

James Hutton and Plate Tectonics: Parallels in
Time?

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<u>Table of Contents.</u>	<u>Page Number</u>
Précis	4
Introduction	6
Background Context	6
Biographical Summary: James Hutton	6
Historical Context of Work	8
Description of Hutton's Theory: In Brief	10
Neptunism vs. Plutonism	13
Geology after Hutton, Before Tectonics	14
Plate Tectonics: Evolution of the Idea	17
Discussion	19
Thomas Kuhn: Establishing a Working Model	19
Application to Hutton	21
Application to Plate Tectonics	23
Conclusion	24
References	28
Appendix A: Tectonics timeline	32

Précis

This paper stems from trying to incorporate a cross-discipline interest in geology, history and philosophy into one topic of investigation. Thus from an initial inquiry into the life and works of James Hutton, the research expanded to include the potential modern parallel of plate tectonic theory, and the way each could fit into proposed frameworks of scientific development by modern philosophers and historians of science. The research question investigated, then, is historic development of geology by focusing on two significant events, the publication of James Hutton's *Theory of the Earth* and the advent of plate tectonics, any potential parallels they may exhibit and how well they fit into the developed framework of scientific development.

This line of investigation fits into the context of both the philosophy and history of science as applied to geology. In understanding this topic it is important to understand the historic details of Hutton's time, and the conception of plate tectonics, and the social impacts on each. Also, it is worth knowing some of the general trends identified in the progression of different scientific disciplines and universal scientific knowledge. In this context, exploring the topic question of this paper could reveal something about where the state of geology is at present and where it might be headed in the future based on its established past.

To investigate the relationship of Hutton's *Theory of the Earth* and plate tectonic theory once the context of each is established, Thomas Kuhn's model of scientific development is introduced and applied to each to define a working framework for making comparison. The only specific problem with this is choosing a specific model from

which to work. Kuhn's model of scientific theory is chosen because of its wide application in the sciences and its recognition of social influences on the development of science.

It is found that the history of geology follows the lines of Kuhn's model quite closely with both Hutton's theory and the theory of plate tectonics fitting into specified stages of scientific development. There were some recognized deviations in the areas of deep time and a historical component that separated geology from most of the common historical applications of Kuhn's theory. However, in terms of method, establishing a framework for evaluating specific events in a discipline is worthwhile in assessing major similarities and differences. Overall, exploring the history of the geologic discipline has given me a better appreciation of the current avenues of investigation being pursued and has raised some further questions concerning the direction the discipline may be heading.

Introduction

Two distinct events that are highlighted in the history of geology are the publication of James Hutton's *Theory of the Earth* at the end of the eighteenth century and the advent of plate tectonics in the 1960's. Both are widely regarded as historic landmarks in the discipline's development. The question arises as to why these particular events are singled out of all possible advancements in geology. What is it that makes them unique and worth our recognition?

This paper will explore the relationship between these events and try to develop an adequate framework for comparison. First, James Hutton will be looked at in terms of his life, the social climate of the late eighteenth century, the main components of his theory, and the main schools of thought within geology around the time of his paper's publication. The direction of geology between 1800 and the development of plate tectonics will then be briefly summarized to provide an element of continuity. Next, the major elements of plate tectonics will be outlined and its historic development will be examined. In hopes of establishing a working framework for deriving a comparison, Thomas Kuhn's model for the development of scientific theories will be introduced and applied to both Hutton's *Theory of the Earth* and plate tectonic theory. Lastly, conclusions from the evidence will be postulated and discussed.

Background Context

Biographical Summary: James Hutton

James Hutton was born in Scotland in 1726 and studied medicine at the University of Edinburgh in Scotland, the Sorbonne in France and Leiden University in

Holland before becoming a farmer in Berwickshire in 1754. Like many others of his time Hutton was able to become a 'gentleman of leisure' due to his merchant father's substantial finances and his partnership with James Davie in manufacturing sal ammoniac (Bailey 1967). In 1768, Hutton returned to Edinburgh to pursue his interests in chemistry and the natural processes of the Earth. There, he was a member of both the Royal Society of Edinburgh and of the Oyster Society. His friends and contemporaries included Joseph Black, John Playfair, John Clerk of Eldin, Adam Smith, Robert Adam, James Hall, Adam Ferguson, Dugald Stewart and David Hume. These and others of Hutton's acquaintance comprised the core of Edinburgh's intellectuals at the time (Hallam 1989).

Hutton himself has been described a number of ways throughout history. Hallam claims "as a scientist he combined to an unusual degree a skill in acute observation with a capacity for bold and original theorizing" (Hallam 1989). In a review by James Buchan, he sees Hutton as portrayed in a portrait by Henry Raeburn as "sort of an idiot savant, enthusiastic, plain, ascetic, reticent" (Buchan 2003). Most notably his biographer John Playfair acknowledged him by saying, "his figure was slender but denoted activity; with a thin countenance, a high forehead, and a nose somewhat aquiline bespoke extraordinary acuteness and vigor of mind" (Bailey 1967).

In the arena of geology, Hutton first presented his "Theory of the Earth" to the Royal Society of Edinburgh in 1785 in a series of readings. The paper was later published in the Transactions of the Society in 1788. In response to attacks mainly by contemporaries such as Richard Kirwan in Ireland, and with new field evidence, Hutton put forward an extended version of his "Theory of the Earth with Proofs and Illustrations" in a three-volume set. The first two parts were published in 1795 and the

third after Hutton's death in 1797. Some sites which served to illustrate key components of his theory and which today are still identified as important localities for understanding Earth processes include Salisbury Craigs, a section of the Portsoy granite, Siccar Point, Glen Tilt, a site in Galloway and another on the Isle of Arran off the west coast of Scotland (McIntyre 1999).

