Philosophies for the Palaeosciences - A Review

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Abstract

The philosophy of historical sciences focusing on palaeontology, earth sciences, geology, ecology and evolutionary biology has been given much interest in the recent past. In this article, the focus is on the philosophies that are relevant to palaeosciences that only deal with the temporally disconnected past. Palaeosciences, an aggregate of sciences that deal with the past, are shown to be slightly different than the historical sciences. The questions that are attempted to be answered by reviewing the research literature are, 1) what are the appropriate metaphysical views and metaphysical guidelines for palaeosciences? 2) can a palaeoscientist follow multiple methodologies to understand the past and what are the philosophical foundations for that approach? and 3) are the palaeosciences, science? It is found that scientific realism seems to be the appropriate metaphysics for palaeosciences. Uniformity of process and simplicity (Ockham's razor) are shown to be necessary but not sufficient metaphysical guidelines for palaeosciences. Catastrophism and complexity may be invoked in explaining a palaeoscientific hypothesis on the availability of sufficient evidence. The disunity of sciences, epistemological pluralism, and methodological pluralism are shown to be beneficial philosophical views and strategies to do research in palaeosciences. The palaeosciences are science not on the basis of naïve falsifiability (Popper) but on sophisticated falsifiability (Lakatos) and family resemblance approach (Wittgenstein). Explained are the palaeoscientific methods such as 1) smoking gun with common cause explanation and 2) consilience when there is plenty of trace evidence recognized in the field (lucky circumstance) and, methodological omnivorous (Currie; unlucky circumstances). It is also shown that the misuse of palaeosciences can be minimized within Lakatosian methodological framework, and by the active participation of civil society in palaeoscientific research activities. A case study, on the color of the dinosaurs, is given to explain the salient features of palaeosciences as mentioned above.

Keywords: Palaeosciences; Historical sciences; Philosophy of science; Scientific pluralism; Scientific realism; Color of dinosaurs

Introduction

Most of the philosophy of science articles are published in philosophy journals, and that too are on physics, rather than in science journals, with a few exceptions to my knowledge (von Engelhardt and Zimmerman, 1982, Moharir, 1993, Cleland, 2001, Mukunda, 2007, GSA Special Paper 502, 2013, Kravitz, 2014). Except for a few attempts, rarely do these two groups of people (practicing scientists and philosophers of science) meet and discuss their views (Philosophical Tool box project; O'Rourke and Crowley, 2013). In this paper, I would like to give a status review on the relevant philosophies of science that focus on palaeosciences (the definition of palaeosciences is given in the next section). As this is a review, I do not take any side (except an unintentional bias) but present various views that are published. However, in some places, I have given my understanding although it has not been thoroughly analyzed and hence is only sketchy. As I am neither a philosopher nor is the target audience philosophers (but scientists), I have tried to use fewer philosophical terms. Instead of being an 'armchair' philosopher, Wimsatt (2007; p26) who encourages the philosophers of science to be activists that involve themselves in doing science as well. Similarly, practicing scientists should have some mental training towards philosophical thinking, and I am trying to do the same here. In the context of home-grown philosophy for the palaeosciences, this mini-review will hopefully stimulate deeper philosophical analyses on this topic in the time to come. The purpose of this work is to bring the philosophical discussions going on around the globe regarding palaeosciences to the table. In doing so, I believe that this should encourage or provoke practicing scientists in palaeosciences to take these issues further. That may improve our thinking about the way these sciences are to be done, and that helps the way they are practiced and taught in academic institutions and universities (Orzack 2012).

The motivations that led to this work are two. First, there is a general notion that 'the geosciences in general and the climate science, in particular, is not testable and hence not science' (www.theguardian.com/science/political-science/2013/jul/30/climate-sceptics-scientific-method, including that climate-change denialism, is pseudoscience, Hansson, 2018) and 'palaeobiology (and evolutionary biology) can't be tested using experiments either and hence is un-scientific' (Gee, 1999). These points need to be discussed in detail so that a student who has opted to study geosciences or earth sciences should not feel that he or she is studying non-science. It is also argued that it would be better to ask "is this a good way of generating knowledge in this given context?", rather than "is this science or not?" (thanks to Adrian Currie). Even if it is not science, then one should know what it is. Second, there is a widespread problem of globalization where some people, especially those from older (ancient) established cultures, feel they have lost their identity and want to regress back to that old culture however primitive they may be. They try to strengthen their roots by going back to their glorious past (Narasimha, 2015, Vahia, 2015). If they hold political power, they can construct or deconstruct the past as they want that, at the cost of truth. Here come palaeosciences as their tool. History - including palaeohistory - has the potential to be socially powerful, both a tool for oppressors and a means of defense for the oppressed. As such, it is important to understand the method and limits of palaeosciences to guard against the misuse of history. Overall, it is important to know how much one can reconstruct the historical past using science and the uncertainties that are associated with that.

Recently there was a worldwide protest by practicing scientists against,1) the misuse of science (climate science included) to back up government policies that have no empirical support, and 2) reduction in government funding for research (On the march, Nature Editorial 2017, Nature News, Padma, 2017). Provocatively calling this protest as un-scientific and the protestors as science fundamentalists, Sarukkai (Marching from yesterday, op-ed, The Hindu, 2017) calls for a public debate to know what is science. Three decades ago, Theocharis and Psimopoulos (1987) blamed philosophers of science (particularly Paul Feyerabend, Karl Popper, Thomas Kuhn and Imre Lakatos in descending order) for the reduction in government research funding and warned against financial bankruptcy, social anarchism and scientific chaos, confusion, and stagnation in society. All these point to the need for a better understanding of the nature of science. Further, articles on the philosophy of historical sciences show an increasing trend. The number of original research articles (82 %) and review articles (18 %) during 1980 - 2016 (Scopus data-base) with keywords of “philosophy of science” & “Earth science” increased (exponential growth rate of articles of 0.49 year^{-1}) compared to those with the keyword of “philosophy of science” alone (exponential growth rate of articles of 0.32 year^{-1}).

This review focuses on the epistemic issues relating to palaeosciences. Three main philosophical themes, apparently independent of each other (scientific realism, disunity of science thesis, and methodological demarcation criteria) are initially discussed just after the definition of palaeosciences. Practices in palaeosciences either use or exploit these philosophies and hence I would like to explain them, instead of merely referring to them. That is the reason for having a pluralistic title, i.e., philosophies that are relevant for palaeosciences. After the definition of palaeosciences, metaphysics for palaeosciences, scientific pluralism in ontological, epistemological, and methodological aspects (in sub-sections) are discussed. Next section has the philosophical analyses on practices in palaeosciences, in reconstructing past events and processes, and geochronology. After that, I discuss the possibilities of epistemic assistance in palaeoscientific research. Before concluding remarks, I would like to mention a failed bet of Derek Turner, on the epistemic impossibility of the color of dinosaurs with the advancement of science.

What are the palaeosciences?

Palaeosciences (palaios *past* + scientia *to know*) simply mean 'knowing the past'. It is neither science of the past (or ancient science) nor merely a tool (or technique) to know the past. It is used in a pluralist sense as Ian Hacking (1996) has done in one of his essays 'The disunities of the sciences' by quoting Augustus Comte (on ways, we are able to know *the past*). It is an aggregate of all such sciences and hence uncountable. This word, to my knowledge, was coined first by Taylor (1975), in a singular sense – palaeoscience, to mean palaeobotany, palaeopedology, and palaeoclimatology. However, there is a definition given in the Encyclopedia of Environmental Change edited by John A Mathews, which defines palaeosciences as "historical sciences or more appropriately those branches of the natural environmental sciences (palaeobiology, palaeoclimatology, palaeontology, palaeoecology, palaeoentomology, palaeohydrology, palaeolimnology and palaeooceanography; *anything that has happened in the Earth i.e., human history and sociological changes*) that focuses on the reconstruction and modelling of past events (*antecedent conditions, processes and entities associated with that event*) rather than direct observation and experiment". My modifications are in italics. Cosmology, astronomy, earth sciences, geology, palaeontology, evolutionary biology, ecology, archaeology, anthroecology, forensic science, and cliodynamics are regarded as historical sciences. Historical sciences including geology, neontology, and ecology are temporally in continuum with history and give equal weight to both present and past phenomena. But palaeosciences are temporally disconnected from the present, and the present is a methodological tool to understand the past; hence the primary aim of palaeosciences is not the present but the past. Ontologically, time doesn't have any distinction between past and present (as per the growing block theory of time, Miller, 2017) and temporal disconnectedness is a methodological requirement. The comparison between the historical sciences like geology (Simpson, 1963) and ecology (Brown, 2011) with palaeosciences like geohistory/historical geology and palaeoecology respectively, might help to differentiate historical sciences from palaeosciences. Palaeotiology (palaios *past* + aetiology *the sciences which deal with causes*) as used by William Whewell (1794 - 1866), comes closer to the intended meaning of palaeosciences in this study. But a closer analysis shows that the combination of phenomenology and aetiology is meant to be palaeotiology, whereas the palaeosciences are the combination of palaeophenomena and palaeotiological sciences (Whewell, 1840). In this case, palaetiology and palaeosciences are not the same. Palaeosciences deal with unique, contingent and particular events that happened in the past and they cannot be manipulated in the laboratory.

Can palaeosciences deal with planets other than Earth? Yes, it can deal in principle, and there have already been some studies that reconstructed the presence of water on Mars (Currie, 2018; Chapter 7).But, this article mostly focuses on terrestrial palaeosciences because not only we do have a better understanding about the inorganic materials of the Earth but also about the biology and sociology of it in finer details. In essence, terrestrial palaeosciences deal with the past's spatio-temporal heterogeneous and interdependent systems (geosphere, biosphere, and anthrosphere) whose behaviour depends not only on initial conditions, but also on boundary conditions.

Metaphysics for the palaeosciences

Positivism/empiricism study the present phenomena and their formal relationships among other phenomena (observables); and it does not invoke any causal theory (unobservable) to save the phenomena (Feyerabend, 1993; Disworth, 2006, p.9-48; Psillos, 2000, 2009). Empiricism mainly deals with the observables and does not bother about attaining the truth that is mind-independent reality (for a more detailed discussion, see Disworth, 2006). Its goal is to be consistent with the observables and to move on without invoking any metaphysical notions. Constructivism constructs the reality and does not believe in the existence of objective, mind-independent reality. Constructive empiricism (CE), as promoted by van Fraassen (1980, 2004), is of the view that science aims to give us theories that are empirically adequate; and acceptance of a theory involves belief only that which is empirically adequate. Realism in general, scientific realism (SR) in particular, is of the view that the world/universe described by science is real and that it deals with both observables and un-observables. SR encourages postulating theories to explain the unobservable part of the world as well, and it also believes that with more scientific investigations we are asymptotically nearing the truth. The difference between van Fraassen's constructive empiricism and scientific realism is in the acceptance of a scientific theory as the belief that it is empirically adequate (CE) or that it is true. Questions of scientific realism are 1) what attitude should we have towards our best current science about the un-observables; 2) should we, for instance, believe what science tells us, should we withhold judgment, or should we distrust what they say about the un-observables?

