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Method, Explanation, and Epistemic Justification in Historical Natural Science

by

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A thesis submitted to the
Faculty of the Graduate School of the
University of Colorado in partial fulfillment
of the requirement for the degree of
Master's of Art
Department of Philosophy
2010

This thesis entitled:
Method, Explanation, and Epistemic Justification in Historical Natural Science
written by Randy Krogstad
has been approved for the Department of Philosophy

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Date ________________

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Find that both the content and the form meet acceptable presentation standards
Of scholarly work in the above mentioned discipline.

Krogstad, Randy (MA, Philosophy)

Method, Explanation, and Epistemic Justification in Historical Natural Science

Thesis directed by Professor Carol Cleland

Philosophical analysis of scientific practice, methodology and theory has primarily focused on the classical experimental sciences, while little work has been done on other areas of science. Recently, philosophers have begun to address issues pertaining to scientific areas that do not fit the framework of the classical experimental sciences. This paper will address issues in the historical natural sciences and the historical aspects of earth science in particular. The historical claims made within the earth sciences face different methodological challenges, which require different forms of explanation and epistemic justification than those in the classical experimental sciences. A description of the methodology in the historical natural sciences will be addressed in light of a case study in the field of geochemistry. Epistemic asymmetries between the historical natural sciences and classical experimental science will be addressed and it will be shown that the unique claims made in the historical natural sciences require forms of justification that are inherently different than classical experimental science.

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1. Introduction:

Historically, philosophers of science have primarily concerned themselves with the classical experimental sciences, such as physics and chemistry, while neglecting other areas of science such as the earth sciences. There are inherently historical aspects in many of the claims made in these areas of science that do not exist in the experimental sciences. As a result, these historical natural sciences tend to utilize different methods in their investigations. The first section of this paper will focus on the methodology employed by historical natural science and contrast it with the methodology of the experimental sciences. Recent work by Derek Turner and Carol Cleland has shown that certain asymmetries exist between the claims made by historical natural science and those made by experimental science. An analysis of these asymmetries and the conclusions they draw from them will be given in the second section. It will be shown that the difference in methodologies can be explained by the existence of these asymmetries in nature and is necessitated by the types of systems and phenomena that comprise the investigations of these different areas of science.

2. Historical Science:

This section aims to give a general account of the methodologies employed by "historical natural science" and contrast them with the methodologies of "classical experimental science" so that relevant similarities and differences can be addressed. By "classical experimental science" I have in mind the generic view of science, which is held up by the paradigmatic fields of physics and chemistry. In this classic view, scientists form hypotheses, run experiments in a controlled laboratory setting and draw conclusions from results of these experiments.[1] Philosophers of science have predominately focused on classical experimental science and as a result most theories of science set classical experimental science as the standard of successful science. "Historical natural science" is meant to embody the fields of science that take present observable data and try to assert claims about events or environments in the past. Much of the work done in the earth sciences, astronomy and evolutionary biology can be considered historical natural science. Although aspects of certain social sciences, such as archeology, may fit into historical natural science, the focus of this paper will remain on the fields stated earlier.

Within philosophy of science the analysis of historical natural science has primarily focused on aspects of evolutionary biology and has rarely touched on the earth sciences. My analysis will break with this tradition and concentrate on the earth sciences. The term 'earth science' is relatively new; the field of geology once encapsulated all of the sub-fields of earth science but has since received a more narrowed definition. One of the early pioneers of the field, Sir Charles Lyell states:

> "Geology [earth science] is the science that investigates the successive changes that have taken place in the organic and inorganic kingdoms of nature; it enquires into the causes of these changes, and the influence which they have exerted in modifying the surface and external structure of our planet." (Lyell [1887], p. 1, brackets added)

Since Lyell's time, earth science has fractured into many different sub-fields, including but not limited to: geology, geophysics, geochemistry, geobiology, atmospheric science, paleontology, geomorphology, physical geography, etc. As with most major fields of science, earth science is becoming more and more specialized.

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[1] This idealized view of experimental science has been argued against by several philosophers. For examples of more recent detailed work on experimental science and the role of experimentation see Hacking [1983], Franklin [1986, 1990, 2002, 2005] and Galison [1987].

2.1 Case Study - Comet Shower or Lunar Asteroid Impact?

In addressing the methodology of historical natural science, it is always helpful to refer to a particular case study. A good example of the methodology employed in historical natural science, particularly geology, is the on-going debate concerning the cause of increased levels of extraterrestrial Helium-3 (^{3}He) during the late Eocene (35.8 Ma). Low levels of ^{3}He are naturally produced on Earth at a geologically constant rate from interactions with cosmic rays, lithium spallation, and the beta decay of tritium (^{3}H). Extraterrestrial ^{3}He is found in interplanetary dust particles (IDPs), which are created by asteroid or comet fragments that come into contact with Earth. The increase in flux of ^{3}He can be seen in contrast to the constant levels of ^{3}He produced on Earth. These increased levels of ^{3}He are important to geologists because they are usually indicative of major events in the solar system. Two peaks in ^{3}He levels have been observed during the Cenozoic Era (65.5 Ma to present): one during the late Eocene and one during the late Miocene (8.2 Ma). (See figure 1) There is a consensus that the peak in ^{3}He during the late Miocene is the result of a disruptive asteroid collision that produced a group of newer fragmented asteroids known as the Veritas family. The evidence for this comes from the lack of observed impact craters dating to the late Miocene and the calculated origin of the Veritas family (8.3 ± .5 Myr) at around the same time period. (Farley [2006]) The origin of the ^{3}He peak during the late Eocene is not quite as obvious and is the source of current debate.

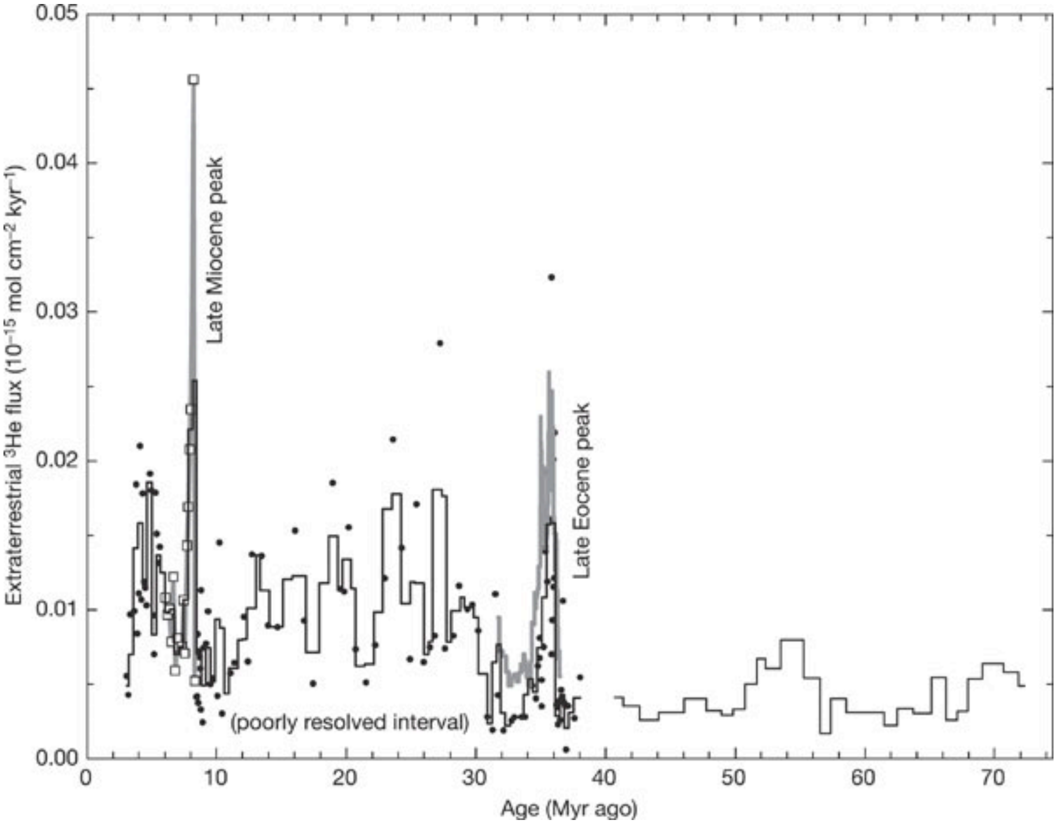

Figure 1 (Farley [2006])
Open and filled symbols are individual new ^{3}He measurements from ODP Site 757 (central Indian Ocean, 17801.4580 S, 88810.8990 E). Lines are 3-point running means through the data points, taken to minimize the effects of occasional sampling of large individual IDPs. The grey segments of the running mean line indicate the late Miocene event (highlighted by open symbols), and the previously reported late Eocene peak from the Italian Apennines.