Historical Context of Work

In order to understand the circumstances that brought about Hutton's ideas it is important to examine the intellectual climate of the eighteenth century. Britain and much of continental Europe, towards the end of the eighteenth century experienced dramatic changes in society, religion, and science. "The upsurge of economic improvements of various kinds in town and country, the overcoming of many of the political handicaps of the past, the awakening of a new scientific curiosity, the rise of a new spirit in the universities, and finally, a new upsurge in letters, both what were called *belles lettres* and more philosophical and historical productions—all of these were little short of phenomenal" (Lehmann 1971). The political climate was one that included the Rebellion of Bonnie Prince Charlie in 1745, the French Revolution in 1789, and bitter political fighting throughout the 1820's and 1830's (Johnston 2000).

Religion, at the end of the 1700's and in centuries preceding it, played a very prominent role in the everyday lives of people as well as the direction of scientific investigation. In the late seventeenth century and early part of the eighteenth century there was a break away from a conservative view of religion emphasizing original sin as the backbone of class ordering to a more "optimistic, individualistic and egalitarian" outlook which allowed for the propagation of inquiries via one's senses and reasoning

into the natural truths established by a benevolent God for the benefit of mankind (Johnston 2000). Newton's mechanical natural philosophy in conjunction with loosening religious constraints had a very large impact on all areas of scientific investigation. Thus by Hutton's time, religious interpretations such as deism (to which Hutton prescribed) were possible. Deism held that the world was governed only by rationally explainable truths because God, once He created the world, no longer had any direct involvement in its maintenance (Johnston 2000). The loosening within society was not universal though, when cases such as the sedition trials in Great Britain from 1793-1797 or the 14 year imprisonment penalty for lending a copy of Thomas Paine's reply to Burke's *The Rights of Man* are considered (Şengör 2001).

However, science and religion were still greatly intertwined. A strict interpretation and acceptance of the Mosaic history of the Earth (the Biblical account of creation) was extremely popular during the late eighteenth century. For those such as Thomas Burnet, the investigation of natural philosophy was simply an extension of theology (Gould 1987). Even for Hutton, the recognition of a 'Grand Design' of nature in his theory of the Earth was extremely important, although it is debated if the large emphasis on it within his Theory of the Earth was just an attempt to appease the conservative majority of his contemporaries and within society (Şengör 2001).

In the late 1700's, there were many investigations into 'natural philosophy' and the Earth, mostly by leisurely gentleman, members of the clergy, philosophers, chemists and others of the general scientific community. There were a few important discoveries and recognitions about the Earth prior to Hutton that bear mentioning either for their possible influence on his theory or for their similar conclusions. Nicolaus Steno in the

sixteenth century developed a principle of uniformitarianism that had far reaching implications for Hutton and is still widely applied today. In 1693 and 1695 John Ray and John Woodward, respectively embraced the idea of a renovating agent acting on the Earth's surface, though this approach seems to have been abandoned prior to 1750 when most, like Charles De Luc, Reverend William Richardson and Richard Kirwan, expressly denied the existence of such a mechanism (Davies 1972). Lazzaro Moro (1687-1740) proposed that mountain uplift was due to lava and 'fiery gases' from the inside of the Earth (Hallam 1989). Vasilievich Lomonosov (1711-1765) developed a concept of internal dynamism in the Earth from an evolutionary point of view; one to which it is thought, but not directly known, Hutton was exposed (Dott 1969). It is important to note, however, the great deal of thought that was put into geology at the time even in the absence of a defined school or discipline. In 1764 there were forty-nine theories of the Earth's formation listed by de Pauw and in 1797, during the year of Hutton's death, there were thirty-five other accounts of the Earth by de la Mettrie (Johnston 2000).

Description of Hutton's Theory: In Brief

James Hutton is widely known as the 'Father of Modern Geology' for his theory of the Earth that was both contradictory to the dominant hypotheses of the time and introduced a series of profound conclusions, some of which still hold today. His contributions are summed up in the following quotation:

"Among Hutton's major contributions to the science of geology are his insistence on the basic orderliness of terrestrial processes; the centrality of heat; the duration of time; the significance of denudation, consolidation and uplift; the efficacy of rivers; the intimate association between the Earth's crust and subsurface forces; the nature and significance of plutonic and metamorphic rocks; and the ongoing nature of petrological creation. Other geological theorists have given us

one or two good points, but none competes with Hutton in the number of sound principles established” (Dean 1992).

Hutton proposed a model of the Earth as a cyclical progression of building the continents starting with the deposition of sediments by the oceans that are compacted and uplifted under the important mechanism of internal heat (this is a heat separate from fire and combustion). Once uplifted the continents underwent denudation (erosion) by meteoric processes supplying fresh soils for human exploitation and transporting the debris to the oceans where it was compacted and uplifted again. In this cycle, he saw the Earth’s history as a string of old and new ‘worlds’ stretching back in time, beyond what he could reasonably calculate from his observations.