One can't directly observe the things that are so distant (horizon problem in cosmology, Kosso, 1988), or tiny (Higgs Boson which can't be observed as it is so small and its existence time is very short), or that existed in the past. In palaeosciences, the un-observability is because of the things that formerly existed, and it is not possible, as of now, to observe them unless we have a time-travel machine. Kosso (1992) argues that the observability is itself theory-laden and prefer to ask "is that really an observation of a particular dinosaur?" rather than "is that dinosaur observable?". Although the past is unobservable, the literature that discusses SR mainly focuses on the micro-physical objects such as sub-atomic particles but not on the past (temporal dislocation; Jeffares, 2010, p.137). Compared to the tiny and the distant, the past can offer definite objects for scientific realism. Because, even if it is claimed that unobservable things due to tininess and distance are the constructs of scientists, the past time has certainly left its wake, which indicates that the past event surely happened. The very presence of the observable, tangible fossils indicates the certainty of the past events. The uncertainties associated with the past truths are not ontological (e.g. unknowable by its nature) but epistemological (e.g. uncertainty in one's perception), so the truth about the past is real. Historical anti-realism denies the historical truth and suggests that history can be constructed as well (Dummett, 2004; p.68). It says that history depends on the mind (memory) of human beings and hence it is not an independent reality. Essentially it boils down to the local under-determination problem discussed by Turner (2005), and this is also discussed in detail below.

Derek Turner (2007, p.10-36) was the first to discuss and examine historical realism in detail, and he found that there are two asymmetries between historical realism (past) and experimental realism (tiny). The first asymmetry, familiar to the scientific community, is that of the manipulability of the tiny and the past. Micro-physical objects can be manipulated in the laboratory but Cretaceous dinosaurs cannot. The second asymmetry is the background theories. Background theories are established theories that are taken for granted by the scientists during their scientific investigation. Background theories, mid-range theories (Atici, 2006), dependency relationships and relevant background knowledge are, sometimes, used interchangeably (Currie, 2018). Turner (2007) has included technology in this list as well when he mention about theory of optics in instrument building to detect the tiny. The background theories of micro-physical objects broaden the scope of those objects' observability whereas the background theories of the past are all about how the evidence/traces are degraded with time, that limits the scope of the observability of the past. For example, the background theories of the Higgs boson (micro-physical object) will help scientists design the equipment to detect that transient appearance of tiny particles in given experimental conditions. But the background theories of the dinosaur’s fossilized heart (past entity) will inform the palaeoscientists about the on-going degradation processes of that fossil that reduces the scope of understanding of the details of dinosaurs. Turner (2007) argues that background theories play an enlarging role for micro-physical objects and a dampening role when it comes to the past. Although it cannot be generalized, background theories seldom play an enlarging role in palaeoscientific research.

In fact, palaeosciences are left with only physical things and no consciousness or life that is preserved in the traces or fossils and seem to be more physicalism (meaning all the realities supervene on physical reality) in a strict sense. Without invoking any theory and only relating to the present day phenomena with each other, palaeosciences will not serve any purpose in understanding (Potochnik, 2015). I mean just describing the fossils and other traces of the past and its relationship among themselves, as positivist or empiricist does, will not even tell about the physical history and even less about the histories of life (biological) and consciousness (anthropological and sociological). In this context, scientific realism is the best metaphysical view for palaeosciences (Turner, 2007, Jeffares, 2010).

Another important but much debated metaphysical guideline for palaeosciences is uniformitarianism, and this is not unique to palaeosciences but to any science (Gould, 1965, Shea, 1982, Romano, 2015). Uniformitarianism, the word coined by Whewell (1832; to differentiate from catastrophism) includes uniformity of law, uniformity of process, uniformity of rate and uniformity of state (Gould, 1965, Baker, 2014a, Romano, 2015). The work of William Thompson (Lord Kelvin) on the cooling of the Earth (hotter to warmer) and Charles Darwin's evolution concept (speciation and extinction) refuted the uniformity of state and uniformity of rate (Kravitz, 2014). Thus only the first two i.e. uniformity of law and uniformity of process remain. Discussions are going on whether the uniformity of law is true or not (Smolin, 2014) but that is difficult to test (Hume's problem of induction; Vickers, 2016). Finally, uniformitarianism has been left with the uniformity of process (actualism), and that is what Geologists mean by uniformitarianism. Actualism is not like English usage but French which means contemporary (Shea, 1982). It seems strange that the work of Charles Darwin, a uniformitarian, led to the abandonment of the uniformity of state and the uniformity of rate. I tend to think that he was probably a uniformitarian who assumed only the uniformity of process but not the others. Uniformity of process states that the process which is acting today can be assumed to be the same process that happened in the past (present is the key to the past, as stated by Sir Archbald Geikie, 1835 - 1924). The uniformity of process cannot be blindly applied to palaeosciences because of spatio-temporal configuration dependent processes (configurational causes as coined by Simpson, 1963). For example, the trajectory of a feather and an iron rod will be treated by different equations and models (Cartwright, 1994) because a simple system that is embedded in different configurations need to be treated differently.

Severe criticisms also apply to the uniformitarian principle (Romano, 2015) and suggest that this should not be used at all (Shea, 1982). Uniformity of process was needed at that time when the supernatural causes were invoked to explain geological phenomena, but now it is not needed (Gould, 1965). However, he mentioned its vital role in the history of geology, i.e. palaeosciences (Gould, 1965). Catastrophism is now equated with naturally caused extreme events (terrestrial or extra-terrestrial), and enough empirical evidence is available for the occurrences of extreme events. So catastrophism cannot be ruled out during palaeoscientific reasoning (Baker, 1998). Instead, the principle of simplicity (Occam’s razor) has been suggested as a metaphysical guide (Baker, 1998). Simplicity neither assumes that reality is simple by nature nor it is to be invoked for practical or aesthetic reasons (Riesch, 2010). Simplicity in our hypotheses that can be tested, understood and gradually able to reach the truth (Popper, 1983; O’Hear, 1985). Whenever uniformitarian simplicity cannot handle a situation, only then should catastrophic complexity be invoked (Goodman, 1967). Before continuing, it is better to see the difference between complicatedness and complexity. A system is complicated but it is deterministic because it may have many interconnecting components that are acting together following strict rules, but its collective behaviour is relatively simple.. And if a system is complex, then it is non-deterministic because it has diverse interconnecting components that work together following strict rules, but it influences the environment and can be influenced by it and hence its collective behaviour is non-linear. Complicated systems are the engines that are made; there is no emerging property/entity when all the interconnecting components work together. Complex systems will have emerging properties/entities, where the sum of parts is more than the whole. In that sense, inorganic part of the earth is not complex but complicated. But the organic, psychic and social parts of the Earth are complex systems. In Earth sciences, one needs to deal with all the parts of Earth (inorganic, organic, psychic and social parts). So, the events and phenomena of the 'present' Earth themselves are the non-linear effects of varying interacting Earth systems. Hence, the objects of the past bring higher degree of complicatedness as those complex systems of the past are unobservable now. Coming back to the uniformitarian simplicity and catastrophic complexity, uniformitarian simplicity may be considered as a null hypothesis and can reject that upon compelling evidence (thanks to Prof. Robert Wasson). Hence, uniformity and simplicity can be individually necessary but not sufficient criteria, however, to consider any palaeoscientific theory for further investigation.

Thus far, palaeosciences are shown to be the sciences that are dealing with the temporally disconnected past, and this temporal disconnectedness makes palaeosciences different from historical sciences. Terrestrial palaeosciences are shown to deal with the spatio-temporal heterogeneous interconnected systems such as geo-, bio- and anthrospheric systems in finer details. Scientific realism is shown to be a better metaphysical framework for doing palaeosciences. Also, it is shown that uniformity of process and simplicity (uniformitarian simplicity) collectively plays as a metaphysical guideline in palaeoscientific research activities. In the forthcoming section, another important aspect of palaeosciences, scientific pluralism, is discussed.

Scientific pluralism

This section and the following subsections may look odd at this point, but it needs to be introduced now. Because palaeosciences is a subset of special sciences, 1) the scientificity, demarcation criteria to call some endeavor science or pseudoscience) and 2) the taxonomical position of these sciences should be discussed before we analyze the practice in palaeosciences. Special sciences investigate their own part of nature such as biological, psychical, and societal and hence specialized whereas physics is considered to be a generalized science. Both these points cannot be discussed without any analysis on the nature of science itself, and in fact, the palaeosciences exploit the disunity of sciences thesis as shown in the next section (Wylie, 1999, Currie, 2015a). Scientific pluralism is of the view that some phenomena need multiple accounts of them to have a clear picture (Kellert et al., 2006). So, scientific pluralism might be a guiding principle in dealing with nature that is so diverse and complex to finite human beings. Especially, a palaeoscientist is in an epistemic situation that is similar to that of a forensic scientist, who needs to pin point the culprit that is responsible for a crime. She has to follow multiple ways (pluralism) to reach a conclusion about a past entity. Here, we'll see how much diversity or pluralism can be adopted in our approaches and the philosophical arguments for and against that. There is also a boom of special sciences and the proponents of ontological (reductive) disunity of science (DUoS) as John Dupre (1983) claim that the special sciences are by nature heterogeneous and that cannot be reduced down to micro-physics. Within the metaphysical commitment of scientific realism, let us see in the following sections how scientific pluralism can be understood in ontological, epistemological and methodological aspects.