Kenneth Farley states that matching a particular solar system process with interplanetary dust is based on several lines of evidence. They include, but are not limited to:

1. The temporal evolution of the dust event recorded by the ^{3}He flux.
2. The temporal relationship between the enhanced ^{3}He flux and terrestrial impact craters (if any)
3. The geochemical fingerprint of any impactors associated with the event
4. A peak in the distribution of cosmic-ray exposure ages of meteorites (asteroid impacts only)
5. The age of formation of asteroid families obtained by orbital “backtracking” of family members (asteroids only) (Farley [2009])

As was stated earlier, the cause of the late Miocene event was inferred from a combination of 2, 5, and 1 (as can be seen from the figure above). As with all sciences, several independent lines of observable evidence are preferred, so 1-4 are usually based on many different samples. Also, it is important to note results from orbital "backtracking" are usually made independently by astronomers; it is preferable to have multiple independent numerical models for this as well.

Although both the late Miocene and late Eocene deposits show increased levels of ^{3}He, there is a distinct difference in the rate at which these levels increased. Although this does not necessitate different types of causes, it does suggest that there may be a difference in the origin of the events. Another difference is that the two largest impact craters of the Cenozoic era, the Popigai and Chesapeake Bay craters, coincide very well with the time period of the late Eocene event and also correspond well with observed iridium spikes, which are indicative of meteor impacts. (See figure 2)

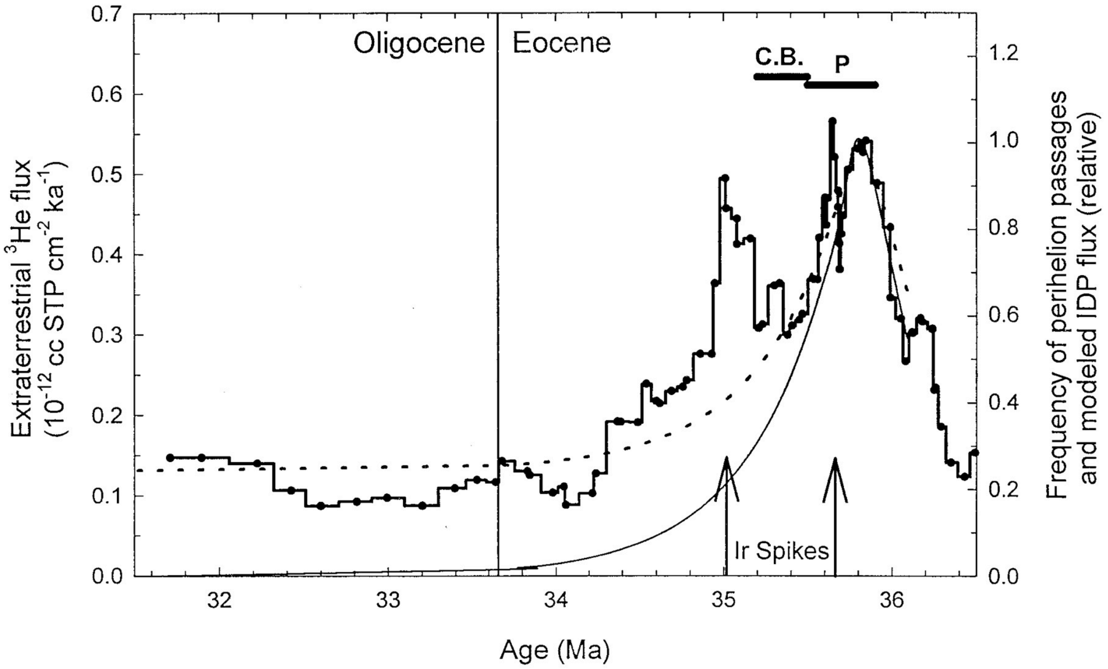

Figure 2: solid stepped line shows ^{3}He flux, solid line is the modeled frequency of perihelion passages, The dotted curve is the same but is offset vertically and scaled to accommodate the preshower and postshower "baseline" IDP flux. (Farley [1998])

The evidence stated so far strongly suggests that the impactors responsible for the Popigai and Chesapeake Bay craters are also responsible for the increase in ^{3}He levels. The question now becomes whether the impactors were asteroids or comets?

Farley argues for the comet hypothesis based on three different, independently derived models of the "temporal evolution of cometary activity produced by an impulsive perturbation of the Oort cloud [region with a relatively high concentration of comets], for example by a close stellar encounter." (Farley [2009], brackets added) The resulting frequency of perihelion passages (comet shower intensity) from these models match well with the flux of ^{3}He as well as the effects of the two impactors. (See figure 2) These models were originally done to show the relative probability of a comet impact with the Earth due to a particular perturber at *any* given time. This means that the models provide no direct temporal evidence that a comet shower occurred during this specific time period. So although the models of cometary showers ultimately support the comet impact theory, they are not as substantial as they would have been if they provided temporal support as well.

The first alternative to Farley's comet shower hypothesis was proposed by Roald Tagle and Philippe Claeys in 2004. Their proposed hypothesis stated that the impact craters and the increase in ^{3}He levels were due to asteroid impacts rather than comets. They based their results on the chemical composition of the Popigai crater. The impact-melt rock they sampled was found to be a result of an L-chondrite bolide, a known composition of certain asteroids.

> "An L-chondrite bolide is difficult to reconcile with a cometary origin. The PGE [platinum group elements] concentration of comets is unknown. Nonetheless, it is unlikely that a cometary bolide would display PGE elemental ratios similar to those of L-chondrites. Comets are believed to be primitive bodies with a composition like that of carbonaceous chondrites, which differ in PGE concentrations from ordinary chondrites." (Tagle [2004], p. 492, brackets added)

Tagle admits that there is a slight chance, ~1%, that the impactor could be an asteroid and still originate from the Oort cloud during a comet shower, but states that this probability is too low to be a viable option. Tagle and Claeys also suggest that a future investigation into the composition of the Chesapeake Bay impactor may support their hypothesis. (Tagle [2004], p. 492)

At this point the comet hypothesis had the advantage of better accounting for the ^{3}He flux during the late Eocene (#1 and #2 from the list above), while the asteroid hypothesis had the advantage of accounting for the chemical composition of one of the impactors (#3 from the list above). In 2007 Tagle, along with Jörg Fritz and Natalia Artemieva, proposed an alternative variation of their asteroid impact hypothesis to account for the temporal observations of ^{3}He levels. Tagle refers to the fact that an asteroid shower would not only affect the earth, but would also affect the Moon. The reason this would be beneficial to their theory is that the lunar surface contains relatively large quantities of ^{3}He and a portion of lunar surface material lofted up as a result of asteroid impacts would eventually settle on Earth's surface.

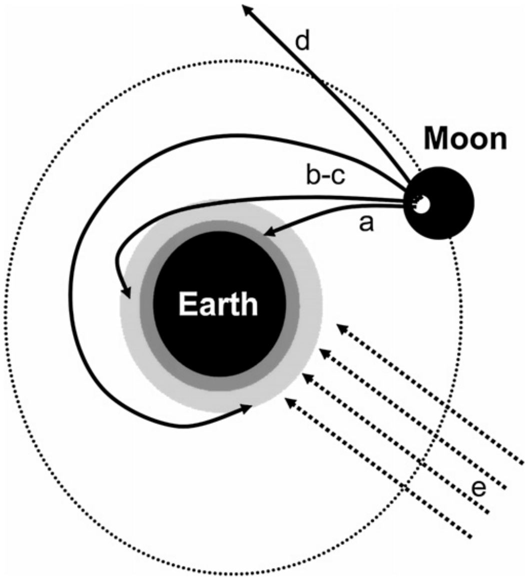

Figure 3: Projection of the Earth–Moon system onto the ecliptic plane. Solid arrows display orbits of lunar impact ejecta (Fritz [2007])

The slow settling rate of lunar material would also retain much of its ^{3}He as opposed to the degassing of bolides due to high velocities of incoming comets/asteroids. It is interesting to note here that, by proposing a more complicated explanation, this hypothesis steps away from the quest for parsimony so often advocated by philosophers of science.

