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FOREWORD

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FOREWORD

Earth history is rooted in the very questions we asked as kids and continue to ask ourselves today. From pondering why the sky is blue to questioning human life on Earth, there is history to be dissected, research to be conducted, and even more questions to be asked. With each and every discovery in Earth history, we have learned more about our home than one could ever imagine! Today, we know that the Earth is 4.54 billion years old. However, figuring out the age of the Earth did not occur overnight. Understanding and discovering protons, electrons, and neutrons were the first steps in identifying the existence of isotopes. The process of radiometric dating had to have been developed, tested, and validated as a proxy to measure the age of rocks. The oldest surface rocks on Earth were sought after to confirm the Earth's age and to test and confirm that the Earth was at least 4 billion years old. Coming to this conclusion involved decades of research, trial and error, and the development and testing of concepts. It was a *process* to answer the question of "How old is the Earth?", and the scientific process will be required to address the remaining questions of Earth History.

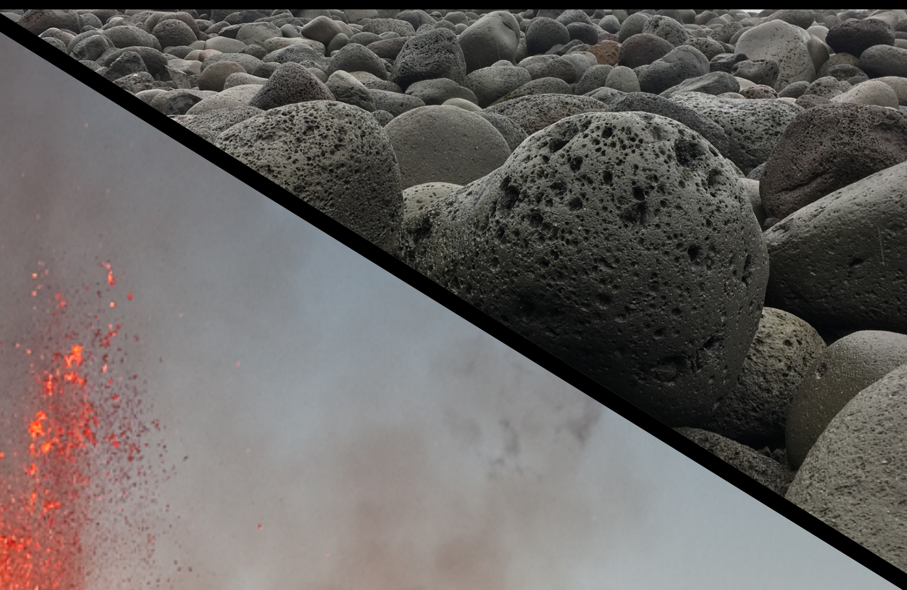
This History of the Earth book written by the Integrated Science Class of 2020 focuses on blending history, philosophy, science, and culture to understand the processes leading to how we understand our world. It beautifully tells the story of how we interpreted Earth systems to be in the past, what we know to be true today, and what is projected for the future. This book is engaging, thought-provoking, and enjoyable. With topics ranging from alchemy, evolution, mineralogy, to paleontology, there is something for everyone! Enjoy this book, as the writers enjoyed working on it!

Supriya Singh

M.Sc Candidate (McMaster alumna, 2017)

WE HAVE THE
CAUSES UNDER OUR
FEET.

- IMMANUEL KANT



CHAPTER 1

A Changing Landscape: Earth Processes & Land Formation

As we begin our journey to uncover the history of the Earth, we must first understand the nature of Earth itself. The Earth is our home. And like every brick or stucco home of human labour, the Earth is the result of the labours of many different geological processes. Each glaciation, each volcanic eruption and each attachment and detachment of continental plates is a renovation and these numerous and yet still-ongoing renovations have resulted in our dynamic home. Due to the brief time stamp of human existence on Earth's lifetime, we have not witnessed many of the large-scale changes that have molded the Earth into its current state. Instead, we must rely upon an amalgamation of scientific evidence provided by seismological data, geomagnetic measurements, fossil evidence and geological theories to piece together the chronicles of the Earth's past.

Each puzzle piece provides a glimpse into an arcane yet explorable past. However, knowledge of this past was not uncovered overnight. The scientific discoveries of numerous decades have built upon each other. When an individual forms a hypothesis, the individual indirectly and unknowingly chooses to contribute to an ever-changing truth. Every hypothesis challenges a preconceived notion that supports the status quo. Questions and arguments result in the gathering of data and evidence for proof, which ultimately amount to conclusions founded in empirical and theoretical knowledge. Ultimately, these conclusions allow us to better understand processes that shape our planet.

Science and the arts are inextricably linked and the relationship between the geologic processes that govern the Earth and the culture of populations is no exception. Societies too influence scientific thought and innovation, as acceptance of novel ideas regarding the Earth's formation and activity are first critiqued by the general population. Theories are cemented with further collaboration from scientists of different backgrounds and expertise, who contribute their remnant to humankind's understanding of the globe.