Ontological pluralism

There are two views on the nature of science. The first view is that the reality is one and, the most basic science is sufficient to explain the whole reality, and this is called the ontological unity of science. The second view is that the reality is patchy and we need different sciences to understand the patchy reality and it is called ontological disunity of science. In literature (Potochnik, 2011, 2017), the unity of science mean both reductive unity and coordinate unity, and I would like to mean the unity of science as reductive unity (by nature) and coordinative unity as epistemological unity (as a strategy to explore the reality). Unity of science (UoS) says that any science (of processes, events, and entities) can be reduced to a fundamental science, which is physics. For example, sociology can be explained by psychology which can be explained by biology; biology can be explained by chemistry, and that can be explained by physics. The higher level sciences (of processes, events, and entities) are ontologically dependent on the lower ones and finally on physics. It is true that there are emergent entities (like life and consciousness) which would be arising during the supervenience from lower to higher level sciences (Fig. 1). Although these phenomena of emergence have not been well understood as of now, such lack of knowledge should not lead to the conclusion on the irreducible nature of science (Carrier and Mittelstrass, 1990). It is called reductive unity, and this is the unity of science in the strict sense (Oppenheim and Putnam, 1958). As of now, the unity has not been attained; will this ever be attained at all? The authors (Oppenheim and Putnam, 1958) are optimistic about it. The principle of evolution, ontogenesis, and synthesis make vivid sense as in the case of Big Bang theory that tells us there was a day without yesterday (Lemaitre, 1927, Farrell, 2005) and everything else - starting from sub-nucleus particles, atoms, stars, life to conscience - started to exist since then. There was a time when there was no electron, no atom, no star, no life and no conscience (ontologically, not epistemologically; Fig. 1). As per this sequential development, a set of few fundamental, irreducible laws govern the interaction between the most fundamental constituents, and they are the 'bed-rock' laws from which everything else can be supervened, and all else can be reduced to that. However, the most fundamental constituent of this universe is yet to be found or perhaps was 'nothing' there except fluctuations (Fig. 1).

Fig. 1

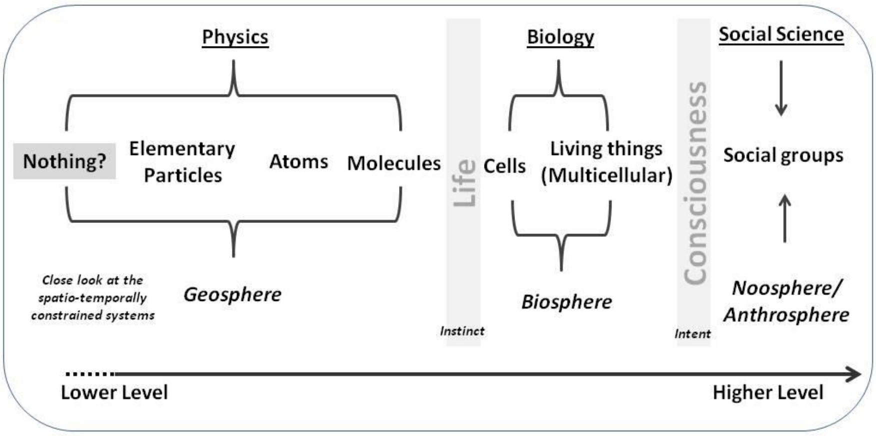

Fig 1. Schematic diagram to explain the reductive unity of sciences. Higher level sciences can be reduced to a basic lower level – rock bottom – science. Life and consciousness are the emergent entities at some point of time. Generally fundamental particle physics is considered to be at the lowest level. With time, we may come to know that the current fundamental particle is no more fundamental, and hence the bottom most also will shift with the progress of science.

An example of de Regt, Buskes and Kleinhans (2015) would help to understand this UoS point.

Consider a statement "Earthquakes are generated in the rigid plate as it is subducted into the mantle." This is a generalized, but not universal, statement and it is not a law. The geological terminologies (vocabulary) such as 'mantle' and 'plate' can easily be understood with the terminologies of physics and chemistry such as 'the stony but slightly fluid layer surrounding the core of the planet made of minerals rich in the elements of iron, magnesium, silicon, and oxygen' and 'broken piece of the rigid outermost layer of the Earth' respectively. Similarly, the processes like 'Earthquake' and 'subduction' can be understood in terms of the physical and chemical processes, such as 'failure of the plate when static friction is exceeded, and a movement of one block with respect to the other block occurs, giving rise to oscillations or seismic waves' and 'the sinking of heavy material of the crust into fluid material, caused by the collision between two plates' respectively. Here a law of special sciences, here earth science, has been reduced down to that of basic physics. But palaeosciences do not have only inorganic aspect but also biological, psychological and social aspects. Reducing such higher level laws to those of fundamental physics is shown to be practically useless, in the paragraphs below. For example, it is useless, also nobody will fund, to study the dynamics of quarks there in various conditions and configurations to reconstruct the palaeoecology of a pond.

The disunity of science (DUoS) is an antithesis of the unity of science. Fodor (1974) defended the DUoS as a working hypothesis to do scientific research especially special sciences. Another defender of the DUoS thesis is John Dupre (1983), and he put his arguments powerfully against practical uselessness of UoS thesis as a working hypothesis, and this is an empirical (using biological sciences) rather than Fodor's (1974) logical argument. He criticized UoS as a working hypothesis proposed by Oppenheim and Putnam (1958) as massively simplified by pointing out that a mere collection of molecules cannot make a living cell. He mentioned that as concrete laws work only under certain functional conditions and hence they are different from general laws. In special sciences, only abstract laws (similar to concrete laws as Nancy Cartwright (1993) calls it) are practically useful (no use of general laws), and they cannot be reduced to micro-physics. The point Suppes (1978) and Cartwright (1999) bring out seems not contradicting the ontological unity (i.e. single reality). Because the patches of reality are not in reality itself but in our models to represent them using different sciences. Also, Dupre (1983) gave examples from ecology (a part of biology) where not only intrinsic characteristics decide a particular outcome but also extrinsic conditions like weather and epidemics. Dupre's main point is that although the core law is operational intrinsically, the influence of the environment or critical zone of the Earth system will alter the course of action and hence is the final output. So the output cannot be predicted based on the intrinsic law, which is exception less, because of external influence of the spatio-temporal dependent configuration of the environment. So this renders reductionism not possible. For example, even within biology, the theories of population biology are different than those of physiology or behavioral psychology. In genetics, not only random mutations but also external environmental conditions make reduction difficult to a lower level science. He suggests that the irreducibly unique events will need abstract models that deal with real individuals, and also said that evolutionary processes cannot be described in isolation from the macroscopic properties of the organisms whose interactions that constitute it. He pointed out the irreducibility of nature from the biological point of view and, further, he said that the irreducibility would be at the greatest for the mind-body problem and intentional psychology (Millikan, 1999).

There are a couple of objections to the disunity of science thesis, and they are mostly against Fodor's (1974) paper but not against that of Dupre (1983), except Ereshefsky (1995) when Dupre generalizes the pluralism not only by methodologically but also metaphysically. The strong objection came from Jones (2004), and he mentioned that if the physicalism and causal closure principle are endorsed, the reduction should be possible, in principle. If physicalism can be placed within naturalism as an empirical hypothesis (physicalism is needed for the existence of chemical, biological, psychological, and cultural entities either directly or indirectly), then the sciences can be non-reductive (Cahoone, 2013; p.74, Henriques, 2003; p.154). At the same time, he continues, if the special sciences can be given autonomous, the epistemic nightmare in trying to explain all the properties of special sciences regarding physical properties can be removed. Although all the sciences can be reduced to physics, relying on physics alone without any special sciences is not an efficient approach in knowledge production (like studying quarks behavior to reconstruct the palaeoecology). Special sciences will advance the knowledge production rate, and reduction can be done when there is a sufficient accumulation of special knowledge to unify the knowledge.

Epistemological pluralism

Although ontological monism (i.e. reality is one where all are related to one another as all have been originated from one particular event, Big Bang) is the reality, having that as a working hypothesis is useless for progress and is an inefficient approach. So for the time being pluralism can be used as a strategy to deal with the complex reality. If explanatory unity or reductive unity is one tradition of the unity of science, then egalitarian coordinative unity is another tradition that has roots in Otto Neurath's (1882 - 1945) notion. In the first tradition of the unity of science, physics is given the privileged epistemic status and in the second tradition diverse fields of science coordinate together, and none of them are given privileged epistemic status. Different domains of nature are probed using different disciplines and try to attain the truth from inorganic (physics), organic (biology), psychical (psychology) and sociological (sociology) investigations. But this is for our convenience, nature can be assumed to be unified, and the truth is not fragmented (Ontological Pluralism section). Evidential relationships do not respect disciplinary boundaries, and scientific research projects should be based on problem-oriented rather than methodology or discipline-oriented so that different fields of science can share the evidence and can explain the past state of affairs (Potochnik, 2011).

In recent years, the word "interdisciplinary" has become very popular and, fanciful terms such as ‘philosopher's stone’ (Mansilla *et al.,* 2015),‘mystical Mesopotamia’ (Wohl, 1955, Miller *et al*., 2008) are used to emphasize the importance of interdisciplinary approaches in scientific research in general, and geosciences in particular (Manduca *et al*., 2013, Baker, 2017). The difference between disciplinary and interdisciplinary approaches is like autonomous and integrative models of science. The autonomous model of science can address and solve some research problems, and it does not need to be integrated with other sciences. But the integrative model of science needs to integrate other sciences to address a particular research issue. The disciplinary approach (autonomous model of science) has been found wanting in solving problems of complex systems such as climate system, biological system, and social-ecological systems. As a single cognitive tool will be insufficient to deal with scientific questions about complex systems, there is a need for a tool box where multiple cognitive tools are available. Certainly, palaeoscientific questions need an interdisciplinary approach, as they are to deal with the past's complex systems. For example, the dynamics of Earth surface during the Anthropocene cannot be studied without various disciplines such as geology, biogeochemistry, biology, ecology, psychology, sociology, history, urban ecology and cliodynamics.

Not only various disciplines need to come together to solve a particular scientific problem, especially palaeoscientific problem, but also the investigators should come from various walks of life. Scientists from various walks of life, i.e. with different standpoints or situations will see and approach a problem in different ways. There is a criticism that only the dominant few (males and whites; Euro-centrism) and ablests (one who is able, in superlative adjective, having skills, power, opportunity to do something) in the society participate in scientific activities and marginalize others (Harding, 1992). In the Indian context, casteism should also be added to the list. The participation of the dominant few is against pluralism as it skews the standpoint spectrum from which the scientific problems are investigated. Although science is generally claimed to be objective, the history of science informs us that there is a social element that is embedded in the way science is practiced (Kuhn, 1970). If these subjugated and marginalized populations are included in the scientific research activities, they 1) enrich the research activity with their situated knowledge from their various standpoints and 2) the objectivity will be maximized because of their democratic participation in the knowledge production endeavor (Feyerabend, 1978). It is very much true with indigenous knowledge (IK) where the local downtrodden people have more information than elites. Palaeosciences need to have better ‘present’ understanding so that the past can be reliably reconstructed through the uniformitarianism principle. The present condition of the biota and abiota cannot be understood without the down-to-earth peoples' contribution. The role of civil society in designing research projects is being emphasized in scientific literature as well (Moran and Lopez, 2016).