Hutton’s Theory of the Earth also deals extensively with the origin of granite and other igneous rocks. He stressed that granite was not a sedimentary deposit, as was held by the Neptunian school of thought (this will be discussed further in the next section), but was an intrusive rock formed in the Earth as the result of exposure to great amounts of heat. His mechanism of heat is one of the original ideas he is credited with introducing in his paper. It is suggested Hutton proposed the idea of heat as a criticism to the idea, held by the Neptunian and other schools of thought, that igneous rock was precipitated from the ocean (Şengör 2001). Another is that it precipitated from his theory of matter, his great interest in chemistry and his acceptance of his friend Joseph Black’s discovery of latent heat (Gestner 1968). Regardless, it was a central idea to his theory and set him apart from earlier natural philosophers of the Vulcanist school that proposed fire in connection with combustion as the main driving mechanism of mountain building.

Perhaps Hutton’s greatest contribution and most acknowledge addition to the field of geology was his concept of time (Dott 1969; Dean 1992). Whereas many of the

postulates of the Earth during Hutton's life time and in the earlier parts of the eighteenth century were limited to the extent of the Mosaic time line of a few thousand years (one reason miracles were cited a great deal for the present configuration of the continents). Hutton went to the extreme of citing a limitless time scale or at least one of which he could not identify the limits. It is implied that Hutton was applying Hume's Law that states "as to past Experience, it can be allowed to give direct and certain information of those precise objects only, and that precise period of time, which fell under its cognizance" (Şengör 2001). Thus, Hutton may have developed his use of uniformitarianism from this idea, and his view of infinite time simply from the realization that we cannot perceive of time that we have not experienced (Şengör 2001). Others attribute his view of time to an extension of Newtonian principles of relentless and continuous mechanics (Kennedy 1992).

In summary, Hutton is recognized mostly for his anticipation of a dynamic Earth, original emphasis on heat, and ideas of deep time. It is worth quoting Hutton's most famous passage here:

"We have now got to the end of our reasoning; we have no data further to conclude immediately from that which actually is: But we have got enough; we have the satisfaction to find, that in nature there is wisdom, system, and consistency. For having, in the natural history of this Earth, seen a succession of worlds, we may from this conclude that there is a system in nature; in like manner as, from seeing revolutions of the planets, it is concluded, that there is a system by which they are intended to continue those revolutions. But if the succession of worlds is established in the system of nature, it is in vain to look for any thing higher in the origin of the Earth. The result, therefore, of our present enquiry is, that we find no vestige of a beginning, --no prospect of an end" (Hutton 1785).

Neptunism vs. Plutonism

Proceeding Hutton were two popular and antithetic schools of thought within geology, Vulcanism and Neptunism. Vulcanism had its roots in the ideas of Nicholas Demarest (1725-1815) and Lazzaro Moro, holding that lava erupted from volcanoes and fire was the main catalyst of change. And, unlike Hutton, Vulcanists sided with the Neptunists that granite was a 'primordial' rock of original crust (Hutton classified it as igneous in origin and younger than the original crust) (Hallam 1989). The Plutonist school incorporated Vulcanism in the late eighteenth and early nineteenth century.

Abraham Gottlob Werner (1749-1817), a charismatic teacher from the strong mining tradition in Germany, popularized the Neptunist school of thought (though it existed in one form or another back to the time of Nicolaus Steno and Gottfried Leibnitz) (Adams 1954). Neptunism proposed a series of episodes in the Earth's history similar to seventeenth century cosmogenic systems (see those of Buffon and Burnet for good examples) with the modern continents being precipitation from suspension of a primitive ocean that subsided turbulently at some time in the past. Also Neptunists held there was no internal fire in the Earth. Werner contributed to the school primarily by advancing his classification system of strata (based on that of Lehman and Fuchsel), attracting and teaching many students through the Mining Academy of Leipzig, and holding with the idea of water as the catalyst of deposition (Hallam 1989).

The differences between the Neptunists and Plutonists dominated geologic debate at the turn of the eighteenth century. The Neptunist versus Plutonist debate essentially boiled down to the break between the recognition of both heat and granite as an igneous rock with the idea of water as the source of all the strata on the globe. Also, the

suggestion of a dynamic system by Hutton conflicted strongly with the passive Earth of progressive change of the Neptunists (Hallam 1989). Werner's students and followers included Robert Jameson, Charles de Luc, von Humboldt, Leopold von Buch, von Schlotheim, Reuss, Kirwan, Greenough, D'Aubuisson de Voisins, de la Metherie, Cuvier (prominent figure in stratigraphy in the early nineteenth century), Brongniart, Maclure, and Eaton (Carey 1988). Those who sided with Hutton, though mostly after his death, were Hall, Playfair, Lyell, Breislak, Fortis, Demarest, and Fichtel (Carey 1988). Students of Werner, especially Kirwan in Ireland and Jameson in Edinburgh, were some of the most outspoken critics of Hutton's theory from the time when it was first published, mostly for its rejection of both the principle Neptunian views and the mosaic tradition (Hallam 1989).

The end of the Plutonian and Neptunian conflict is a little unclear. The recognition of volcanic activity connected to granite in the Auvergne district by some of Werner's premier students was probably one of the decisive blows to the Neptunian School, causing many students and supporters to the side of Plutonism. The new evidence discovered in the Auvergne and other regions (including observations of Mt. Vesuvius) did a lot to disprove Werner's conclusions, which were based on his very limited observations in and around Saxony (Adams 1954). A few staunch supporters remained, such as Jamison, Chair of Natural History at the University of Edinburgh, but for the most part the major ideas of the Neptunian School did not last long beyond Werner's lifetime. However, the debate was grand enough to become entombed into Goethe's famous *Faust* (Adams 1954).