It is in this chapter that we will explore how the human race began to understand the evolution of present-day Earth's formation and the ramifications these geological movements had on culture, migration and civilization.

Volcanology at Mount Vesuvius: A History

For many years, researchers and historians have studied the infamous demise of the ancient Roman cities Pompeii and Herculaneum in AD 79 (Figure 1.1). Thousands were killed under the power of the 1200 m tall volcano Mount Vesuvius. It was as if the cities were frozen in time under layers of volcanic ash and lava. Upon excavation, they became famous for their insights into ancient societies (Jashemski and Meyer, 2002). However, Mount Vesuvius itself warrants interest beyond the devastation it brought to ancient Rome. Mount Vesuvius has been the subject of scientific inquiry since 64 BC (Scandone, Giacomelli and Gasparini, 1993). Knowledge of the volcano has progressed greatly over time, yet modern earth scientists struggle to predict when Mount Vesuvius might erupt next.

Pre-AD 79 Eruption

As with any field of science, our understanding of volcanology is constantly evolving. But even without the advent of modern technology, the writings of ancient Greek and Roman scholars imply that they understood the volcanic nature of the mountain to some extent prior to the famous AD 79 eruption. The Greek historian Diodorus Siculus was the first to name the mountain Vesuvius from the Greek word for smoke, after observing that the mountain showed remnants of the fire "which once raged in those ancient times" (Scandone, Giacomelli and Gasparini, 1993; Stylianou, 1998). The Greek geographer Strabo also described Mount Vesuvius: "...the summit… looks ash-coloured, and it shows pore-like cavities in masses of rocks that are soot coloured on the surface, these masses of rock looking as though they had been eaten out by fire: and hence one might infer that in earlier times this district was on fire…" (Scandone, Giacomelli and Gasparini, 1993). However, most citizens took no note of these observations as Mount Vesuvius had been inactive since approximately eighth century BC.

Even Strabo's unusually advanced insights into the nature of the mountain failed to acknowledge the grave hazards associated with living so close to the volcano. In the two decades leading up to the AD 79 eruption, earthquakes were common in the regions surrounding Mount Vesuvius (Jashemski and Meyer, 2002). The discovery that seismic activity tends to trigger volcanic eruptions was centuries away. These precursor earthquakes occurred with such frequency that the inhabitants of Pompeii and Herculaneum became accustomed to the tremors and dismissed their potential foreshadowing of the tragic eruption to come (Scandone, Giacomelli and Gasparini, 1993).

Pliny the Younger

Most of what we now know about the AD 79 eruption is attributed to the accounts of one eruption survivor named Pliny the Younger, the nephew of Pliny the Elder (known formally as Caius Plinius) who died during the eruption when his curiosity brought him fatally close to the exploding volcano. The elder Pliny was an esteemed

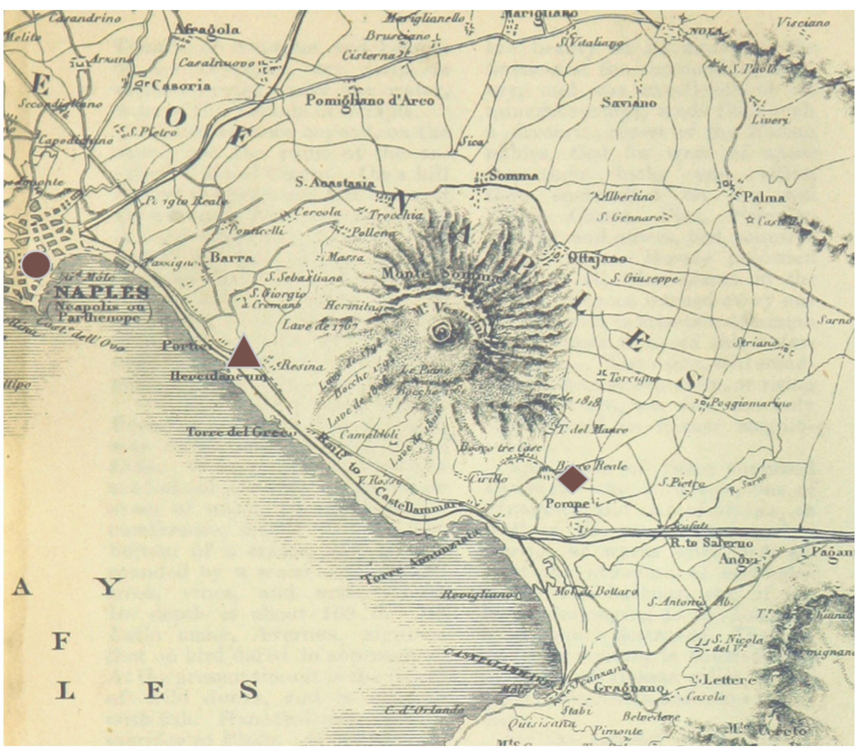


Figure 1.1. Map of the ancient Roman cities surrounding Mount Vesuvius (Pompeii, Herculaneum, and Naples – as it is now known – are indicated by the diamond, triangle, and circle respectively).

academic with a distinguished military career. He was so highly regarded by the community that the historian Cornelius Tacitus attempted to learn more about the circumstances of his death decades later (Hockey, 2014). As the closest surviving relative, Pliny the Younger was asked by Tacitus to explain what happened on the night of the eruption. The letters written by the younger Pliny carefully recount the chronology of events that night. Part of what makes Pliny's writings so valuable is that he seemed to recognize the importance for objectivity and accuracy in his telling of the havoc wreaked by the volcano; to Tacitus he wrote disdainfully of people "… who added to the real perils by inventing fictitious dangers … though their tales were false they found others to believe them" (Jashemski and Meyer, 2002).