Methodological pluralism

Demarcating science from pseudoscience (scientificity), is one of the two motivations to write this article. Whether any pursuit in science is regarded as scientific or pseudo-scientific depends on the methodology it undertakes. Although many philosophers of science consider demarcation is not at all a problem now (Lauden, 1983 and many personal communications), I feel the need is still there (Pigliucci, 2014, Padma, 2017, Sarukkai, 2017) and needs to be discussed. Historical development along the lines of the demarcation problem has been described well in Lauden (1983).

Verificationism criteria (if $H \rightarrow E$; E does occur; so H is true; affirming the consequent, *modus ponens*) was used to demarcate science from pseudo-science. But, Popper found a problem with this inductive inference ('All swans are black' hypothesis will never be proved by observing new black swans) and proposed falsificationism (if $H \rightarrow \neg E$; E does occur; so H is false; denying the consequent, *modus tollens*) as a demarcating criterion. As per falsificationism, a theory should propose a crucial negative experiment where a potential falsifier is to be anticipated and hence that theory is falsifiable and is scientific, and otherwise pseudo-scientific. If the potential falsifier is observed to be true, then the theory is falsified indefinitely without any possibility of resurrection at any time. It does not consider the occurrence of type II errors (false negatives). If that falsifier is not observed to be true, the theory survives, but not proved. Here it doesn’t consider the type I error (false positives) but considering the consequence, type I error is not more fatal than type II error, and this is shown in Fig. 2a. According to falsificationism criteria, no theory can ever be proved but can only be falsified. This criterion is considered to be too stringent (Penrose, 2005; p.1020) and brutal. But the history of science never said that any theory had ever been falsified based on this criterion, but on the contrary, in spite of anomalies, Newton's theory and Einstein's theory were not falsified during their infant stages (Lakatos, 1976). No theory can be tested in isolation and if the predicted falsifier has been observed, it may not be that the theory is wrong but one of the auxiliary hypotheses (Duhem-Quine thesis; under-determination problem). A syllogism for the under-determination problem is, if $H \ \& \ aH_n \rightarrow \neg E$; E does occur; so either H or at least one of the ***n*** auxiliary hypotheses, aH_i is false; this is also called testing holism. A classical example is the discovery of Neptune. Neptune was discovered while examining the auxiliary hypotheses when the orbit of Uranus was not as expected as per Newton's theory. Einstein's theory of relativity was not tested by laboratory controlled experiments but by field expedition. Similarly, Popper's example of finding a white swan will only be possible not in laboratory but in field!

Fig. 2

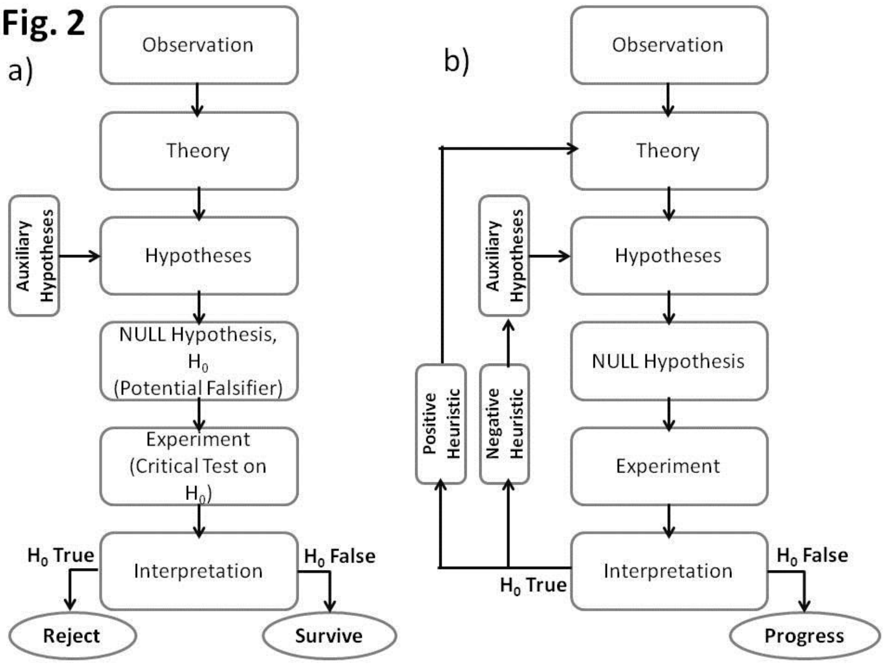

Fig 2: Flow chart explaining a) Popper's naïve falsificationism criteria for scientificity and b) Lakatos' sophisticated falsificationism, where a scientific research programme can be progressive or degenerative but without brutal rejection forever. Degenerated scientific research programme can be progressive with the later time scientific developments and vice versa.

Lakatos (1976, 1978) proposed a methodology for a scientific research programme, where each programme consisted of core theory and sets of methodological rules such as negative heuristics and positive heuristics. Negative heuristics (protective belt) is to modify (or even invent) auxiliary hypotheses to protect the core theory from being refuted when an anomaly (or sets of anomalies) is observed. Positive heuristics is an anticipated modification or improvement on the core theory itself, and this is mostly done at the theoretical level (Fig. 2b). If any theory has a novel prediction of facts, then it is progressive otherwise degenerative. In palaeosciences, a hypothesis may be said to be progressive based on the explanatory power, coherence with other established hypotheses, in addition to the novel prediction. It is worth mentioning about coherence and prediction here. Coherence is a word that is more compatible in normal science than in revolutionary science (Kuhn, 1970). Feyerabend (1972) may point Copernicus heliocentric theory that was not coherent with the other established hypotheses of his time. Further, prediction is not possible in palaeosciences but retrodiction or postdiction but that too is a debatable point (Turner, 2013,Cleland, 2011).

Lauden (1983) stated that falsificationism is not a necessary and sufficient condition to demarcate science from pseudo-science and hence demarcation is not possible at all. Pigliucci (2013) in his belated response to Lauden (1983), agreed with him on the issue that there are no necessary and sufficient conditions to regard anything as science; but that shouldn't stop us working towards finding better criteria, because the pseudo-science is harmful to the society and the individual. He proposed Wittgenstein's family resemblance approach (FRA) which can capture the dynamic, complex and diverse nature of science in a philosophically neutral way. FRA is more comprehensive, open-ended and will evolve with time. FRA will influence scientific practice and be influenced by it (Irzik and Nola, 2010). In the FRA framework, there is no single commonality among the sciences but only inter-dependence and overlapping between them, and all the sciences are regarded as science. In a family, not all the members look the same, but they are not entirely different as well. Some features will resemble others, and some overlapping features will be there among the members. There is no single science but members of the family of science. FRA would neither reject any science nor glorify any but give proper weights at particular times (Pigliucci, 2013). It may give low weight to astrology and creation science and more weight to particle physics, but it would not shun astrology and creation science in a dogmatic manner. In this sense, the sophisticated falsificationism of Lakatos (1976), and FRA sound similar. Thus, methodological criteria have taken a course from analytical philosophy to continental philosophy (Frodeman, 1995, Jones, 2009, Pigliucci, 2014). We can understand Feyerabend's provocative words in a slightly different tone that it is not 'anything goes' (Feyerabend, 1978, 1993) but 'many things go' (Currie and Turner, 2016) and certainly, he couldn't have meant 'everything goes' see Kidd, 2016). Feyerabend himself mentioned in his book titled Science in a Free Society (1978, p.188) that 'anything goes' was a jocular summary about the predicament of the rationalist who insists on universal standards (Sankay, 2011). Feyerabend has been reappraised in recent years by philosophers of science as his ideas of the 60's and 70's that were heavily criticized and rejected, make sense now in the light of contemporary developments in the history and philosophy of science (Brown and Kidd, 2016).

As an upshot of this section, although nature is undivided, special sciences are needed to probe different parts of nature efficiently. As these different parts of nature are complex and the past's evens and phenomena render complicatedness, not only disciplinary coordination but also the democratic participation of citizens (civil society) are needed for a fair understanding of the dynamics of nature. Further, it is shown that apart from Popper’s falsifiability criteria, Lakatosian sophisticated falsifiability and Wittgenstein’s family resemblance approach can be used to test whether any endeavor is science or not. Thus the core philosophies that are required to discuss practices in palaeosciences have been provided and now let us turn to practices in palaeoscientific research.

Philosophical analyses of practices in palaeosciences

Although no philosophical analysis with the name of palaeosciences has been published, related analyses with the name of historical sciences (geology, palaeontology and archaeology) have been published (Albritton, 1975, Baker, 1996, Kitts, 1977, Inkpen, 2008, Inkpen, 2009, Jeffares, 2009, Baker, 2014b). Regarding geology or earth sciences, hermeneutics (Frodeman, 1995) and geosemiosis (Baker, 1999) have been found to be appropriate reasoning styles or descriptions of scientific practice in those disciplines. Simpson (1963) pointed out the diverse nature of geology as it deals not only with the ever-changing processes (contingent or configurational properties) but also immanent properties. Although a palaeoscientist may be equated with a detective, Turner (2009) argues that she is more than a detective because she follows empirical testing (non-experimental) such as 1) crunching the fossils (testing hypotheses about large-scale evolutionary processes using a huge dataset of fossil records) and 2) virtual experiments using computer models. Although a forensic scientist can use the above-mentioned method of non-experimental empirical testing, utilizing a pool of evidence and computer simulation, in my point of view, a palaeoscientist takes a different position. Because she will never be in a position to commit type II errors (false negatives, benefit of doubt goes to the victim) as she can withhold judgment on palaeoscientific hypotheses, whereas a forensic scientist has to make a time-bound decision. There are discussions about whether palaeontology is idiographic science that aims to reconstruct sequences of particular historical events or nomothetic science that aims to discover laws and regularities. Nomothetic sciences are the ones try to generalize into a law (like physics). Idiographic sciences are the ones that are dealing with contingent and unique phenomena and hence can only specify or individuate but cannot generalize (like history). Stephen Gould (1980) in a revolutionary attitude tried to establish palaeontology as a nomothetic science while keeping the idiographic aspects as well, whereas Simpson (1963) firmly claimed that it is not nomothetic but idiographic. Although Gould defended palaeontology as nomothetic, at later times, he has come back to the Simpsonian view in his book *Wonderful Life* (1980) via a middle view (1980, p. 113). Cleland (2001, 2002, 2011, 2013) has been consistent in her view that palaeosciences have a distinct way of doing science and it is an idiographic science; it is what she called prototypical historical science, and its epistemic status is on an equal footing with classical experimental science. On the contrary, McShea and Brandon (2010) defend the view of palaeontology as nomothetic science by pointing out that there are general laws for biology such as ZFEL (zeroth-force evolutionary law) which explains the increase complexity and diversity through time. Turner (2014) is of the view that palaeosciences have both idiographic and nomothetic features in tandem by referring to the Lilliput effect that is neither a law nor a contingent event. Similarly, historical explanation is different from natural scientific explanation. Mostly, natural scientific explanations are deductive-nomological (D-N explanations, Hempel, 1942) whereas historical explanations are abductive (inferring the cause from the effects and the law). The historical explanation, also called genetic explanation, describes the chains of events in which earlier causes that are causally necessary but not sufficient for the downstream effects (Gallie, 1959). In the sub-sections that follow, we will see the philosophical issues related to the epistemic status of knowledge of the past (in the reconstruction of past events or past processes) and geochronology.