In a recent paper, Farley argues that although the asteroid-lunar model accounts for an increase in ^{3}He levels there are still problems; a few are listed here:

1. There is no specific model for the proposed asteroid shower, nor is there independent evidence from the asteroid orbits for a major collision at the appropriate time from which such a model might be developed. [Recall Farley had such an independent model for his late Miocene hypothesis]
2. As a result of #1, there is no natural temporal evolution with which to compare the ^{3}He data.
3. Existing models of asteroid showers have longer durations than the duration proposed by Tagle.
4. Tagle's hypothesis would require hundreds of lunar impacts, which is unlikely. (Farley [2009])

Farley then mentions some observations that may support one hypothesis over the other and concludes with the most promising of these possible observations, "Finally, upcoming astrometric observations might be sufficiently complete and detailed to directly observe the "smoking gun" of a comet shower – a star that passed close to our solar system at the appropriate time." (Farley [2009]) Thus, both hypotheses face problems and both have proposed areas where new supporting evidence may be found; astrometric data for the comet hypothesis and the chemical composition of the Chesapeake Bay for the asteroid hypothesis.

2.2 Methodology:

It is well known among scientists that each scientific field uses methods appropriate for that particular field and avoids methods that are inappropriate. It has only been relatively recently that philosophers, Carol Cleland in particular, have really begun to focus on the role these different approaches play. (Cleland [2001, 2002]) While experimental sciences operate primarily within their own respective areas, historical natural sciences often employ interdisciplinary methods, which include concepts and methods from the experimental sciences as well as other historical sciences. Evolutionary biology uses findings from cellular and molecular biology as well as paleontology, and the field of geophysics uses methods from physics, engineering, and geology. Of course there are fields within experimental science that draw on several other fields, such as quantum electrodynamics, but the point here is that the historical sciences tend to use, and require, many different approaches to make acceptable claims within a particular field. Recall, in the previous case study that although the primary field of research was geochemistry, supporting evidence was found from geology, in the form of impact craters, and from astronomy, in the form of comet/asteroid collision models.

This search for interdisciplinary support is essential for claims made in historical natural science. “In some sense the earth sciences must come to comprehend the essentials of all the sciences. At least as much as any other scientists we are interested in the fundamental assumptions of all the sciences and in their consistent application.” (Chamberlin [1904]) The earth sciences in particular use concepts and techniques from a huge range of other fields such as: physics, chemistry, biology, ecology, and civil/mechanical engineering. For example, nuclear physics, in the form of radiometric dating, as well as the findings of paleontology are often used in dating techniques, and the influence of human and other ecological factors need to be considered in the analysis of certain erosion processes. For this reason some authors have questioned the overall autonomy of the earth sciences. (Nagel [1961]) It is important to understand that the findings and concepts of other fields are often used as tools, such as radiometric dating, or as practical aids, such as geophysical models. These uses of other fields help to properly interpret current observations, and one of the autonomous features of earth science lies in interpreting how these current observations came to be, which is intrinsically historical in nature. So while earth science may be one of the most diverse and interdisciplinary of the sciences, we find that this approach is necessary to produce an adequate explanation of past events and environments.

Earth sciences can be split into two separate aspects, namely historical and non-historical. Non-historical aspects aim to analyze current observations while the historical aspects aim to provide explanations of how these current observations can be interpreted as traces of past events. George Simpson uses an example of the process of erosion and weathering to describe non-historical aspects of geology, while the changing of unique phenomena by this process, such as the Grand Canyon, represents historical aspects. (Simpson [1963], p. 24) These historical aspects are partially what give geology and other historical natural sciences autonomy. How historical natural science uses current observations to make claims about the past will be addressed in section 2.3. The rest of this section will primarily focus on the scope and methods of earth science and contrast them with the experimental sciences.

An obvious difference between historical natural science and experimental science is that the first is historical while the later is not. But, what exactly does this entail? Energy and matter in the universe display certain properties that appear to be unchanging throughout history and from these properties certain principles and processes seem to arise. These properties, processes, and principles are the main concern of experimental science. They exist throughout history, but do not appear to be dependent on it. In contrast, there are states and events in the universe that are contingent to a particular place and time. These contingent states and events are the concern of historical natural science. The scope of historical natural science may even extend to the sequencing of processes or events through a period of time, such as the analysis of the fossil record in paleontology.

While experimental science is primarily concerned properties and processes that persist though time, historical natural science is primarily concerned with the present and past. How far into the past an investigation goes is dependent on the subject being studied. Paleontology and historical aspects of evolutionary biology are broadly concerned with a time scale ranging from the origins of life to the present, but each particular investigation, such as hominid evolution, only needs to be primarily concerned with a unique, appropriate time scale that may be in the more recent past. Likewise, the historical aspects of the earth sciences are broadly concerned with a timescale ranging from the origin of the earth up to the present, where traces of past events are observed. This huge time scale can create problems for the historical sciences. When dealing with such a large expanse of time scientists must discern whether a phenomenon occurred by an intense process over a short duration or a gradual process over a long period of time, which was one of the most important debates in the history of geology. This large time scale also contributes to the general lack of laboratory experimentation due to the fact that most processes historical natural scientists are concerned with take far more time than a laboratory experiment would allow. As a general rule, the further back in time a phenomenon occurred, the more likely evidence of the phenomenon has been lost. Of course there are exceptions to this rule, but the point is, unlike experimental science, historical natural science must contend with what has been referred to as ‘geologic time’ and as such has to be constantly aware of processes and events that may have had an effect on current observations. The affect these *information degrading* processes have on knowledge claims in historical natural science will be addressed in section 3.2.

In addition to a broad range of time, earth sciences must deal with a broad scale of observation. “Scale in geology ranges from the sub-microscopic to the planetary, from the structure of crystals to the structure of the planet.” (Hagner [1963], p. 236) While physicists and chemists are mainly concerned with processes and properties on a very small scale, earth sciences must be concerned with the very small and the very large. Take volcanic activity for example. To determine large scale properties of the volcano, scientists must considered microscopic properties of the magma; such as the silica and water content, as well as the depth and size of gaseous bubbles in the magma. These only represent a portion of the small scale properties that ultimately determine the large scale properties of the volcano. Although this example does not necessarily represent historical investigations, the same analysis, from small to large, applies to particular historical volcanoes as well. Scientists must search for evidence of a particular volcano and interpret its size, location in space, location in time, and its magnitude from the properties of relatively small remnants, such as ash and other pyroclastic materials, as well large remnants, such as plutons and calderas. Along with the large time scale, this range in observational scale also prevents earth scientists, historical or otherwise, from recreating these types of events in a laboratory setting.

Earth scientists must also deal with a broad range in the size and complexity of the systems they investigate. Experimental scientists are often able to create closed systems and isolate particular variables, and much of the work they do goes into justifying and creating these closed systems. Although earth scientists are able to isolate certain variables, such as the material properties of minerals, the size of the full scale objects or events being investigated does not allow for this type of isolation. For this reason the systems earth scientists are concerned with are necessarily open systems. This being the case, earth scientists must deal with extremely complex systems with many unknown variables. Scientists can analyze the composition, elasticity and forces surrounding an earthquake fault, but there are still too many unaccountable variables to accurately predict the next earthquake; the system to too complex. For this reason, earth scientists often deal with end products, which is a historical aspect. Only a relatively few pieces of evidence are necessary to determine the occurrence of an event in the past, while the prediction of such an event in the future requires much more evidence and knowledge of the system.