Geology after Hutton, before Tectonics

The conflicting views of the Neptunist and Plutonist schools, though fairly resolved by the first few decades of the nineteenth century, contributed to some of the fundamentally different ideas concerning geologic time to the newly developing generation debate between Catastrophists and Uniformitarianists. Catastrophism took after Neptunism in emphasizing the sudden catastrophic nature of past events, whereas the uniformitarianists heralded by Charles Lyell (1797-1875) held with Hutton's ideas of the long age of the Earth and that present processes in operation are the standard for examining the past (Mason 1962). Catastrophism dominated geologic inquiries in the early 1800's following the French Revolution, until Lyell's *Principles of Geology* in 1830 attempted to synthesize geologic thought up until that point. Lyell emphasized his steady-state views and principles that scientific investigation should be conducted through hypotheses based on observable processes (Bowler 1976).

During the 1800's and early 1900's many advances were made in the field of geology, though no true school or 'theory of the Earth' was dominant. The early part of the nineteenth century was characterized by: a strong progressivism movement; the establishment of the basic geologic time scale (notably derived from the field techniques of William 'Strata' Smith from England); the investigation into the actual age of the Earth using new physical and chemical discoveries; and the development of the cooling-Earth theory. By the second half of the eighteenth century, geology had become well established in university departments around the world and a large amount of data was collected compared to what was known prior to 1800. Also, the discipline was characterized by an increasing divergence, specialization, and decline in communication

with the emergence of paleontology, seismology, magnetics, geology, marine geophysics, etc (Cox 1973).

At the turn of the twentieth century three new and different models were proposed, mostly to try to explain the problem of orogenesis or mountain building (Oreskes 2003). The dominant theories centered around the idea of a simple contracting Earth model, such as the 'drying apple' model proposed by Eduard Suess (1831-1914). James Dwight Dana (1813-1895) proposed a different 'permanence' theory where the continents and oceans were permanent and mountains acted like the seams as the Earth contracted. This version was well received and accepted in the United States. Lastly, the geosyncline theory proposed by James Hall (1811-1889) was linked both to the idea of permanence and the observation that basins subsided along the continental margins. However, the geosyncline theory was fairly weak in explaining the transition of shallow marine sediments into mountain belts (Oreskes 2003).

The different versions of the contraction theory were challenged by both new evidence and new theories that emerged in the first few decades of the 1900's. Evidence from the discovery of radiogenic heat in the Earth and that palinspastic reconstructions of the Alps were too wide to be accounted for by simple contraction, fairly successfully discredited the general theory of contraction (Oreskes 2003). New suggestions and findings by geologists, both in the US and Europe, seemed to support the new theory of isostasy, stating that the continents floated in a substrate like large icebergs. In addition to the idea of isostasy, there were new propositions of continental fragmentation and migration. Most well known were those of Wegener, John Joly, and Reginald Daly in the 1920's. The theory was widely debated at the time, though in the United States its lack

of a mechanism, the general commitment to multiple working hypotheses, its disparities with isostasy, and conflicts with the principle of uniformitarianism as set forth by Lyell all contributed to its general rejection. Instead, the ad hoc isthmus hypothesis of Schuchert and Willis in 1933 was accepted as an alternative to continental drift (Oreskes 2003).

Plate Tectonics: Evolution of an Idea

Plate tectonics theory has its roots in the ideas of continental drift and sea-floor spreading. Its advantages are in its stronger theoretical base, unification of all the major sub-disciplines within geology, elegance and explanative abilities, and far reaching predictive capabilities (Allegre 1999). The main postulates of the theory are as follows:

Postulate 1. “The plates are internally rigid but are uncoupled from each other. At their boundaries two plates may pull apart, or slip one beneath the other, but within the plates there is no deformation.”

Postulate 2. “The pole of relative motion between a pair of plates remains fixed relative to the two plates for long periods of time.”

Theorem 2.1 “Transform faults between two plates lie along segments of concentric small circles centered on the pole of relative motion of the two plates.”

Theorem 2.2 “The pole of relative motion for two plates may be found by constructing perpendiculars to local segments of transform faults. The common intersection of the perpendiculars is the pole.”

Theorem 2.3 Euler’s Theorem: $v = \omega R \sin \theta$ Where v is the particle velocity of a point of the Earth, ω is the angular velocity of a vector tangential to the Earth’s surface, R is the radius of the Earth and θ is the angle between the polar north and the latitudinal position of the point on the Earth’s surface.

(Cox 1973)

The evolution of plate tectonic theory occurred for the most part within the 1950s and 1960s between four major institutions of research and benefited from the contributions of over a dozen key scientific players in four general lines of research. The four central institutions involved were Princeton University, Cambridge University, the Lamont Geological Observatory (Palisades, NJ), and Scripps Institution of Oceanography (La Jolla, CA). In addition, scientists from Canada, Berkeley, CA and Canberra, New Zealand made important contributions. Key players in the conception of plate tectonics were Arthur Holmes, Harry Hess, Griggs, Dietz, Bruce Heezen, Maurice Ewing, Richard Doell, Allen Cox, H.W. Menard, Elsasser, E. Irving, S.K. Runcorn, Vine, Matthews, T. Wilson, Raff, Mason, Sykes, and many others. It was between 1962 and 1968 that four main lines of research merged together into plate tectonics. The different lines of research include: the mapping of the sea floor (echo sounding); the measuring of the sea floor's magnetic rock record using proton precession magnetometers; the establishment of the Earth's magnetic pole reversal history from rock residual magnetic memory and advanced Potassium-Argon radiometric dating; and the precise locating of Earthquakes using worldwide recording stations (Cox 1973).