Epistemic under- and over-determination

Let us imagine a person who returns to her home and finds her glass window broken. She is rich enough to have a servant maid to keep her home clean regularly. If she comes home after a day before the servant cleans, she would have figured out the cause for the broken window from the broken window, broken glass pieces inside and outside the house, and space where the local guys play cricket just opposite to her house. Here she is in a better position in terms of the epistemic situation and epistemic resources (Currie, 2018). But if she returns after a month and by the time the servant maid fix a new glass window similar to the earlier one, she would not be able to figure out the cause easily as the glass pieces would have been cleaned up. It would bring her epistemic difficulties, and she is in an epistemically unlucky situation.

Turner (2007) discussed in detail about epistemic under-determination where a person cannot choose the correct causal hypothesis for any event that happened in the past. It is different than the global under-determination problem, the Quine-Duhem thesis, which states that given two empirically equivalence hypotheses, one will never be able to choose the better one as no hypothesis can be tested in isolation except with numerous auxiliary hypotheses (Methodological Pluralism section). It is under-determination of theory by evidence, and this is a logical constraint that happens only in natural sciences like physics as per the argument of Stanford (2000). What Turner discussed is epistemic local under-determination that make historical sciences suffer. What he suggests is due to the information-destroying processes of nature (Sober, 1988, p.4), where the evidence is progressively destroyed, degraded, decayed and dispersed which imposes epistemic constraints (Fig. 3). In the example above, if the servant cleaned away the broken pieces, which is likely to happen, then the house owner will not know what caused the window breakage. Thus he described a palaeoscientist is in an epistemic predicament, and she will remain pessimistic.

Fig. 3

Fig. 3

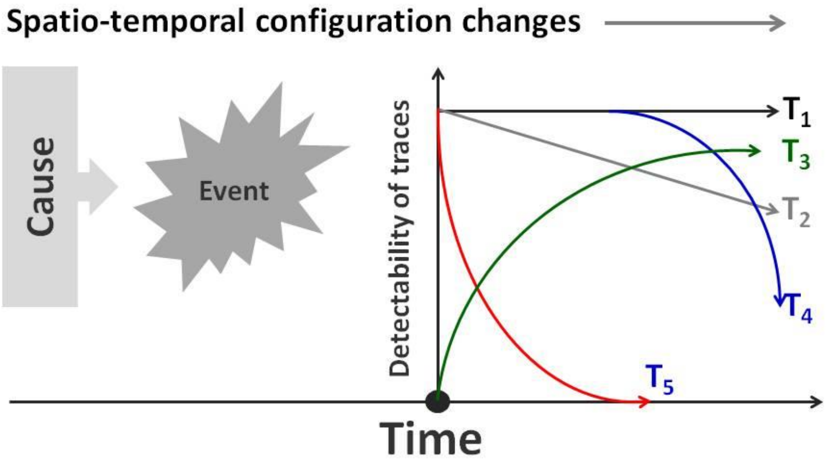

Fig 3: Schematic diagram explaining the cause, event (effect) and trace evidences that are ever available (T_1), decayed (T_5), decaying (T_2), decaying beyond recognition (T_4), and transformed to something else ($T_5 \rightarrow T_3$) with time.

In contrast to Turner, Cleland (2001, 2002, 2011, and 2013) rests her argument on over-determination of the cause by the evidence. She may argue using the above example, a particular cause produced many observed traces (broken window, broken glass pieces, and a nearby cricket ground) and they can be considered as evidence for that cause. All these traces were produced by that particular cause, and hence a common cause has produced all these traces. Now, even if the servant has cleaned the broken pieces from inside the house and replaced the broken glass window with a new one, the presence of broken glass pieces under the sofa or bed or somewhere in the house can still be evidence for the broken window. But it would not help her to pin point the specific cause and how that window was broken. Further, a detailed discussion with the servant can also give plenty of clues for the broken window. The discussion with the servant may help her to search for the 'smoking gun' that will help her unambiguously to pin point the cause. The smoking gun here is the cricket ball that was found inside the house by the servant who remembered the event where the boys were asking for the ball back for their game. Cleland says a palaeoscientist can be an epistemic optimist as the evidence/traces outnumber the downstream causes. Psillos (2009) also defends a view that a scientific realist can be an epistemic optimist without imposing any epistemic dichotomies and based on no-miracle argument (if the successful scientific, however approximate, theories failed to describe the world, then it is a miracle). But this is a general scientific realist position and not historical realist position as discussed in Turner (2007). In fact, Cleland develops her view from that of Lewis (1979) that identifies physically pervasive, time asymmetry between the past and future with respect to the present (asymmetry of over-determination). As per that thesis, ontologically later affairs (the present) will over-determine the earlier affairs (the past) whereas earlier affairs (the present) will under-determine later affairs (the future). Cleland exploits that thesis to take an optimistic view, and Turner criticizes it saying that ontological over-determination will not stand in the presence of epistemological local under-determination due to the information-destroying processes. Currie (2014), who also appeals for optimism about palaeosciences, says that this smoking gun concept will not work in very unlucky circumstances such as the house owner staying in a distant country for a long time and she, being there, asked the servant to rent out the house.

Tucker (2011) compiles both the arguments (Turner's and Cleland's) in an another asymmetry of new background theories and local under-determination which states future scientists will have better midrange theories (as science progresses) and more traces (due to the ripple model; Currie, 2018) to choose the best hypothesis, whereas the fossil data itself will be degrading with time. So the success of a palaeoscientist depends on the rate at which the midrange theories are invented or refined compared to the degrading rate of fossils. The background theories pertained to the past, although it says how the fossils or traces are degrading with time (dampening role), and can also suggest how the degrading past can be detected not only by using highly precise instruments (to detect T_5) but also the transformation processes that relate T_5 to T_3 or the rest (T_2 and T_4) as shown in Fig. 3 and play an enlarging role. Further, Tucker says that common cause compared to separate causes would be over-determined from the evidence whereas the degrading fossils will be under-determining the causes. Thus, there is both epistemic under-determination and over-determination occurring in palaeosciences (Turner, 2016) and the truth lies in between (Tucker, 2011).

No human agency was there in deep time to do the information-destroying/dispersion process intentionally as is done in forensic science. So natural processes, such as extreme events (volcanism, earthquake, tsunami, flood, and storms), weathering, and erosion are the agents of the information-destroying/dispersion process, and they are the object of palaeoscientific research.

Further, this epistemic under- or over-determination is empirical research (background theories and instrument technology) rather than armchair philosophical reflections. Currie (2014) has synthesized both the above epistemic accounts of Derek Turner and Carol Cleland into a ripple model of evidence (Currie, 2018; Chapter 5). As per this model, any event triggered by a particular cause will have numerous traces, and these traces will undergo decay, degradation, deformation and will be transformed with time which results in heterogeneous traces (Fig. 3). Assuming an event happened at t_0, the number of traces showing an increase with time, t_1, t_2, t_3 ($t_1 < t_2 < t_3$), like ripples in water, grows radially outward (over-determination) but the quality of the traces will be fainter and may have gaps (under-determination). In spite of the epistemological optimistic position of a palaeoscientist, local under-determination is ubiquitous in palaeosciences, and any method we develop for this should consider this issue seriously. This local under-determination is the most limiting factor that informs how much one can learn about the past and the uncertainty associated with any historical reconstruction. However, this is not an ontological limitation but an epistemological one. Because of the inter-dependency of nature (Currie, 2016) and the progressive unveiling of these inter-dependent relationships (mostly by natural sciences), we will be able to go higher and higher in the scaffolding (Wylie, 2017, Currie, 2016) that will enable faithful and precise historical reconstruction. Scaffolding (in archaeological point of view), a term borrowed from Wimsatt (2014), is made using material resources, skilled practice, institutional and social infrastructure, kinds of background knowledge, analytical techniques and there is an element of shared cognitive-emotional-interactional platforms and repertoires (Wylie, 2017a).

Past events

Many processes with different periodicities or particular processes with different antecedent conditions result in different events in the historical past. If such events of the past caused lethal effects to Earth systems, they would become one of the important objects of palaeoscientific research. Time-averaged processes can also be called events; e.g. palaeoclimate during the Quaternary Period. In this section, we will discuss the reconstruction of the events of the past. Palaeoscientists go to the field and laboratory and identify traces of evidence, activities that are theory-laden. They collect various traces (let us say, $\boldsymbol{n}$) and in principle, can formulate $\boldsymbol{n}$ number of hypotheses. All the traces need to be processed physically and chemically to be observed through various microscopes can look for traces (biotic and abiotic) with various types of equipment. Physical, chemical and biological, and sometimes ecological, understanding about the proxies can help to equip a palaeoscientist to be prepared with background knowledge, auxiliary hypotheses, interpretative principles and bridge principles which relate the trace and the past entity (cause, event, process, and antecedent conditions). Wylie (1999) mentioned how archaeologists exploit the scientific pluralism or disunity of science using both vertical and horizontal independencies, by which she means nothing but the independence between background theories & the hypothesis being tested and independence among multiple pieces of evidence, respectively (Kosso, 2011).