We have seen that, faced with large scales of size and time, the earth sciences, and historical natural sciences in general, do not have the same access to experimentation as the experimental sciences do. This does not necessarily mean that historical natural scientists do not utilize experiments in their reasoning. The role of experimentation can change depending on what is being investigated. In the experimental sciences experiments tend to take on a ‘verification’ role where the purpose of an experiment is to *test* a hypothesis or theory. Within the historical natural sciences, experiments play more of a *supporting* role. Often times the experiments done in the historical sciences, such as radiometric dating and geochemical analysis, are simply done to better interpret past events, not to provide direct evidence that the event itself occurred. Considering historical natural scientists are concerned with phenomena that are on a very broad scale and cannot be physically manipulated, they must take the findings from small scale experiments and use them to help justify the occurrence of the particular phenomena they are investigating. Similar to experimentation, another valuable tool historical natural scientists use as an aid is numerical modeling. An analysis of numerical modeling and its applications will be addressed in section 3.1.

Considering experimentation plays a less direct role in historical natural science, scientists must utilize other methods of inquiry. For this reason, *field observation* plays an essential role in historical investigations. Using the volcano example again, scientists can observe specific properties in a broad range of current, active or inactive, volcanoes and match the observed properties with observed behaviors; such as the presence of high silica content in explosive volcanoes. One benefit of 'geologic time' is that scientists can observe a wide range of types and also a broad range in ages of phenomena such as volcanoes. This is different than experimentation because variables are not being isolated and manipulated; rather they are being observed along with many other variables and matched with corresponding behaviors. Considering the previous case study, an experiment cannot be done to replicate a comet or asteroid impact so observations must be matched with known results, such as the composition of impact-melt rock from the craters and the duration of the increase in ^{3}He. It is easy to see that obtaining numerous samples and observing a large age variation in the samples usually leads to better understanding and interpretation of phenomena.

This focus on observation has led many philosophers and scientists to refer to the earth sciences and other historical natural sciences as *qualitative* rather than *quantitative*. The criticism then being that qualitative statements are somehow more subjective than quantitative statements. (Hagner [1963], p. 236) Although there has been an increase in quantitative analyses within the historical natural sciences with the recent popularity of numerical modeling, these fields still remain largely qualitative. This does not necessarily mean that a qualitative approach is any more or less subjective than a quantitative approach. The experimental sciences are more apt to use quantitative analyses because they are able to create simple closed systems that are relatively easy to model mathematically. Once a system becomes more complex a quantitative analysis becomes much more difficult. Take quantum mechanics for example, the mathematics involved can accurately explain simple particle systems, but as the system becomes more complex the mathematics involved becomes problematic and a more qualitative explanation must be given to accurately describe a phenomenon. The same can be said concerning the previous earthquake example, a very quantitative analysis can be given of the forces needed to fracture a sample of a mineral found along a fault, but the more complex the system gets, i.e. an entire fault structure, the more qualitative the analysis must be. Thus, although quantitative analyses provide a more exact description of a particular phenomenon, they are only applicable to relatively simple closed systems. Alternately, qualitative analyses are better suited for complex open systems, which is the main concern of historical natural sciences. This difference in approach does not make one better than the other, it simply limits how exact a description can be for a particular scale of phenomena and that sometimes a general qualitative description provides more relevant information of a system than a quantitative description.

2.3 Explanation:

The analysis of *explanation* in science usually includes an analysis of scientific *laws*. The concept of scientific laws themselves has consistently been a central debate within the philosophy of science. For the purpose of this paper, a precise analysis of scientific laws is not necessary and so a general description will suffice. General descriptions of scientific laws usually depict them as being deterministic or probabilistic/statistical in nature, as well as being universal and exceptionless. An example of a deterministic law can be found in Newtonian mechanics, while examples of probabilistic and statistical laws can be found in quantum mechanics and thermodynamics respectively. The presence of such laws has conventionally played a distinguishing role in determining whether or not a particular field could be considered a *real* science. Traditional accounts have set physics as the paradigm example of "good" science considering the success of the laws it describes. Although some philosophers, such as Nancy Cartwright (Cartwright [1983]), have argued that even the laws of physics may not maintain the universal and exceptionless criteria of scientific laws, it is none-the-less apparent that experimental sciences like physics and chemistry do provide scientific laws that concisely express relationships that are consistent over a set range of values and that they are at least close to universal and exceptionless in their respective domains.

If scientific laws are numerous and widely accepted within established fields of science such as physics and chemistry, do the fields of historical natural science also require scientific laws? Although the fields of earth science and evolutionary biology are relatively young in comparison to the experimental sciences, it would be wrong to attribute this to the lack of laws in these fields. Contemporary earth scientists are even less likely to try a formulate laws today than they were 100 years ago. (Bradley [1963], p. 18) In fact, in 1933 geologist Walter Bucher even tried to formulate 46 different laws in structural geology. (Bucher [1933]) Rather than attempting to formulate laws, historical natural scientists are more apt to try and formulate 'principles'. The term 'principle' is used relatively loosely within these sciences, but can be thought of as a *ceteris paribus* empirical generalization.[2] An example of a principle is the *principle of superposition* in geology, which states an undisturbed sedimentary rock layer will be younger than the one below it. Historical natural scientists are primarily concerned with unique processes and phenomenon related to the earth, or other planets, and so they do not strive to meet the "universal and exceptionless" criteria of scientific laws. They understand that principles act like rules that may have exceptions and that the *ceteris paribus* clauses are rarely, if ever, met. Historical natural scientists have realized that stringent scientific laws are not necessary in their fields. To gain an adequate understanding of historical events and processes loose generalizations or principles may work better because the scientists must remain aware of other influences that may violate the principle they are using.

It is apparent that the historical natural sciences tend to be more concerned with unique events and processes than the experimental sciences. While the experimental sciences strive to discover law-like regularities, the historical natural sciences look for causal explanations of current observations; this difference can be described as a difference in event-tokens and event-types. Carol Cleland states, "Thus, the hypotheses of prototypical historical science differ from those of classical experimental science insofar as they are concerned with event-tokens instead of event-types." (Cleland [2002], p. 480) Cleland attributes the focus on event-tokens to the fact that causal chains between the particular event and current observations are so long that regularities are usually superseded by contingencies. Although Cleland is right that historical natural science puts much more emphasis on event-tokens than the experimental sciences do and that historical natural scientists use loose generalizations to provide evidence for past events, it

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[2] Sandra Mitchell (2000) offers a detailed pragmatic approach to the distinction of scientific laws based on their use by scientists that avoids this distinction between 'laws' and 'principles'.

would be a mistake to infer that historical natural sciences are not specifically concerned with the regularities themselves.

As was stated earlier, although earth scientists are reluctant to try and formulate laws, they do try to form loose ‘principles’. This pursuit extends into both the historical and non-historical aspects of the field. In order to properly infer the specifics of past events from current observations one must have a general understanding of the causal mechanisms that link the past event to the current observations. Considering the interdisciplinary approach of the historical natural sciences, often times these causal mechanisms come from the findings of experimental sciences, but they can also come from regularities proposed by the earth sciences, evolutionary biology or other historical fields. In a similar line of argument, Ben Jeffares uses the volcano example to show that understanding volcanic activity as an event-type helps scientists to understand a unique volcano event-token, whether historical or non-historical. (Jeffares 2008) For this reason historical natural scientists are not only concerned with event-tokens, but also event-types. An excellent example of this can be seen in the earlier case study where one of the central arguments rest on the processes of asteroid showers and comet showers as event-types to explain the particular event-token.

Cleland goes on to elucidate the approach of natural historical science by stating, “Instead of inferring test implications from a target hypothesis and performing a series of experiments, historical scientists focus their attention on formulating mutually exclusive hypotheses and hunting for evidentiary traces to discriminate among them.” (Cleland [2002], p. 480) This method of forming “mutually exclusive hypotheses” has long been advocated by earth scientists and was endorsed by Thomas Chamberlin back in the 1890’s. Chamberlin proposed a “method of working hypotheses” that has greatly influenced the field of geology to this day. The method of working hypotheses states that it is the scientist's responsibility to bring up multiple rational explanations of a phenomenon and attempt to develop a hypothesis to the cause and history of the phenomena. (Chamberlin [1904]) Chamberlin's original intention was to prevent scientists from favoring one hypothesis over another for personal reasons, but the method seemed to work well for reasons beyond preventing personal bias in the earth sciences and has since become established as proper methodology within many fields of historical natural science. The cause of increased levels of ^{3}He in the late Eocene provides an excellent representation of this method. In this debate, the goal is not to show which hypothesis is the "correct" hypothesis, but rather to show which hypothesis better explains the evidence and is more likely than the other. Both sides of the debate have developed arguments for and against the competing hypothesis and have even proposed where new evidence may be found to support one side over the other. Although this is a common practice in all sciences, it seems to be more prevalent in the historical natural sciences because of the increased role of interpretation of observations.

