers will be imprecise, unsatisfactory, distorted, and confusing. Does this mean that "*Geology is not a science*" (Sheldon Cooper in "Big Bang Theory") and that − because past scenarios cannot be tested by experiment and therefore are supposedly unscientific (Gee, 1999 p. 5-8) − geologist 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, in order to choose the best way to design our future. As Daniel Kahneman (2011) aptly wrote "*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 penetrate Nature, which is absolute, with our subjective concepts and limited intellectual and material means. How then to proceed?

Figure 3. Human knowledge, geological knowledge being no exception, is based on assumptions that have no firm base (from 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.

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, are models that 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), however, remains a patent nonsense.

The steady state (i.e., unchanging conditions internal to, and at the boundaries of the considered system) is a similar nonsense, because change is the primary driver of natural processes. If changes are negated, then the concept of Nature itself is misrepresented. Moreover, if changes in conditions are forbidden, then steady state is eternal, with no way to escape. Yet, assuming the 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, 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 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, collisional 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).

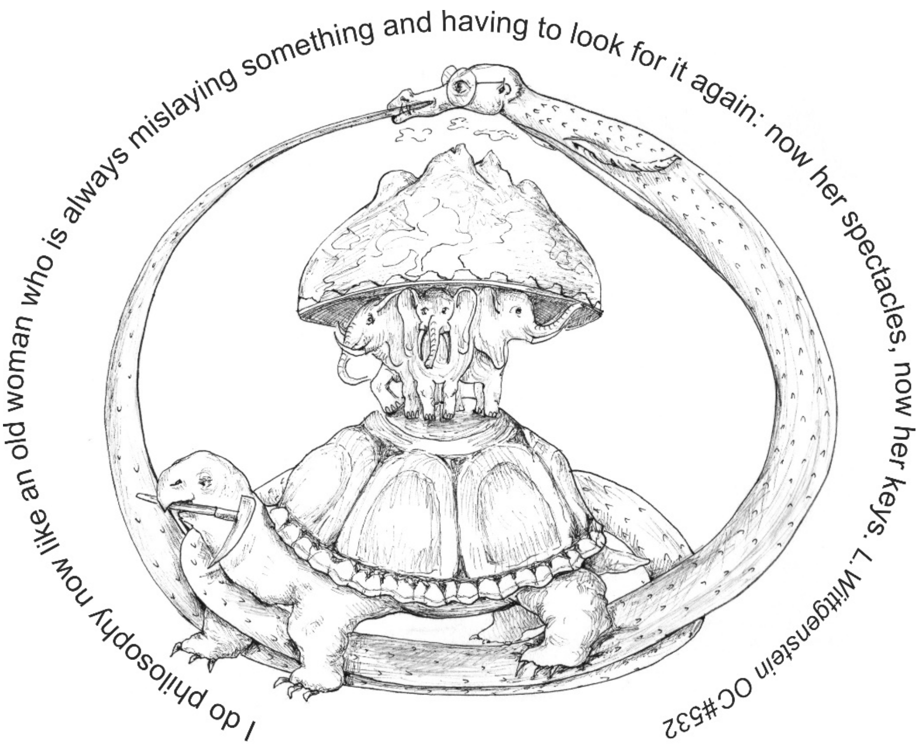


Figure 4. The world turtle (also referred to as the cosmic turtle or the world-bearing turtle; drawing by Laura Medina) is a mytheme of a giant turtle (or tortoise) supporting or containing the world. The mytheme, which is similar as that of the world elephant and world serpent, occurs in Hindu mythology,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

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 p.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 as 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. A procedure not exempt from risk (Fig. 3). As one example, assuming that a landscape is at 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 and Tucker, 1999; Willett, 2010; Romans et al., 2016). As another example, assuming 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). As a further example, assuming that the geothermal gradient is at 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 a given place on Earth (Braun et al., 2006; Malusà and Fitzgerald, 2019).

Explaining Nature in this way, however, 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 ch.XII). The risk is that, in the exciting up-and-down course of such a complex "matrioska" modeling 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 to considered 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, ch.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 homogenous and undeformed, and most geomorphological and tectonic models of orogenic belts are bidimensional, thus implicitly assuming cylindrism 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 never be taken as solid evidence. If we believe that our models are true, then we are kept in circular autoconfirmation. 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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