There are a couple of evaluation criteria used to test palaeo-scientific hypotheses, namely 1) a common cause explanation and the search for smoking guns, and 2) searching for multiple independent lines of evidence (each line of evidence that is resting on independent, non overlapping auxiliary hypotheses) and weaving them together to arrive at a conclusion, i.e., consilience. Essentially, both are saying that traces (evidence) are collected from the field, and multiple hypotheses are constructed with a common cause for a token-event (type-events are those that can be generalizable). It should be mentioned that multiple working hypotheses concept generally should avoid non-empirical hypothesis such as “God created this world just five minutes ago” (Russel, 1921). Such radical skepticism has little to do with scientific practice (Turner, 2017). More traces are collected, if possible, as per the hypotheses' guidance. If one or two traces which are not possible with other hypotheses except but one, then those traces are the telling traces or smoking guns for that particular hypothesis (Cleland, 2001, 2011) and that hypothesis is chosen as per the 'inference to the best explanation', IBE (Harman, 1965; de Regt, Buskes and Kleinhans, 2015). IBE is a kind of abductive inference and called method of hypothesis as well (Psillos, 2009, Blachowich, 1996). If multiple independent pieces of evidence (from independent, non-overlapping auxiliary hypotheses) suggest one particular hypothesis over the others, then that hypothesis stands as per the consilience criterion (Forber and Griffith, 2011). In the lines of consilience, Currie (2012) discusses further where analogies (as evolutionary biological evidence) should be incorporated as one of the multiple evidence streams to test a hypothesis and its parts, as a whole. Consilience, compared to the smoking gun criteria, can get rid of the 'testing holism' problem where every auxiliary hypothesis to be tested. Consilience avoids this problem because the independent evidence will have auxiliary hypotheses and only those hypotheses are to be tested, not all. Such chosen/inferred hypothesis explains most of the traces/evidence observed in the field and is shown in Fig. 4.This fits well with a realistic metaphysical view where scientific realism, epistemic optimism, and inference to the best explanation are inter-related (Psillos, 2009).

Fig. 4

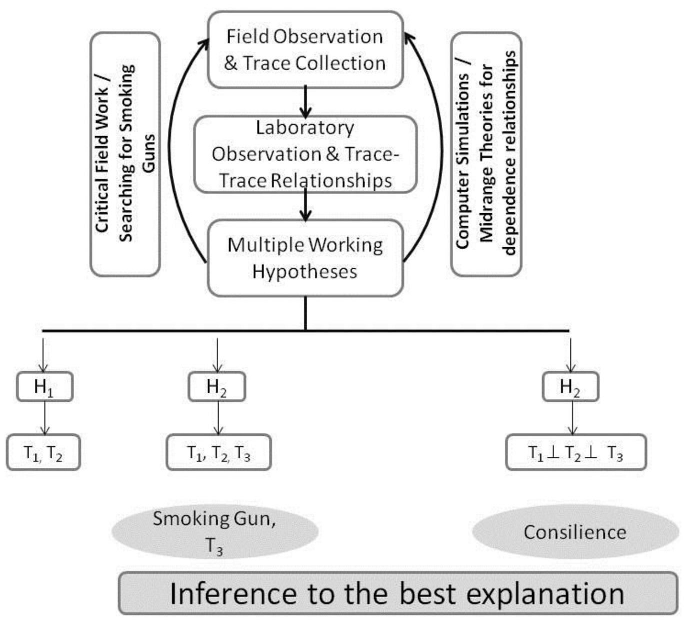

Fig 4: Flow chart explaining how smoking gun with a common cause explanation and consilience in

choosing a palaeoscientific hypothesis over others. Two hypotheses (H_1 and H_2) are constructed to explain a hypothetical past event/process using the traces observed in the field (T_1, T_2 and T_3). H_1 can't explain the observed evidence, T_3 and hence T_3 is the smoking gun evidence for H_2. If all the traces have independent auxiliary hypotheses, the consilience method can be adopted that favor H_2. Inference to the best explanation is the inference method used in palaeoscientic research.

A philosophically widely discussed event occurred at the K-T boundary (Cretaceous-Tertiary boundary; End-Cretaceous mass extinction) and the associated dinosaur extinction that happened around 66 Ma ago. At the boundary, there is an anomalous enrichment of iridium (Ir) along with various metals such as Os, Au, Pt, Re, Ru, Pd, Ni and Co, spherules (65 Ma old unusual rounded glassy rocks), shocked quartz (that can only be formed at pressures greater than 8.5 GPa) and a big 65 Ma old crater (Chicxulub Crater) were observed. From these observations, multiple working hypotheses were constructed. They are impact hypothesis, massive volcanism, rapid climate change and the natural decline of dinosaurs. The first two have more support from the empirical data set. Cleland (2001, 2013) argues that although the presence of Ir can be attributed to Earth's magma, shocked quartz and the crater act as smoking guns that vindicate the extra-terrestrial impact hypothesis. Forber and Griffith (2011) advocated for the consilience approach that says that if many independent pieces of evidence with non-overlapping auxiliary hypotheses are jointly pointing to a particular cause then that hypothesis may be vindicated. It is also a similar approach to common cause explanation by Cleland (2013), and common cause explanation is the one suggested by Ockham' razor, i.e. simplicity.

Unlike experimental science, Bromham (2016) mentions, there is no 'killer test' in palaeosciences to choose the definitive hypothesis that accounts for the palaeo-cause. For example, there are counter observations that are not explained by the impact hypothesis. But there is no definite number of observations that are needed for a hypothesis to be accepted or counter observations to reject a hypothesis in palaeosciences. Because of the local under-determination problem, lack of background theories and uncertainties (type I and type II errors), no one-size-fit-for-all approach can do justice to the palaeosciences (Cleland, 2013). Palaeoscientific hypotheses can be evaluated after many research years because the progress is slow. The range of investigations produces much evidence, and this evidence has to be weighed against the proposed hypotheses. Thus filtered hypotheses may suggest some more evidence and that needs to be sought. So palaeoscientific research revolves around the method of hypothesis testing and, as Bromham (2016) observes "This process of circling around a hypothesis by gathering evidence for and against a particular explanation using a collection of independent tests is not so different from classical experimental science." Pointing out the inadequacy of a single approach to science, *that is more than true for palaeosciences*, Kosso (2011) draws attention to the network of knowledge where coherence and expertise play additional deciding roles. As seen earlier, coherence has to be handled carefully as it can reject revolutionary scientific explanations. Although experts have better knowledge, they may also be biased (objectivity minimized and skewed) and hence a citizen science approach may reduce this problem as seen in Epistemological Pluralism section, although citizens will have their own biases.

Palaeoscientific hypothesis testing will be robust if the evidence is accessible (detectable, measurable, derivable, producible, or the like) in a variety of independent ways (Hacking, 1983). Independent lines of evidence are strictly not possible if the reality is ontologically inter-dependent because the evidenceis inter-related, if not directly. So, the strategy is to assume epistemological independence in spite of ontological inter-dependency. This is a plausible assumption because we, as finite beings, are dealing with highly interacting complex systems of the past (Wimsatt, 2007). However, with the advancement of science, more and more dependency relationships will be unveiled with time with subsequent development of background theories. And, this can be exploited in understanding the past (Currie, 2016). This is what keeps a palaeoscientist on a higher conceptual and technical scaffold from where shadowy data can be brought to light with a post 'pre-understanding' (Wylie, 2017). By subjecting thus illuminated old data to secondary retrieval, recontextualization and experimental simulation, one can get to know the past better and better even in the face of local under-determination (Wylie, 2017).

Past processes

If reconstructing a particular event of the past is one aspect of palaeo-scientific research activities, reconstructing the process (token-process), such as climate, tectonics and ecology of the past, is another aspect. There are very few publications that deal with the philosophical aspects of reconstructing past processes compared to that of past events. Although a couple of articles with titles such as philosophy of climate change, they are not focused on the reconstruction of past climate but are concerned with modeling of climate (Frigg et al., 2015a,b, Peterson, 2000) and on attributing the cause of climate change to particular agents (Petersen, 2000, Bradley, 2015). So, reconstruction of the ecology of the past can be taken for the discussion here, and some relevant discussions, although not directly on that point, have already been published (Scott, 1963).

Palaeoecological reconstruction is done using the available floral and faunal remains that are found in the sedimentary context. First, the biotic fossil is identified to the lowest level of taxa possible using various analytical microscopic tools, after cleaning them properly. Then, the modern analogue of that fossilized taxon is looked for (sometimes in a modern sedimentary context) and their responses (either individually or population-wise or both) to various environmental factors such as temperature, precipitation, salinity, sunlight, number of dry months, and duration of rainfall are studied. Once the relationship between environmental factors and the abundance of the modern taxon or morphological differences of the taxon are established, past environmental factors can be inferred using the fossil taxon. Here uniformitarian simplicity is the underlying synthetic, *a priori* assumption based on which the ecology of the past is reconstructed. Apart from the uniformity of processes and simplicity, there is another principle, i.e., analogues. A modern analogue shouldn't have undergone any evolutionary change (genotypic) since the fossil taxon was alive; so that any change in the analogue can be attributed to the environment (phenotype) alone.

The uniformity of process cannot be assumed blindly as well. Let us see the development in four different stages, and they are in sequence, and technically they are ontogenesis. First, geological (terrestrial inorganic) processes, biological processes, psychological processes and sociological processes are the second, third and fourth respectively. Even if the processes are considered to be constant (invariant with time), these processes are acting in a particular environment, and that environment is changing all the time. This may be true for terrestrial inorganic processes and for palaeoclimate reconstruction (where there is no life) but not true for biological, psychological and sociological reconstructions where the processes involve life, O_2 (present only for the last 2 billion years) and consciousness (individually and socially) that started to exist at later stages of the planet's development. Even if it is assumed that during the reconstruction time there was no evolutionary change in the species, the species adapt to the constantly changing environment, and hence the process cannot be assumed to be uniform. Similarly, it can be reasoned that psychological and sociological processes cannot be assumed to be uniform to reconstruct anthroecology (Ellis, 2015). In this light, the key (the present is the key to the past) may unlock so many doors, and it will not be known for sure which door was the correct one (an idea attributed to Sir Charles Cotton; Scott, 1963). If the local underdetermination problem is brought in, then the lock is rusty and the key will be useless (Scott, 1963). So the claim that 'without uniformity, there be no science' (Gillespie, 1951, p. 121) is not valid. However, until a better key is found to unlock the past, it is wise to use the available key to enter into many rooms and then apply coherence to choose the best one.