One way to discriminate between competing hypotheses is to search for a 'smoking gun'. Cleland states, "A smoking gun is a trace(s) that unambiguously discriminates one hypothesis from among a set of currently available hypotheses as proving "the best explanation" of the traces thus far observed." (Cleland [2002], p. 481) The example Cleland uses is the discovery of shocked quartz and an iridium layer at the Cretaceous – Tertiary boundary (KT boundary) that decisively favored the meteor impact theory as the best explanation for the cause of the extinction of the dinosaurs. In the case study stated earlier, a smoking gun may be found in the analysis of the chemical composition of the Chesapeake Bay crater. It is important to note that smoking guns do not usually provide conclusive evidence that a particular hypothesis is correct, but rather that the hypothesis provides the best possible explanation. This fits perfectly into the method of working hypotheses. It is inevitable that in some cases there will exist multiple hypotheses that provide equally persuasive evidence, such as the case study. In such cases, judgment is usually reserved until further, discriminating evidence is discovered.

In certain cases, multiply hypotheses that share equal evidential support are discriminated using arguments from simplicity, or *parsimony*. Parsimony states if two hypotheses are equally supported, the hypothesis that postulates fewer entities or processes is preferable. (Sober [1988], p. 50) Elliot Sober goes on to state that the use of parsimony in discriminating between rival hypotheses may be purely methodological or it may be substantiated by ontological features of the world. I do not intend to argue for one stance over the other, but it is evident that scientists do tend to prefer simple hypotheses over complex hypotheses.

One way historical natural scientists pursue simple hypotheses is by positing common causes; one cause is simpler, and usually preferable, than two. Hans Reichenbach presented a *principle of common cause* that states correlations should be explained by positing a common cause. (Reichenbach [1956]) Of course not all correlations share a common cause. Sober uses examples of *homoplasy* and *homology* in evolutionary biology as a counterexample. (Sober [2001], p. 335) A *homology* is when two or more species share a trait that they inherited from a common ancestor, whereas a *homoplasy* is when two or more species share a trait that they inherited from different ancestors. The classic example of a homoplasy is the wings of bats and birds; they are similar traits, but they do not originate from a common ancestor. Homologies have a common ancestral cause, while homoplasies have separate ancestral causes although they may have common environmental causes. A major concern for historical natural scientists is when and how to discern common causes from separate causes. So it seems a distinction must be made to justify when it is appropriate to postulate common causes and when it is appropriate to postulate separate causes.

In the K-T boundary example the evidentiary traces of shocked quartz, iridium layer and fossil record were “tightly” correlated; meaning they all occurred at same time (geologically speaking) and the probability that they would occur at the same time yet have separate causes is extremely low. In the late Eocene event the correlation between the two meteor impacts at roughly the same time and the increased concentration of ^{3}He is “tightly” correlated as well, which is why both rival hypotheses propose common causes. In both of these cases the correlations had a high probability of sharing a common cause and a low probability of having separate causes. This is why common cause hypotheses were pursued and now provide the best explanations. If a separate cause explanation is just as plausible as a common cause explanation the method of working hypotheses tells us that we must develop both and choose the most adequate. It is not that scientists immediately assume common causes to correlated events, it is simply that the types of hypotheses historical natural scientists are primarily concerned with are token-events and the most interesting and valuable traces they investigate are the ones that provide evidence for a common cause; namely, the token-event.

In the case of the K-T boundary, the existence of the iridium layer was not predicted and was discovered by chance. The tight correlation of the iridium layer and the other evidentiary traces is what led scientists to investigate whether the traces shared a common cause. Although it occurs within the experimental sciences as well, this lack of predictive guidance and matching of evidentiary traces is more common in historical natural science. This does not necessarily mean that prediction does not play a role in historical natural science.

As the case study shows, both hypotheses predict where new supporting evidence can be found: geochemical analysis of the Chesapeake Bay crater and astrometric data. These predictions are essentially different than the usual predictions found in the experimental sciences. It is necessary to distinguish between two types of predictions; there are predictions of *processes* and predictions of *outcomes*. The experimental sciences tend to predict both processes and specific outcomes based on background theories and generalizations, while the historical natural sciences tend to primarily predict outcomes. The background theories and loose generalizations found in the historical natural sciences help scientists to predict potential outcomes, which in turn helps to guide historical natural scientists in the pursuit of evidence. Although historical natural scientists search for predicted outcomes and evidentiary traces, we have also seen that discovery of evidence does not always need a guide and sometimes unpredicted evidence is just as influential as predicted evidence.

Although both experimental and historical science use predictions in their methodology, the role prediction plays in refuting hypotheses is different. Predictions in the experimental sciences tend to be rooted in strict scientific laws and are traditionally thought of as logical conclusions from those laws and relevant conditions. Thus, if a prediction fails there is a high probability that there is a problem with the law, the background theory that supports the law, and/or auxiliary assumptions. The failure of a prediction in the historical natural sciences is usually not nearly as severe. The reason for this is that the ‘principles’ of historical natural science are not as stringent as scientific laws and are full of contingencies. If a prediction fails it does not necessarily mean that the generalization that was used to make the prediction was wrong, it may simply be the case that there were other processes at work that prevented the predicted outcome from being observed. The historical scientist then has the extra burden of discriminating contingencies from mistaken principles to show what prevented a predicted outcome from being observed. For this reason *falsification* plays a much weaker role in the historical natural sciences. (Cleland, forthcoming)

We have seen that while historical natural science shares much in common with experimental science there are many distinct differences. Historical natural science tends to be much more interdisciplinary and attempts to provide explanations that unify a broad range of findings from the experimental sciences as well as other historical sciences. Historical natural science also deals with complex open systems that exist over a large scale of space and time. Because of this, historical natural science cannot experiment in the same ways as experimental science and is much more reliant on field observations. Principles, or loose empirical generalities, are preferred to scientific laws. Historical natural scientists use a combination of these scientific principles and laws along with evidentiary traces to provide justification for event-tokens. Finally, hypotheses are chosen by the method of working hypotheses and the search for a smoking gun. This analysis will be useful in the next section where the epistemic differences between experimental science and historical natural science will be addressed.

3. Epistemic Asymmetries:

Certain asymmetries between historical and experimental science will inevitably arise considering both are forced by their distinct epistemic situations to use different methodologies when pursuing empirical research. Although the existence of these asymmetries is apparent, the way in which they favor one field over the other is not nearly as simple to recognize. Some philosophers, such as Derek Turner, have argued that these asymmetries favor experimental science over historical, while others, such as Carol Cleland, have argued that certain asymmetries provide historical natural science with unique forms of justification. This section will address a few of the asymmetries proposed by Turner and Cleland; such as the *asymmetry of manipulability*, the *role asymmetry of background theories*, the *time asymmetry of knowledge*, and *asymmetry of overdetermination*. It will be shown that the methods used in historical natural science incorporate these asymmetries and that the claims made in both areas of science are justified with these asymmetries in mind.

3.1 Asymmetry of Manipulability:

"This *asymmetry of manipulability* means there is something – namely, our inability to intervene in the past – that limits our knowledge of the past without so limiting our knowledge of the tiny." (Turner [2005], p. 25) This quote is taken from an argument in which Derek Turner aims to show the epistemic advantages that experimental science dealing with the microphysical world has over historical science. The *asymmetry of manipulability* is fairly straight forward: experimental scientists can manipulate the objects they are investigating in a way that historical scientists cannot. Even microphysical entities, such as electrons and other subatomic particles, can be manipulated either directly or indirectly even though they cannot be directly observed. Historical scientists do not have the ability to manipulate the objects they are investigating and are thus limited by the finite number of present observations and must then interpret the past from these observations. They must then justify their interpretation using these observations, as well as other background theories and generalizations.