There are some key points to take into consideration when looking at the historical outline of plate tectonics. Much of the conclusions reached in the 1960's would not have been possible without the wealth of new data and information amassed about the ocean floor, magnetic reversals, earthquakes, etc. Communication between different scientists, such as Harry Hess and R. Dietz concerning the model of sea-floor spreading, and chance meeting between leading scientists at both Cambridge and Berkeley during the 1950's, aided in the exchange of ideas and the rapid culmination of diverse lines of

evidence. Early discoveries on the road to the plate tectonics model, like that of Harry Hess in 1946, Runcorn and Irving in 1956, and Oliver and Issacks in 1966, all falsified parts of earlier theories and supported components of plate tectonics (see Appendix A for details). In 1963, Vine and Matthews as well as L.W. Morley arrived independently at the conclusion new crust formed at mid ocean ridges. Also, the predictions of the tectonic model, that symmetric magnetic stripes should form around spreading ridges and that transform faults existed, were confirmed in the 1966 *Eltanin* magnetic profile of the East Pacific rise and a in paper by Sykes in 1967 concerning transform fault focal mechanisms. Lastly, by the 1970's plate tectonics had become a widely accepted tool for explaining geologic phenomenon within the general community.

Discussion

Thomas Kuhn: establishing a working model

In establishing a framework for comparing the historical events surrounding the publication of James Hutton's *Theory of the Earth* and the advent of plate tectonic theory within geology, it is worth exploring the basic philosophical models that exist for the propagation of scientific knowledge. Specifically, the ideas of Thomas Kuhn as his receive the widest attention and application in geology. It is hoped that by exploring the Kuhnian model a good fit for events in the history of geology will be found.

Thomas Kuhn published *The Structure of Scientific Revolution* in 1962 in which he outlined his theory of scientific development. In it he described different stages he termed 'pre-paradigm', 'normal science', and 'revolutionary' periods within a scientific discipline. The pre-paradigm state exists within the early history of a discipline before any sort of dominant paradigm is established. It is characteristic for the subject to be

explored from widely different points of view and for radically conflicting schools of thought to exist within one subject area. The establishment of a paradigm marks a more mature scientific stage. A paradigm is “universally recognized scientific achievements that for a time provide model problems and solutions to a community of practitioners” (Kuhn 1962). A paradigm is oftentimes been described as a ‘super-theory’ incorporating the content of a diverse collection of laws, methods and worldviews along with its function of providing a focus and guide for continued scientific inquiry (Gutting 1980).

Following the establishment of a paradigm there is a period of normal science where a discipline works within the framework of the paradigm at ‘problem solving’ such as exploring its possibilities, using it to make and test predictions, and developing new applications of the theory (Greene 1980). The last stage is the ‘revolution’ of a new paradigm after a ‘crisis period’ within the scientific community. A crisis occurs when enough unexplainable anomalies accumulate under the old paradigm in the process of normal science that its functionality within a discipline is questioned. A new paradigm is “brought about by the achievements of a scientific genius that defines and exemplifies a new conceptual and methodological framework incommensurable with the old” (Greene 1980). The new paradigm has stronger explanatory power, predictive capabilities, and elegance. The transition is supposed to take place over a very short time period during ‘a Gestalt switch’ where it becomes accepted by the consensus of the scientific community.

Kuhn’s framework includes more radical components when compared to other historians and philosophers of science. Like his contemporary Sir Karl Popper, Kuhn rejects scientific progress simply through accretion, emphasizes revolutionary processes, and opposes characteristics of classical positivism (Kuhn 1974). Science moves via a

step-wise pathway once a discipline is established with long periods of ‘normal science’ followed by shorter times of crisis and revolution (the geologist might see this as a case of punctuated equilibrium). Kuhn focuses on the influence of a social or an irrational factor as intrinsic in the development of scientific theory, noting the role played by the acceptance or denial of a theory within a scientific community as well as the dogmatic tendencies of older generations of scientists (Wisdom 1980).

Application to Hutton

In analyzing the historical content of Hutton’s contribution to the science of geology it is worthwhile to review a few key observations from his era. In the late 1700’s, science and religion were dynamically and directly connected with one another, especially in respects to investigations into the Earth. Also, most of the geologic theories reflected the biblical account of time and Neptunist ideas. Hutton’s *Theory of the Earth* was one of the notable exceptions, introducing the importantly recognized concepts of deep time, a dynamic Earth, and the mechanism of heat removed from fire. Hutton’s theory helped established the Plutonist view of the Earth that was directly opposed to Neptunism. However, at the time of its publication and in the years following Hutton’s death, his theory had very little direct impact and only limited acceptance (it wasn’t until Playfair’s *Illustrations of the Huttonian Theory* in 1802, which expressed Hutton’s ideas much more clearly than he himself did and removed much of the emphasis on ‘Grand Design,’ that it was received by a wider audience).

Using the Kuhnian model to evaluate the Hutton’s theory, one notices immediately the differences between the two models. At the end of the eighteenth century, although there was a great deal of controversy between different theories of the

Earth, it was not characteristic of the ‘crisis’ stage having no established paradigm in which anomalies could be recognized. It bears little resemblance, either, to the establishment of a dominant paradigm as the majority of the geological ‘community’ rejected Hutton’s theory. One might be able to see the Neptunist school of thought as a paradigm at the time, but the fact that they received such strong opposition from both the Vulcanist and Plutonist camps suggests that this is not the case. The idea of normal science operating at the time must also be discarded due, again, to the lack of a dominant paradigm to establish any focus to the scientific inquiries.