One example of the reconstruction of a palaeoscientific process may help here. Zong et al. (2006) reconstructed palaeo-monsoon (East Asian Monsoon, EAM) in the region of southern China for the last 8500 years. The authors decided to understand the dynamics of the EAM during the Holocene (the last 11.2 ka). As Medawar (1963) pointed out that there is very few scientific papers that describe the real trajectory of scientific research, I try to present in a way that touches upon the issues I have described here. This large-scale process (EAM) would have left its signatures in the form of various smaller-scale processes; in their case it was the variation in the relative contribution of fresh water to the Pearl River Estuary. This variation in the relative contribution of fresh water in an estuary happens because of relative sea level changes as well. So, two hypotheses were at hand to be tested. These hypotheses, from the available background theories and dependency relationships, suggest what proxies need to be looked for in the field. They retrieved a sediment core of 1340 cm from the estuary and studied the fossil diatom assemblages, $\delta^{13}C$ from the bulk organic matter, and the C/N ratio as proxies at 6 cm intervals. They have observed that the fossil marine diatom species showed a decrease and freshwater species showed an increase from 7500 to 6000 years ago. During the same period, $\delta^{13}C$ was decreasing, and the C/N ratio was increasing.

Contemporary observations were made in and around the estuary to study the dependency relationships between water quality and the proxies ($\delta^{13}C$, fossil diatom assemblages and C/N ratio). This study of the 'present process' is the key to unlock the past that was obtained from the sediment core. From the modern/contemporary analogue data set, the proxy results from the sediment core (decreasing and increasing trend of marine and freshwater diatom species respectively, and decreasing and increasing of $\delta^{13}C$ and C/N ratio respectively) can be interpreted to suggest that when the terrestrial organic matter was higher the freshwater input was relatively higher. Although $\delta^{13}C$ and C/N are dependent, these two are independent of the fossil diatom assemblage, and hence the inference was strong. Using the fact that global sea level was rising during that time, a relative sea level decrease as an alternative hypothesis was ruled out, and the null hypothesis i.e., the intensification of the EAM was accepted as the inference to the best explanation (Fig. 4).

On geochronology

There is only one research article (Oehrstroem, 1987) that deals with the philosophical analysis of geochronology, to the author's knowledge, and that calls for more analysis in the future. Geochronology is the heart of terrestrial palaeosciences. Geochronology is more than geochronometry which is a measurement tool or simply getting a number for the age. To interpret this number, one need geology, geophysics, geochemistry, petrology, chronostratigraphy, tectonics, and climate so that the rate of processes, time-scales of the processes, and physical mechanisms can be understood. Geochronology can be defined as the science of dating to determine the time sequence of events in the history of Earth (Harrison et al., 2015). According to Oehrstroem (1987), geochronology mostly rests on three assumptions. They are: 1. There is an absolute time scale from any radiometric or trapped charge dating technique; 2. a relative time-scale can be derived from stratigraphy and palaeontology; and 3. uniformity of process (order changed from 3, 2 and 1; Oehrstroem, 1987).The first assumption is chronometry, i.e., quantification of an entity that is changing (decreasing or increasing) with time, ***a(t)***, and this involves both physical processes on which a particular technique is built and the measurement procedures. The other two are needed to interpret this chronometric entity, ***a,*** within the palaeoscientific context. The second assumption makes geochronology dependant on inter-disciplinary research activities. The third one is an important key, probably the only available key, to unlock the past.

If two samples from the same strata (same age) yield discordant ages beyond instrumental error, how can this discrepancy be explained? The above three assumptions are necessarily required but they are not sufficient. One more dogmatic condition is needed, and that is 'ages of an undisturbed rock obtained by different dating techniques must agree' (Oehrstroem, 1987). This condition can be the fourth assumption. This fourth assumption can be stated in a sedimentary context as in the Quaternary Period, that 'ages of non-reworked sediments by different dating techniques must agree.' In the Krishna-Godavari inter-deltaic region, radiocarbon ages and luminescence ages of a palaeo-beach ridge haven't been consistent within the instrumental error. Later on, those luminescence ages were inferred to be of re-worked grains. The discrepancy can now be explained as the deviation from the fourth assumption, i.e. the rock was a disturbed one at some point in time in history. It is also like an auxiliary hypothesis that can be modified to explain the observation i.e. one particular technique produce lower age than the rest. Although many sub-samples of the same un-disturbed rock may yield the same age within instrumental uncertainty and this fact may support the validity of the above four assumptions, but they can never be tested together. As they cannot be tested and hence cannotbe falsified, Oehrstroem (1987) called geochronology, like evolutionary biology, a metaphysical research programme, following Popper's terminology (Popper, 2005, Ruse, 1977). Oehrstroem (1987) calls geochronology as 'normal' science in Kuhn's words because there is a paradigm (the 4 assumptions) within which geochronologic research is carried out (Kuhn, 1970).

Possible avenues for epistemic assistance

Smoking gun and consilience methods can be done only when the evidential situation is better or lucky, and both are trace-centric. There are some unlucky circumstances when there is no trace (to know the cause of a particular event of the past), or if we want to have more details of the past (such as whether dinosaurs are endothermic or not).Then these above two methods would not work, and that will lead to a pessimistic attitude towards reconstructing the deep past or detailed reconstruction of even the near past. In the sub-sections below, we will see the avenues that can be exploited to get epistemic assistance to do palaeosciences.

Omnivorous investigation

One example, in which a detailed reconstruction of a Pleistocene organism was carried out, will help to explain better and that is taken from Currie (2015). Thylacaleo carnifex (*T. carnifex*, marsupial lion) is an extinct animal species that lived 150 - 45 ka ago in Australia. Many fossils were found,and the structure of *T. carnifex* has been recently reconstructed. Palaeobiologists wanted more detailed information about this species regarding its food habit and its ecology as a part of evolutionary biological investigations. From the size and structure of limbs, biting capacity, the skull structure, phylogenetic models and biomechanical properties, they could conclude that they were cursors; killing large herbivores using their crushing bite. This was done by, as Currie (2015) called, omnivorous investigation. Omnivorous investigation utilizes multiple and disparate methods to generate streams of evidence and this may be attempted when there is very little information available as traces. So in unlucky circumstances where we do not have the luxury to get more traces (smoking guns) and independent lines of evidence (consilience), we opportunistically use whatever we have in our hand. In those circumstances, being opportunistic and omnivorous is acceptable. The words 'opportunistic' and 'omnivorous' may make us uncomfortable as these support multiple results; i.e. multiple reconstructions of a particular organism of the past. But that is one of the few options we have. Methodological omnivorous (Currie, 2015a) and integrative pluralism (Mitchel, 2000), that is integrating non-equivalent models to explain a local phenomenon of the past, can work in tandem. Both are exploiting the disunity of science thesis, that we have discussed earlier, as a strategy one can adopt. Further, this investigation involves climbing the scaffold where a breakthrough in one of the omnivorous investigations will bring the investigators higher up the scaffold. From there, an overlooked trace at an earlier time, all of a sudden, may become a valuable trace, probably can even become a smoking gun, and the investigation proceeds towards a faithful reconstruction of the detailed past.

Modeling

In the palaeobiological reconstruction of the marsupial lion (*T. carnifex*), modeling played a key role in producing the evidence streams that led to better background theories (Currie, 2018). Similarly, simulation can help to explore for a rare trace in the field as well. Not only the modeling helps the trace-centric palaeoscience (event reconstruction), but also it helps to reconstruct the processes of the past. The main problem for the philosophy of science that focuses on complex systems is in dealing with condition- and configuration-dependent entities that include materials, laws, events, and processes (Hooker, 2011). The presence of feedback loops, global spatio-temporal constraints, and emergent properties make any system more complex. The emergent entities would not exist in different conditions and configurations (Hooker, 2011). When some processes happen at well-defined but different frequencies, at a particular time the subsequent effects look so haphazard and chaotic due to the co-occurrence of all these processes together. In the epistemology of complex systems, the role of intermediary models is important.

When we need to deal with complex systems of the past that are not amenable to controlled experimental observation, computer modeling helps as a bridge between theory and experiment (Winsberg, 2000). There are two types of modeling. One is to explain some real phenomena by constructing simple mathematical expressions with few parameters. If this does not explain the phenomena, gradually the mathematical expressions may become more complicated. This type of modelling is called indirect theoretical investigation, and this is different from theorizing using non-modeling; i.e.. abstract direct representation (Weisberg 2007). He demonstrated indirect theoretical investigation with the work of Volterra (in explaining the population dynamics of small and big fish communities in the Adriaticsea, Italy) and abstract direct representation with the work of Mendeleev (explanation of chemical properties *via* their periodic atomic mass dependence). Mostly, the kind of modeling used in palaeosciences is of abstract direct investigation (Turner, 2013) whereas indirect theoretical investigations can be used for background theories to be refined or invented. Gee (1999) relied on statistical modeling (cladistics) so that the subjective, untestable stories can be avoided in evolutionary biology.

It is understood, from the practices in palaeosciences, that if the trace evidence is better, either the smoking gun with common cause explanation or consilience methods can be employed in reconstructing past events/processes. If the evidential condition is poor, where the traces are meager and a detailed reconstruction is demanded, then one can be methodologically omnivorous, where one is not restricted to use the available trace evidence alone but can also unveil a stream of evidence either by inventing new background/midrange theories or using modeling. As per the robustness realism (Eronen, 2012), these analyses are robust, and the hypotheses about the past represent the truth or near the truth. Justified in believing that property, P is real if and only if property P is robust, that is, it is detectable, measurable or producible in variety of independent ways.

This whole reasoning can be best described by the Lakatosian method of scientific research, and methodological omnivorous is compatible with this research programme. Let us say, we have a palaeoscientific research programme to reconstruct a past event, for example, the K-T boundary. This research programme can have multiple working hypotheses (core), and each core hypothesis will have their own set of auxiliary hypotheses. It is worth mentioning that many literature, including Lakatos (1978), mixes research programmes, theories and hypotheses with each other.