To compensate for the lack of manipulability, historical natural scientists have devised several different methods, including physical analog and numerical modeling, that supply similar benefits as laboratory experimentation; such has isolating and manipulating a particular variable while holding the rest of the system constant. One of the reasons why historical natural sciences, earth sciences in particular, have experienced such rampant progress in the last few decades is a result of the advance in computation techniques. Numerical simulation models have become common place in fields of historical natural science, such as evolutionary biology and earth science, and are even commonly used in making social policy decisions. Much work has been done on issues resulting from the use of computational techniques in the sciences, but for addressing the asymmetry of manipulability a general analysis with suffice.[3] To see how computational techniques help overcome the asymmetry of manipulability we must address two questions, namely: What is it about numerical models that assists historical scientists in making claims about the natural world and what limitations do these models have?

Although evidential traces of past events can be gathered, the past events themselves cannot be physically accessed with experimental methods. To compensate, historical scientists use the next best thing – numerical experimentation. Of course there are many different ways to utilize numerical modeling as well as many different ways to interpret them, but for the sake of this paper the process of numerical modeling will be dealt with in general terms. Numerical modeling allows scientists to manipulate input parameters, which are meant to correlate with natural conditions, and observe the different effects the inputs have on the computational system. The model itself is intended to represent a specific set of natural conditions and generalized parameters. The reason numerical models are so useful is that once a model has achieved a good fit with empirical observations, the resulting relationships between dependent variables (the most well known) to independent variables (the least well known) can be analyzed. Predictions, via generalizations, within the model can be made and observed by varying the initial conditions.

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[3] For more comprehensive treatments of this topic see Creager [2007], Magnani [1999, 2001], Morgan [1999], Nersessian [2008] and Parker [2009].

Although the model results do not always match empirical observations, they do provide scientists guidance on where to look for new empirical evidence and then better fine-tune their model.

A benefit of numerical modeling is that it can deal with complex and large-scale problems that would be impossible to replicate in a laboratory or natural setting. This brings up an initial concern of any numerical model: the scaling problem. Numerical models are scaled to best represent a particular natural process. A model of global climate patterns is going to have a much different scale than a model of sediment transport of a specific river system. Considering the sensitivity to initial conditions, numerical models can only reliably provide information for a limited reference scale. Anything that significantly departs from the model's scale will not provide useful information of the system. For this reason a model and the information gained from the model is limited to the particular scale it was designed for, as well as the reliability of the generalizations it was based on.

Another relevant problem with numerical modeling is the problem of uniqueness. When multiple models can produce the same results it is said to be 'nonunique' in scientific terms, or 'underdetermined' in philosophical terms. Naomi Oreskes addresses this problem and states, "If two theories (or model realizations) are empirically equivalent, then there is no way to choose between them other than to invoke extraevidential considerations like symmetry, simplicity, and elegance, or personal, political, or metaphysical preferences." (Oreskes [1994], p. 642) To limit the problem of nonuniqueness, modelers must take extra care to ensure their input parameters are as close to the natural conditions as possible. Of course this is just another example of the Duhem-Quine thesis, which affects all areas of science, but may be more damaging in historical sciences because the input parameters/initial conditions tend to be more numerous, more uncertain and more complex than in experimental sciences.

It is evident that Turner is right when he states, “numerical experimentation can only take us so far; ultimately there is no substitute for intervention in nature.” (Turner [2005], p. 129) Numerical models are not intended to replace physical experimentation; rather they act as supplements within a broad range of techniques; such as the use of generalizations, interdisciplinary background theories and detailed field observations mentioned earlier. They are meant to simulate and provide insight about the natural world, but scientists are well aware that a model can never fully replicate nature. As Oreskes argues, the benefit of numerical models lies in their heuristic value, or as guides for further study. (Oreskes [1994], p. 644) So although there is a distinct asymmetry of manipulability between historical and experimental science, with the help of numerical modeling the asymmetry is not quite as damaging. Numerical models can play an analogous role to experimentation by providing a form of confirmation of expected outcomes, as well as applying generalizations and background theories to scenarios that have either happened in the past or are expected to happen in the future.

“The experimental manipulation of microphysical entities and events makes it possible for scientists to test, and in some cases, confirm new theories. We cannot, however, manipulate things and events that existed and occurred long ago.” (Turner [2005], p. 24) Turner goes on to use the *asymmetry of manipulability* to support his argument that background theories within historical natural science almost always play a *dampening role* while theories within experimental science almost always play an *enlarging role*. An analysis of this argument will be given in the next section. The main point to be taken away here is that, considering the *asymmetry of manipulability,* historical science does seem to face an epistemic disadvantage.

How much this particular disadvantage weighs on his argument for the overall superior epistemic justification of experimental science over historical science remains to be seen.

3.2 Role Asymmetry of Background Theories:

Turner argues another asymmetry arises when the roles of background theories are considered in historical and experimental science. Using Turner's terminology; a background theory can either take on an *enlarging* role or a *dampening* role. In short, theories that play an *enlarging* role expose ways to create new types of evidence, while theories that play a *dampening* role expose reasons why new evidence can never be found. "Background theories about the past seldom, if ever, tell scientists how to create new empirical evidence, which is to say that they seldom, if ever play the enlarging role. By contrast, background theories about the microphysical world frequently do tell us how to create new evidence by which to test claims and theories." (Turner [2005], p. 25) Turner uses an example from the field of optics to show how background theories in experimental science have allowed for the development of better equipment and thus the development of new ways to test hypotheses dealing with optics. He uses a dampening example from the field of taphonomy to show how knowledge of fossilization processes exposes limitations to the amount of evidence we can expect to find of past life on Earth.

Elliot Sober (1988) provides valuable insight into the reason why background theories within the historical natural sciences tend to play a dampening role more often than in the experimental sciences. "It is not the complexity of the system or our inability to produce an accurate theory that makes historical inference difficult… it is the nature of the physical process itself, correctly understood by a well-confirmed theory, that destroys information." (Sober [1988], p. 4) For Sober, there are two idealized possibilities: 1) a present state holds regardless of what the past was like and 2) a present state is profoundly affected by a past state. The problem for historical science would then arise when scientists encounter the first possibility. Consider the theory of plate tectonics, particularly sea-floor spreading. According to these theories, the oceanic crust is constantly being created at spreading centers and constantly being subducted under continental crust at subduction zones. Some of the oldest oceanic crust that scientists can observe is located at these subduction zones; older oceanic crust has been subducted into the mantle and subjected to many other processes preventing scientists from conducting certain observations, such as magnetic remanence measurements. This would constitute an *information destroying* process. Although this is a single example of an information destroying process, similar processes are commonly found in one form or another within historical natural sciences.

Although Turner addresses the dampening role that fundamental theories of Physics, such as string theory, may play because of their speculative nature and inability to obtain empirical confirmation, he does not address the dampening role that many other theories in Physics play. Take for instance quantum mechanics, although in many cases quantum mechanics has been able to successfully account for previously observed phenomena and even been successful in predicting new phenomena, it still plays a *dampening* role in certain instances. Heisenberg's uncertainty principle is explicitly limiting because it states that certain pairs of variables, such as position and momentum, cannot be simultaneously known. The uncertainty principle is theoretically limiting, but there are other empirically limiting examples that face Physics as well. In the field of particle physics the existence of many entities must be inferred from indirect evidence. This in itself would not be a problem for Turner's theory because most of these entities can still be indirectly manipulated. There are however many entities that cannot be manipulated. Dark matter for instance is a hypothetical substance that is thought to account for a substantial amount of the energy in the universe, but does not interact with any currently observable entities and cannot be directly, or indirectly, detected. This is not to say that scientists will never be able to observe dark matter, but this does show that certain theories within experimental science do play a *dampening* role and they are not as uncommon as one may suspect.

The issues currently facing dark matter are similar to the issues that once faced theories involving neutrinos and the elusive Higgs boson. In the past, both of these theories were limited by lack of empirical observations (currently this still holds for the Higgs boson, but that will soon change), but advances in technology and methodology have since allowed us to determine whether or not these entities exist or not. Of course this merely supports what Turner found to be advantageous about experimental science to begin with, but the fact that the dampening effect of a theory can change as methods and technologies advance is actually shared by both experimental and historical science.