The best fit for this episode in history into the Kuhnian system would be in the stage of ‘pre-paradigm’ before the establishment of any dominant ‘super-theory’ or of a mature community of scientists. The great diversity in thought, the directly conflicting ideas, and the appeals to ad hoc hypotheses, all fit Kuhn’s description of this stage. The only real difference occurs when the religio-philosophical outlooks of natural theology and mechanical natural philosophy are taken into consideration. These ways of looking at the world could possibly be seen as guidelines whereby investigation into the world was motivated and focused. Hutton himself, proposed a ‘Grand Design’ view of the world as the continuation of a good, and habitable environment for human life. He stated, “truth and error are forced to struggle together in the progress of science; and it is only in proportion as science removes erroneous conceptions, which are necessarily in the constitution of human knowledge, that truth will find itself established in natural philosophy” (Hutton 1795). Here we see not only Hutton incorporating the element of truth, not recognized by Kuhn to be the aim of science, but also stressing the idea of

natural philosophy. This raises issues whether the Kuhnian model is the best one in this circumstance.

Application to Plate Tectonics

Plate Tectonics seems, on the outset, to fit very well into the framework Kuhn supplies for scientific revolutions. A strong similarity to the ‘crisis’ stage, where the unexplained anomalies of a dominant paradigm reach a critical point, is seen in the inability of conflicting theories (diffuse sea-floor spreading, isostasy and contraction theory of the Earth) to inclusively explain either mountain belt evolution or any of the new findings concerning magnetic, seismic, sonar, and bathymetric data. Kuhn’s revolution stage categorizes the subsequent advent of plate tectonics, within a very short time period and its quick but wide acceptance within the geologic community, very well. As Cox states, “the development of plate tectonics, although describable in terms of several theories of the history of science, fits the pattern of Kuhn’s scientific revolutions surprisingly well” (Cox 1973). Also it should be recognized there was a great deal of social influence (a component stressed by Kuhn) on the development of plate tectonics. Conversations and communication between wide groups of scientists were crucial to the melding of the general lines of investigation into a central theory (Cox 1973).

There do appear to be some substantial differences with Kuhn’s model when looking at the establishment of ‘normal’ science prior to the ‘crisis-revolution’ period and when considering some wider implications of Kuhn’s definitions of a paradigm. When examining geologic thought leading up to plate tectonics it is hard to identify one central all encompassing theoretical framework that guided the investigations of scientists. There were traditions, at least in the United States in the early twentieth century, of not

one dominant theory, but multiple working hypotheses of isostasy and contracting-Earth. For 'normal' science Kuhn requires that 'problem solving' occur within an established paradigm. It does appear from the continued research of geologist, between the time of Hutton and plate tectonics, that there was general 'problem solving'; it is debatable whether any of it was done within a dominant paradigm. The only possible resolution would be if one saw application of the principle of uniformitarianism and empirical scientific research combined as the structure for investigation. Even though these basic principles may have provided a loose guideline, it is unclear that they achieve the depth and extent of a Kuhnian paradigm.

Conclusion

In an examination of both the advent of Hutton's *Theory of the Earth* and plate tectonic 'revolution' in the context of Kuhnian philosophical framework of scientific knowledge, important parallels are brought to light. Both historic events incorporate elements from Kuhn's system; however, there are some substantial deviations. Considering the essence of Kuhn's theory is to explain most of scientific history, it is reasonable to conclude that its application to geology is relevant and useful.

From the time of Hutton up until the present, this paper reaches the conclusion it is the Kuhnian model which best describes the evolution of geology. It allows for the construction of a working model of historic development for the discipline and acknowledges the important contribution of social influences on science. If one interprets the time of Hutton as falling within the pre-paradigm stage, the wide divergence in views, strong connection to religious values and explanations become clear

as a representing the initial stage of establishing geology as a valid scientific institution. Hutton, then, in his application of the basic uniformitarian principle that ‘the present is the key to the past’ (without the rate constraints of Lyell) and his recognition of the importance of time, specifically deep time, for geology, becomes a key figure in forwarding the principles by which field work and investigations into the Earth were conducted in the following two-hundred years. Although it will not be assumed he established the first paradigm, it is argued his recognition as the “Father of Modern Geology” is deserved. His propositions were the first step in the long pre-paradigm interval before the revolution of plate tectonics.

Tectonics is the first and only theory that has had wide acceptance, ideological dominance, strong mathematical rigor, simple elegance, powerful predictive capabilities for all areas of geology, and unifying power among segregated areas of investigation. Its progression from its early form as the hypothesis of sea-floor spreading to its now widely accepted postulates seems to fit neatly into the ‘revolution stage.’ The only major digression as noted earlier is the involvement of many contributing scientists instead of just one key player (though it could be argued in favor of attributing the final piece of the puzzle to Vine and Matthews). So, if it is the case that tectonics is the first working paradigm in geology, the years preceding it should all fall into the pre-paradigm stage. This conclusion seems substantiated, as prior to plate tectonics there was not one single dominant theory within geology, only generally accepted principles of investigation and multiple working hypotheses.