Research programme is one, not for the whole sciences or for palaeosciences, and this is particular to one aspect of nature. That research programme will have its own hard core theory and each hard core theory will have its own auxiliary hypothesis. As there is no theory *per se* in palaeosciences, we use hypothesis and that too we use multiple working hypothesis within a research programme. These core hypotheses are not necessarily independent of each other. If some evidenceis not explainable by a core hypothesis, auxiliary hypotheses for that particular core hypothesis can be adjusted, re-adjusted or even a new auxiliary hypothesis invented, instead of rejecting the core hypothesis; this whole process is called negative heuristics. Positive heuristics is to modify the core hypothesis, but this is not common. With time, some hypotheses progress and some would have already degenerated as discussed in Methodological Pluralism section.

Epistemic bet on dinosaur's color – a case study

A case study should only be used for heuristic and rhetorical purposes. With this cautionary note, let us enter into this important case study. A severe and pervasive epistemic challenge to a palaeoscientist is the local under-determination problem (Turner, 2005). The evidence and traces that are directly related to the past event would have been degraded, decayed or transformed into something else beyond recognition due to the information clearing processes (Sober, 1988, Turner, 2005). David Norman (1988, p. 8) mentioned that it is difficult – in fact almost impossible – to know the color of the dinosaurs. He mentioned that it is 'almost impossible' because the color of dinosaurs could only be guessed based on analogies with living organisms. Turner (2005), by referring to the background theories on taphonomy, said that it is impossible to have traces that can help to choose the correct hypothesis about dinosaur color. The reason is, as per Turner's view, the information related to color would have been already destroyed during the fossilization process. So he thought that scientists would not linger on this problem by fruitlessly looking for smoking guns. Based on this problem, Turner made a bet that the color of the dinosaur will never be known, but this betting was criticized (Jeffares, 2010). That is because the color pigment would be vulnerable to decay, and by now the melanin pigments would have already been decayed. Turner further said that scientists might make impressionist statements about the color of dinosaurs based on non-empirical theoretical criteria like 'simplicity' and 'explanatory power' but not by using empirical data. Thus the bet was made based on the understanding at that time.

Vinther *et al*. (2008) re-investigated a few fossil feathers (with dark and light bands) using environmental scanning electron microscopy (ESEM), energy dispersive analysis (EDS) and transmission electron microscopy (TEM) to infer the characteristics of melanosomes (tiny pigment-containing organelles) in the fossil feathers. Earlier investigation (from the Eocene of Grube Messel, Germany) using SEM concluded that the small oblate bodies (~ 2 μm in length) that are found in the fossil feathers are fossilized feather-degrading bacteria (Wuttke, 1983). Comparing the fossil feathers with modern feathers, the oblate bodies found in the dark bands are strikingly similar in size, shape, and orientation to eumelanosomes from modern bird feathers (Red-winged Blackbird). Those microbodies were not observed in light bands. If those were the fossilized feather-destroying bacteria, then they should have been found in the light bands as well. So they concluded that the bodies were not fossilized bacteria but fossilized eumelanosomes. Vinther *et al*. (2008) was hopeful that the color of dinosaurs and birds might be determined, as melanosomes are known to be preserved in the feathers. The background theory has been developed, and that can give the truth-value link or dependency relationship between the color of the dinosaur and the fossilized melanosomes structure. This progress happened without knowing that a bet existed (Derek Briggs, personal communication) and the research was not directed at finding the color of dinosaurs specifically, but to study the preservability of melanin in fossils (Vinther, 2017).

Zhang et al. (2010) and Pan et al. (2016) followed and succeeded in inferring the color of a small therapod dinosaur (*Sinosauropteryx*) and an Early Cretaceous bird (*Eoconfuciusornis*) in the Jehol biota site in northeastern China. This finding caused Turner to perform a philosophical error analysis of his pessimistic attitude about the past and declared that he has already lost the bet (Turner, 2016). He mentioned in that paper that pre-2008 background theories (on taphonomy) would have made impossible identification of the color of dinosaurs, but after Vinther et al., (2008) the background theories had been improved or revised so making knowledge of the color of dinosaurs possible. So betting against palaeoscientific knowledge would go awry if any new evidence surfaces from a new background theory. This is a new background theory because the trace (microbodies) was but wrongly interpreted and this new background theory was needed to identify the correct relationship between the trace and the palaeoscientific process. A development in a background theory of any science (and technology) can improve the epistemic possibilities in palaeosciences (Jefferes, 2010).This can be better described by scaffolding. The structure of melanosomes, which were overlooked due to the unavailability of a midrange theory, has become the evidence to infer the details about the past.

Would this particular dramatic case study remove the local under-determination problem and one should abstain from making such bets in the future, as a consequence? Turner (2016) responds that the local under-determination problem continues to be manifest in finer-details (e.g. the color of dinosaur's eye, as the iris is more vulnerable to decay) and not to bet at all (whether they are short-term safe bets or long-term, riskier bets) is too conservative position and is extra cautious. However, here marked that how much one can know about the past is an empirical question that cannot be settled by armchair philosophical arguments. Stanford (2010) also argues that laboratory experiments or/and modeling give enough inductive evidence to choose a better hypothesis about the past and thus give a way of answering the skeptic worry about the unconceived alternative hypotheses.

Concluding remarks

Palaeosciences is defined to be slightly different from historical sciences. It deals with the temporally disconnected physical, chemical, biological, psychological, sociological past affairs of Earth history. Scientific realism, historical realism, in particular, is found to be an appropriate metaphysical view for palaeosciences. However, it is also found that historical realism needs more philosophical attention as experimental realism has foreshadowed the scientific realism discussions (Turner, 2007, Murphey, 2009). Uniformity of process and simplicity (Ockham's razor) are found to be individually necessary metaphysical guiding principles for palaeosciences but not sufficient. Given that the palaeosciences deal with highly complex systems of the past, hypotheses can provisionally include complexity and catastrophism only when uniformitarian simplicity fails to explain the observed evidence.

Practices in palaeosciences suggest that there is no single methodology to do palaeosciences. Common cause explanation with smoking gun evidence and consilience are widely used methods in palaeosciences. But these two methods have limited scope and are trace-centric. They are limited in the sense that they work in lucky situations where multiple traces are available, and finer detail of the past is not required. On the contrary, wherein there is a paucity of trace evidence, and finer details are required, a palaeoscientist can also be a methodological omnivore who can employ any method that suits her epistemic situation. This is certainly not against (any) method, hence not anything goes attitude, but only a viable provision in that situation. Instead of anything goes, it can be many things go which is similar to the concept of multiple working hypotheses proposed by Chamberlin (1965).The method of hypothesis testing or inference to the best explanation is the inference method followed in palaeosciences. Degradation or transformation of evidence beyond recognition places a limit on the knowable horizon of the historical past, but that limit will be moved by progress in other members of the science family.

Methodological omnivory in general, and smoking gun with common cause and consilience in particular, are shown to be compatible with the Lakatosian methodology of the scientific research programme. Scientificity, the first objective of this review, of palaeosciences would not arise in Wittgenstein’s family resemblance approach (FRA) as this fits into the family of sciences, where every science has a place and no special place (hard or soft science) for any particular science. Popper’s falsifiability could be a too stringent criterion and Feyerabend’s anything goes could be too liberal, whereas Lakatos’ methodology of scientific research (the sophisticated falsifiability criteria) can describe practices in palaeosciences better. Epistemological pluralism has been helpful to palaeosciences, as seen in the case of dinosaurs’ color using melanosomes. Because advances in any science and technology will bring a palaeoscientist to the next level in the scaffolding and she will be able to explain the past events/processes from being there. Pluralism has been systematically exploited in the practices of palaeosciences, and the basis for that is disunity of science as a working hypothesis. Although the reality can be reduced to a most basic constituent based on the currently accepted Big Bang origin of the universe, it is shown that:1) reductive unity is practically useless to study the higher level sciences; and 2) the reality is perceived or understood by us (with plenty of empirical support), not in a unified way but as patches for us asfinite beings, as of now. So the disunity of sciences can be assumed as a strategy. In spite of the ontological unity of sciences (consequently scientific realism) and ontological inter-dependency of nature, ontological disunity of sciences and independent evidence can be considered as strategies.

Regarding the misuse of palaeosciences to mislead history, the second objective, the Lakatosian methodology guides the palaeosciences in a gentle manner and makes any palaeoscientific hypothesis either progressive or degenerative, a decision about which should be left to the informed society to make. Furthermisuse of palaeosciences can be avoided if the objectivity is maximized by the involvement of civil society (citizens) in palaeoscientific research activities without giving all the responsibility to palaeoscientific experts alone (Feyerabend, 1978, p. 86-87). The Lakatosian methodology allows palaeoscientists to start their research programme with weird ideas (for example, humans are not responsible for the observed climate change, or the holocaust did not happen) as one of the alternative hard core hypothesis and whether that is progressive or degenerative will be known with time from the available evidence and reasoning (please see Nayanjot Lahiri, an Indian historian, interview to The Caravan in http://www.caravanmagazine.in/vantage/historian-nayanjot-lahiri-asi-preserving-indian-heritage).

From the case study on the color of the dinosaur, it is clear that one cannot tame the giant of science using the philosophy of science where philosophy informs science (science-directed; Currie, 2015b). With time, palaeoscientists will be at higher levels of scaffolds and make use of breakthroughs and developments in other sciences, and hence they are in a position to break any norms that have already been set for their practice. The history of science also shows that science has always been taking bold steps and proceeded without much help from philosophy. Apparently, it is the philosophy of science that has been modified to align with the practice of science (science informs philosophy or philosophy-directed; Currie, 2015b) and in some places science has completely overthrown the scientific methodology that the philosophers of science proposed (Kuhn, 1970, Feyerabend, 1993, Hartmann and Sprenger, 2012). Overall progress in palaeosciences is in line with naturalism (Godfrey-Smith, 2003; p. 149-150) where philosophy is continuous with science where science teaches philosophy and philosophy use science's results to help answer philosophical questions. As a final remark, the philosophy of science and science are related to each other as that of grammar, and the language itself and the grammar should assist the language to be enriched rather than strangling it.

Acknowledgment

The Director, BSIP is thanked for the permission to publish this article. Dr. Adrian Currie and Prof. Derek Turner are duly acknowledged for valuable inputs and corrections. Prof. S. K. Tandon, IISER, Bhopal, Prof. A. K. Singhvi, PRL and Prof. S. Bajpai, BSIP are thanked for their encouragement in this pursuit. Organizers and participants of GEM-2017 are thanked for their encouragement. Prof. Victor Baker, Prof. Robert Wasson, and Dr. Adrian Currie are acknowledged for their inputs in improving this manuscript, as reviewers. Mr. Phil Clarke and Dr. Vivesh Kapur are acknowledged for their inputs at the later stage of the manuscript.

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