A good example of a supposedly dampening background theory playing an enlarging role is the recent investigations into the color of the dinosaurs. Turner originally used this example to show that there are certain things about the past that we will never be able to know for sure. “No serious scientist would spend time looking for a smoking gun to distinguish between rival hypotheses about the color of the dinosaurs, because there is good reason to doubt the existence of any such clues.” (Turner 48) This statement is founded on the idea that during the fossilization process all evidence of colorization is destroyed and that simple analogies of colorization based on current living organisms is too weak.

In 2008, a couple years after Turner's book was published, a team of Yale scientists published a paper suggesting new evidence that may lead to the discovery of the color of certain dinosaurs resulting from the analysis of fossilized feathers with ages ranging from the Jurassic to the late Tertiary. (Vinther [2008], p. 522) Previous investigations of the color patterns on various fossilized feathers attributed the colorization to the bacteria responsible for the degradation of the feather. The Yale group decided to reinvestigate the fossils to see if the colorizations, and deposits which accompanied them, were a result of melanosomes (an organelle containing melanin) contained within the feathers themselves rather than the remnants of degrading bacteria.

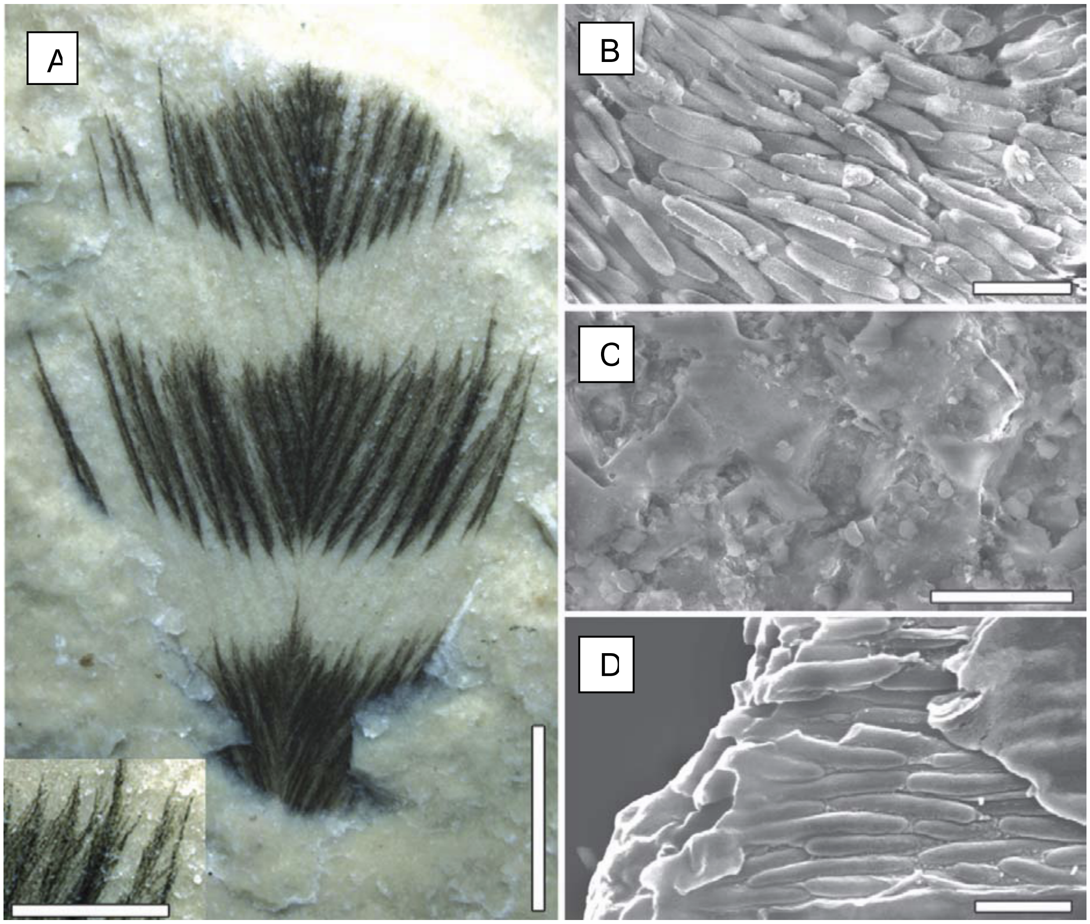

Figure 4: Cretaceous feather ultrastructure compared with that in a living bird. (a) Feather from the Crato Formation, Early Cretaceous, Brazil (Leicester University, UK, Geology Department, LEIUG 115562) showing colour bands; margins of colour bands are similar to those found in living birds and barbules are clearly preserved.

(b) Dark bands, composed of aligned eumelanosomes, contrast with (c) light areas that reveal only the rock matrix. (d) A broken barbule from a modern Red-winged Blackbird (Agelaius phoeniceus, Aves: Icteridae, Yale Peabody Museum 1047) reveals eumelanosomes aligned along the barbule enclosed in a keratin matrix. Scale bars, (a) 3 mm, insert 1 mm; (b) 1 mm; (c) 10 mm; (d) 1 mm. (Vinther [2008], p. 523)

Their investigation showed that, "The oblate structures from the dark bands on the Crato feather are strikingly similar in size, shape and orientation to eumelanosomes from the barbules of a black-pigmented contour feather from a Red-winged Blackbird (figure 4d), and to the eumelanosomes from other modern bird feathers." (Vinther [2008], p. 523) Further research has discovered melanosomes preserved in the same manner in non-avian theropod dinosaurs and has even proposed the color of bands along the tail of the theropod Sinosauropteryx. (Zhang [2010]) These findings lead one to expect that other, well preserved fossilized dinosaur feathers will have retained melanosome structures as well. Vinther's group also reports that other melanin-bearing structures have been preserved in fossilized fish and mammals and that further research may result in colorization patterns in these fossils as well.

It must be admitted that there are certain facts about the past that scientists will probably never be able to investigate, such as oceanic crust that has been subducted beneath continental crust and merged into the mantle, there are also topics in Physics that may never be able to be investigated either, such as whether or not we observe the entire universe or if there are portions that are too far away for their emitted light to have reached us yet. Scientists have a tendency to produce surprising new techniques that allow new horizons to be explored. The discovery of the color of dinosaurs is just one such example.

Although Turner is right that certain theories do tend to have either a dampening role or an enlarging role, limiting the epistemic utility of background theories to these two roles seems to miss a lot of what background theories provide for scientists. Background theories act as a guide for scientists to follow when looking for empirical support. Regardless of a theory playing a dampening role or an enlarging role, background theories provide scientists with information on where to expect to find information and how information may be interpreted. Referring back to the asteroid/comet shower debate, both of the hypotheses offer insight where to find future supporting evidence. Both hypotheses play a dampening role, in-so-far as no new information can be experimentally created and both must deal with millions of years of information-degrading processes, but yet both hypotheses still tell scientists where new observations may be made and what new information, interdisciplinary or otherwise, may provide support for a given hypothesis.

3.3 Time Asymmetry of Knowledge:

The *time asymmetry of knowledge* is a straightforward principle. Turner bases this principle on the idea that we tend to know quite a bit more about the past than we do about the future. Most people know where they were born, but not where they will die. We know what the weather was like a year ago, but not what the weather will be like a year from now. (Turner [2005], p. 17) Turner's explanation for this principle is based on work done by Paul Horwich. Horwich states that our knowledge of the past comes from reliable *recording* systems, while we lack knowledge of the future because there are no analogous *pre-recording* systems. Before Horwich expands on these ideas he first addresses six other competing explanations, one of which is based off of past-oriented overdetermination. This refutation will be addressed in the next section, which deals with issues pertaining to overdetermination.

For Horwich an *ideal* recording system, S, is characterized as:

1. S is capable of being in any of a range of mutually exclusive states S0, S1, S2, …

2. Except for S0, these states are perfectly stable; that is, if S is in state Sk at time t, then S is in state Sk at all times later than t.
3. There exists a range of mutually exclusive external conditions C1, C2,…, to which S is sensitive in the following sense; if S is in its 'neutral' state S0 at time t, and the external condition Ck obtains in the environment of S, then S will go immediately into state Sk; moreover this is the only way that Sk can be produced. (Horwich [1987], p. 84)

We can then see that if any system is found to be state Sk it can be inferred that the prior condition were Ck. Of course, actual recording systems rarely hold up to this ideal and their inconsistency with condition 2 and 3 are things historical natural scientists spend a great deal of time addressing.