Working from Kuhn’s framework the first great anomaly of plate tectonics has been the inability of geoscientists to conclusively identify the nature of the mechanism

driving the movement of the plates. Theories have been suggested as early as the 1800s, with ideas of mantle convection dominating the discussions. Recently the idea has caught on of self-driven plates. Current investigations aim at defining the contact between the lithosphere and the underlying mantle to try to shed some light on this issue. Because of an inability to directly observe and sample this deep boundary, investigations have all been conducted remotely by geophysical techniques, geochemistry, secondary observation, and through mathematical and computer modeling. Also, there have been attempts to identify effects on intercontinental basin subsidence (depression usually due to thermal relaxation of the crust or increased over-load) by way of the self-driving plates using detailed computer modeling.

Perhaps the largest gaps left unexplored or untouched by Kuhn's model when it is applied to geology, are the important notions of deep time and the historical element of the discipline. Deep time has been important from Hutton's era to the present. It is an element in the study of the Earth that complicates current 'normal science' stage by our inadequacies in testing it or failure to take it into account. The main route for investigation into the Earth is done by confirmations from laboratory and other empirical data to support naturally observed features. Though there are many earth processes that occur on the same time scale as laboratory experiments of a few seconds to a few years, there are just as many known to occur in the Earth on the order of a million years or more, where no direct observation is possible. Integrating processes and events operating on both the short time scale of an Earthquake and the long interval of rock deformation, is one unique element of geology separating it from other fields of science such as

physics, chemistry, or biology. Kuhn's model does not explore the complexities created by deep time.

Another break from the Kuhnian model in geologic history is its significant historical component. Geology borrows heavily from chemistry, biology, physics, and mathematics in exploring the natural world. The use of historical perspective and progression in geology separates it from the traditional empirically driven sciences Kuhn uses to establish and illustrate his theory. The singular models nature supplies geologists to base their theories on, such as the Earth and other planetoids, confines the field of geology in its application. The conclusions reached are historical in nature and are not known to be universally applicable as yet. In this way there are separate geologies of the Earth and Mars. Almost every example used by Kuhn comes from sciences whose paradigms are universal in nature. In this way, geology has a recognizable connection to the social sciences of history and anthropology. The freedom allowed geologists in formulating a sequence of history for the Earth, and in trying to decipher the mechanisms at work in the past, gives the discipline an added dimension not considered by Kuhn.

This paper raises some questions to suggest further lines of investigation into geology's history. The first two questions are: 1) to what extent has uniformitarianism influenced the development of the discipline between the time of Hutton and plate tectonics; and, 2) how could uniformitarianism be explained within the context of Kuhn's model and the conclusions reached by this paper. The next major question to address is whether geology is still in a stage of revolution or if it has moved onto the daily process of 'normal science.' Such questions can only be addressed with further research and

future advances in geology. These lines of inquiry all, however, are outside the range of this paper.

In conclusion, the history of geology is best described by the Kuhn's theory of scientific development, with plate tectonics representing the first paradigm in the discipline and the time period preceding its conception (including the late eighteenth century of James Hutton) representing a pre-paradigm and crisis stage. It does, however, deviate in detail and complexity from such a general model. Geology's incorporation of deep time and its historical foundations are not readily placed under Kuhn's ideology. In both Hutton's time as in plate tectonics today, scientific knowledge continues to progress and expand in scope.

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Appendix A.

Plate Tectonics timeline

The 1920's:

- 1920's Alfred Wegener put forward his version of continental drift to reconcile the idea of isostasy with evidence from historical geology. His hypotheses were widely circulated in the 1920's and 1930's, especially in Europe (Oreskes 2003).
- 1923 H. Nakano (and P. Byerly in 1926) developed first-motion studies (aka "focal-mechanism", "fault-plane") that originally led geophysicists away from plate tectonics but later proved to be central to establishing the theory (Cox 1973).
- 1929 Motonari Matuyama was the first to investigate the timing of magnetic reversals while at Kyoto Imperial University. He deduced that the Earth's magnetic field had reversed polarity early in the Pleistocene, determining an age that still stands as fairly accurate. Unfortunately at the time, he was greeted with silence, as geophysicists had not developed a coherent theory of the geomagnetic field's origin (Cox 1973).
- Harold Jeffereys criticizes Wegener's continental drift theory based on geophysical evidence that the oceanic basalt layer was too strong for the continents to move through (Cox 1973).

The 1930's:

- 1931 Arthur Holmes presented some concepts of ocean-floor spreading using the analogy of conveyer belt carrying continents. He erred in seeing the new crust formation as diffuse (Cox 1973).
- 1939 Griggs was one the first to recognize the concentration of Earthquakes along or near ocean trenches (Cox 1973).

The 1940's:

- 1944 Harry Hess's *History of the Ocean Basin*, influenced by Griggs' work in 1939, provided a model of the crust carried passively on an overturning mantle due to thermal convection. The idea of the model was coined 'sea-floor spreading' by R.Dietz in 1961. Hess used both geological and

geophysical data to disprove and support some ideas of mantle convection as well as successfully arguing for the creation of new crust at ridges (Cox 1973).

1946 Harry Hess, a key figure in marine geologic research leading to plate tectonics, discovered flat-topped volcanoes he termed 'guyots' while conducting basic research in the military on the USS *Cape Johnson*. They helped to demonstrate that the sea floor is active and provided evidence the sea floor could be spreading (Cox 1973).

1949 Hugo Benioff brought earlier ideas together in concluding Earthquakes originate on great faults that dip under the continents with the deep quakes recorded being the result of the down warping of the oceanic block (Benioff Zones are named after him) (Cox 1973).

The 1950's:

1950's Bruce Heezen and Maurice Ewing recognized that Earthquake epicenters were concentrated on the median valley of mid-ocean ridges. This was important research for focusing attention on ridges as tectonic zones (Cox 1973).

Also during this time period the WWSSN (world wide standardized seismograph network) of over 125 seismic stations around the world was installed, though it was initially sponsored to discriminate nuclear tests for enforcing a nuclear test ban treaty (Cox 1973).

Most of the geomagnetic reversal time scale dating was done by USGS at Australian National University (Cox 1973).

John Verhoogen, Richard Doell, Brent Dalrymple, Sherman Gromme, Allen Cox, Ian McDougall all crossed paths at Berkeley (Cox 1973).

The invention of the proton precession magnetometer allowed remote sensing of Earth's magnetic field in ocean basins. The magnetic stripes detected showed alternating areas of high and low magnetic intensity in bands across the entire sea floor (Cox 1973).

1952 H.W. Menard and R.S. Dietz discovered Pacific fracture zones that were later recognized to be associated with lateral faulting. This was only really significant after plate tectonics was realized, when they were used to plot the motion of the plate (Cox 1973).

1953 Hospers worked on dating of youngest magnetic reversals since Cretaceous, gaining data confirming Matuyama's conclusions (Cox 1973).

- 1955 Bullard and Elsasser developed a theory of the geomagnetic field's origin by the interactions of fluid motions and electrical currents in core of molten iron (Cox 1973).
- 1956 Maurice Ewing and Bruce Heezen discovered narrow rift valleys in the crest of ridges at ocean centers that were later interpreted, according to Carey in 1958 and Heezen in 1956, as narrow block sinking under tension as the sea floor spreads (Cox 1973).
- E Irving and S.K Runcorn from Cambridge found evidence of drift since the Paleozoic between North America and Europe from paleomagnetic data, reviving interest in the continental drift hypothesis (Cox 1973).
- Runcorn and Irving demonstrated either polar wandering or continental drift occurred showing that the idea around since George Darwin (not Charles or Erasmus Darwin) that of the Earth being too rigid for continents to move was erroneous (Cox 1973).
- 1958 Tsuneji Rikitake proposed two-disc feedback dynamo model to explain the geomagnetic field's origin (Cox 1973).
- S.W. Carey saw large-scale crustal deformation as pervasive and continuous that, although in error, strongly influenced J. Tuzo Wilson who correctly saw deformation as restricted to narrow mobile belts between rigid plates (for the most part) (Cox 1973).

The 1960's:

- 1961 Doell and Cox developed the first tentative time scale for reversals (Cox 1973).
- 1963-7 Groups at Menlo Park and Canberra amassed data from around world that provided the foundation for recognition of short polarity events and a detailed time scale of magnetic reversals back to 4.5 Ma (Cox 1973).
- 1963 Sykes discovered that seismicity was restricted along the fracture zones to areas between offsets. Vine and Matthews combined Hess's theory with research on reversals to come up with a simple explanation for the magnetic stripes. They realized the mid-ocean ridge in Indian Ocean was normally magnetized while adjacent seamounts were reversed, prompting the idea new sea floor formed continuously at mid ocean ridges and were magnetized by current Earth's field (Cox 1973).

- Canadian L.W. Morely independently came to the same conclusion of Vine and Matthews after reading papers by Raff and Mason (1961) and Dietz (1961), on magnetic stripes and sea-floor spreading respectively, though he could not get his work published. Morely's difficulty getting published was probably a result of general objections to the hypothesis that magnetic stripes lent support to sea-floor spreading. Objections cited included: the actual evidence of irregular rather than the predicted symmetric magnetic profiles; the need of a narrow production zone only supported at the time by sporadic land volcanism; and the lack of an accurate time scale for comparisons (Cox 1973).
- 1964 The Alaskan Earthquake in combination with the research of George Plafker convinced scientists that Earthquake on the thrust fault occurred at a low north-dipping angle (Cox 1973).
- 1965 Plafker recognized thrusting as the dominant fault motion along circum-Pacific trenches. Wilson published his classic paper recognizing transform faults and explaining Sykes' earlier observations (Cox 1973).
- Vine and Wilson advanced their original model with better available data citing that the magnetic anomalies resulted from thin a basalt layer over the serpentine and dike rocks (Cox 1973).
- 1966 Oliver and Isacks interpreted Earthquakes as being generated in slabs of rigid lithosphere thrust into the softer asthenosphere, noting the consistency with the new plate tectonics model. By this time there was enough data that the magnetic profiles and time scale fit well together. The National Science Foundation's *Eltanin* "magic profile" of East Pacific rise modeled symmetrical magnetic stripes as the theory predicted converted many to the idea of plate tectonics. A paper by Vine supported previous hypotheses as correct (Cox 1973).
- 1967 Sykes published results finding focal mechanisms for Earthquakes along ridges as consistent with spreading from the ridges helping to convince the geologic community of the transform faults predicted by Wilson (Cox 1973).
- Walter Elsasser from Princeton developed a theory to explain how stress transmitted over great distances by a rigid plate resting on a soft underlying layer (Cox 1973).

This was also the banner year for plate tectonics with the publication of works by Morgan, McKenzie and Parker, Oliver, Sykes, and Isacks uniting the major findings of the different lines of research into a general set of rules and constraints (Cox 1973).