The corresponding pre-recording system, in a *non-ideal* form would then take the form:

1. S* is capable of being in any of a range of mutually exclusive states S0, S1, S2, …
2. Except for S0, these states are fairly stable; that is, if S* is in state Sk at time t, then S* is probably in state Sk at all times earlier than t.
3. There exists a range of mutually exclusive external conditions E1, E2,…, to which S* is associated in the following way: if S* is in its neutral state at time t, and the external condition Ek obtains in the environment of S*, then, *beforehand*, S* was in state Sk; moreover this is what usually happens following Sk. (Horwich [1987], p. 87)

With the establishment of a non-ideal pre-recording system Horwich has addressed the epistemical difference between the past and the future, so the question then becomes, why pre-recording systems, S*, are non-existent? The answer comes from the nature of the universe, we rarely, if ever, see Sk before we see Ek (backward causation). In other words, we don't see a cracked egg before it was cracked. It is important to address the difference between *knowing* the future and *predicting* the future. We can fairly accurately predict effects from their causes, but a pre-recording system would show effects before their causes, which is extremely unlikely. In historical science past events can be inferred from presently observable traces, while future events do not leave traces and can not be inferred in the same manner. As Turner also notes, an interesting result of the asymmetry of recording/pre-recording devices is that, even if the universe was completely deterministic, the asymmetry still limits our knowledge of the future. (Turner [2005], p. 19-20)

3.4 Asymmetry of Overdetermination:

> Any particular fact about a deterministic world is predetermined throughout the past and postdetermined throughout the future. At any time, past or future, it has at least one *determinant*: a minimal set of conditions jointly sufficient, given the laws of nature, for the fact in question. (Lewis [1979], p. 473-474)

In this passage David Lewis is commenting on an empirical, causal fact about macro-scale phenomena in our universe. If something has two or more causes at a given time it is said to be *overdetermined*. Stated differently, overdeterminism can be understood as a situation where one cause has multiple effects; *underdeterminism* on the other hand can be understood as a situation where one effect has multiple causes. Lewis states that not only are cases of underdeterminism extremely rare, but that “extreme overdetermination of earlier affairs by later ones, on the other hand, may well be more or less universal at a world like ours.” (Lewis [1979], p. 474) The last thing that Lewis stresses is that the asymmetry of overdetermination is a contingent, *de facto* matter that should only be applied to relatively local states in the universe. The asymmetry of overdetermination has become a central issue in the analysis of historical natural science, particularly because the type of investigations historical natural scientists are primarily concerned with are unique, macro-scale phenomena that fit into Lewis’s contingent and local stipulations. Most present events are epistemically overdetermined by their past causes, which is beneficial for historical science.

Carol Cleland (2001, 2002) argues for the epistemic equality of historical and experimental science by focusing on the use of the asymmetry of overdetermination within the historical natural sciences. Considering historical scientists usually cannot perform controlled experiments that exactly, or even closely, replicate the particular phenomena they are investigating they must find other ways to empirically support their hypotheses. Cleland argues that they do this by exploiting the asymmetry of overdetermination and looking for evidential traces of the past in order to make a well supported inference about a particular event in the past. As a general example, Cleland uses the eruption of a volcano to elucidate her point. “The eruption of a volcano has many different effects (e.g., ash, pumice, masses of basalt, clouds of gases), but only a small fraction of this material is required in order to infer that it occurred; put dramatically, one doesn’t need every minute piece of ash.” (Cleland [2002], p. 989) So although a particular phenomenon may produce many different traces, only a few of them may be necessary to make a good inference. The most important of these traces are “smoking guns”, which provided support of one hypothesis over another. Moreover, the asymmetry of overdetermination also acts as a type of hindrance on experimental science and the coping mechanism they have developed is the effective use of experimental methods.

As was mentioned earlier, Paul Horwich argued against past-oriented overdetermination to support the use of the asymmetry of recording devices to explain the knowledge asymmetry between past and future. He states, “However, as soon as this line of thought [overdetermination] is spelled out, its defects become obvious. It is one thing to observe a symptom of some event; but another, and much more difficult, thing to observe such a symptom and recognize it as such." (Horwich [1987], p. 82) For Horwich, all the asymmetry of overdetermination tells us is that traces of past events will probably be observed more often than traces of future events. This increase in the frequency of observable races of the past does not explain the knowledge asymmetry because "what makes it hard to know the future is not the scarcity of present phenomena that determine future events, but rather the difficulty in discerning the future implications of what we do see." (Horwich [1987], p. 82) Thus, what explains the knowledge asymmetry is not that there are more traces of past events, but that the qualities of traces of past events are much better as a result of the asymmetry of recording devices.

Although Horwich was addressing the general increase in knowledge of past events versus future events as opposed to the epistemic asymmetries of historical and experimental science, much can be gained from his analysis. Horwich states that it is the quality of traces that matters, not the quantity. He rejects the asymmetry of overdetermination because it only explains why traces of past events are more frequent and does not say anything about how knowledge is extrapolated from the numerous traces. I believe Horwich is correct in this analysis, but what he fails to see is that it is not the asymmetry of overdetermination itself that does the work, but rather the application of the asymmetry. Within historical science, only a few quality traces are needed to make a good inference. What the asymmetry of overdetermination tells us is that, ignoring information destroying processes for the moment, traces will be more frequent for past events. If there are more traces in general, it can be assumed that there will be more quality traces as well. As was discussed earlier, one of the most important processes in historical science methodology is finding and interpreting these quality traces.

Horwich argued that the knowledge asymmetry stems from the fact that that there exists recording systems that provide information of the past, but there are no pre-recording systems that provide information of the future. Another point that Horwich recognizes, but does not address, is that the *traces* and background theories that historical scientists use play the role of the *recording* systems he describes. A trace is simply a particular empirical observation that provides information about a past event, which is essentially what a recording device does. So, in effect, what the asymmetry of overdetermination tells us is that there will be many instances of recording devices that provide information about the past. Of course, when background theories and information destroying processes enter the mix, knowing what to do with these traces/recording devices is very complicated and are issues that every historical natural scientist must deal with.

4. Conclusion:

An analysis of the proposed epistemic asymmetries has revealed there are distinct epistemic advantages and disadvantages in both historical natural science and in experimental science. Experimental science has the advantage of being able to manipulate, either directly or indirectly, the objects of their investigations, while historical natural science uses other methods, such as numerical modeling, that do not involve direct manipulation of the environment. Background theories in both experimental science and historical natural science can either play a dampening role or an enlarging role, but regardless of the role the background theories play they can still be used as guides for the discovery of new evidence. Finally, historical natural science has the benefit of the asymmetry of overdetermination combined with the time asymmetry of knowledge.

The existence of these epistemic asymmetries is reflected in the methods used in both areas of science. The asymmetry of manipulability allows experimental scientists to isolate variables and create closed systems which allows for simple exact relationships to be discovered and formalized into scientific laws. These isolated and closed systems allow experimental scientists to focus on the application of only one, or a small number, of background theories. In contrast, historical natural science is concerned with complex open systems and must utilize a large number of background theories, often from other historical natural sciences as well as the experimental sciences. Lastly, historical natural science is uniquely concerned with event-tokens as well as event types and the asymmetry of overdetermination is utilized to make inferences from present observations to the occurrence of past events.

Scientists are well aware of the methods that work best for their specific area of science. Scientists are also very careful with the degree of certainty they give to certain propositions. It has been shown that the types of claims made by experimental science and historical natural science are different and often apply to different scales of observations. The methods employed by the experimental sciences would not always be appropriate for the investigations of historical natural science and the methods employed by historical natural science would not always be appropriate for the investigations of the experimental sciences. The claims made by historical natural science are necessarily different than the claims made by experimental science. Regardless of the area, good science necessitates that levels of certainty, methods of justification, sources of error and alternative interpretations be addressed. It is not that one area of science is more justified in making claims than the other; it is simply the claims made are different and require different methods of justification.

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