However, it is important to acknowledge the potential shortcomings of this record of events. The letters between Pliny and Tacitus are the only known detailed accounts, so it is impossible to corroborate this information with other sources. The 25-year gap between the eruption and letters suggests that some details were recounted to him by other people (Jashemski and Meyer, 2002). Nonetheless, it is an interesting insight into the beginnings of scientific communication and the understanding of geologic processes.

AD 79 Eruption

Pliny the Younger wrote that a large cloud appeared above the volcano on the day of the eruption. The cloud, composed mostly of ash, grew quickly. Unknown to the Vesuvians, emissions of volcanic gases (mostly carbon dioxide) had likely been leaking from the volcano since as early as AD 62, when flocks of sheep described by Seneca died mysteriously on the slopes of Mount Vesuvius (Picard, 2000). Soon after the appearance of the cloud, hot ash and pumice from the volcano began falling on the communities below while tremors shook the land (Jashemski and Meyer, 2002).

As the tremors continued, the young Pliny describes seeing bolts of lightning over the volcano, but did not know that static electricity was accumulating and subsequently discharging in the clouds of ash. Eventually, the sky became so thick with ash that Pliny described feeling "… as if the lamp had been put out in a closed room" (Jashemski and Meyer, 2002). Pliny observed the receding of the sea from nearby beaches, leaving sea creatures exposed helplessly on land. This phenomenon was most likely the result of tsunamis generated by the seismic tremors. After several hours, the air cleared enough for some dim sunlight to pass through. Only a stump of a mountain remained where the proud cone of Mount Vesuvius had stood just one day earlier (Jashemski and Meyer, 2002).

The trauma associated with the AD 79 eruption of Mount Vesuvius had long-lasting effects on Vesuvian culture and the perceived importance of geological phenomena. The Italian word 'vulcan' meaning 'burning mountain' was introduced shortly thereafter (Hansen, 2004). This change in language indicates a shift in ancient Roman culture following the AD 79 eruption. Conversely, it was not until 1610 that the word 'volcano' appeared in the English language, since volcanism was not an imminent threat in most English-speaking parts of the world (Oregon State, 2018).

Best estimates place the death toll for the AD 79 eruption at approximately 2000 (Gore, 1984). In Pompeii, most of these casualties would have been the result of pyroclastic density currents: hot blasts of volcanic particles which move up to 100 km/h along the ground due to their relative high density to air (Branney and Kokelaar, 2002). It was these hot blasts which resulted in the unusually detailed preservation of Pompeii and its inhabitants; blackened skeletons demonstrated the full force and high temperature of the surge, leading to many

Figure 1.2. An excavated Pompeiian street. Light pumices and ash falls on Pompeii in AD 79 allowed for easy removal of sediments by archeologists (Deiss, 1989). The nature of the deposition preserved many details regarding ancient Roman culture.

instant deaths (Maiuri, 1958).

The excavation of Pompeii lead to a great acquisition of knowledge about ancient Roman life (Figure 1.2). Historians now know that the streets of Pompeii were filled with shops, bars and workshops filled with terracotta jars and decorated with painted signs of gods (Maiuri, 1958) (Hansen, 2004).

Such entombed objects would eventually aid scientists in understanding the composition of pyroclastic density currents.

Figure 1.3. Evening at the Gulf of Naples*, an 1888 painting of Naples which depicts Mount Vesuvius in the background. The volcano was not included in artistic renderings of the city until after the 1631 eruption (Gasparini, Giacomelli and Scandone, 1992).*

Subsequent studies of the buried cities tend to focus primarily on Pompeii, rather than Herculaneum. This is due to the nature of deposition at the time of eruption – Pompeii, which was downwind of Vesuvius, was covered in light pumice and ash while Herculaneum was engulfed by dense lava flows. In the hundreds of years following the eruption, scientists and archaeologists favoured research at Pompeii due to the ease of excavation (Deiss, 1989).

Subsequent Eruptions and Advances in Understanding

As decades passed following the AD 79 eruption, the true volcanic nature of the mountain remained somewhat of a mystery. Vague observations and commentary continued: Aelius Galenus (noted Greek physician and philosopher) (Bernhoft, 2008) remarked in AD 172 that "the matter in Vesuvius is still burning" (Scandone, Giacomelli and Gasparini, 1993).

Mount Vesuvius erupted nine times between AD 79 and 1631, but none so severe as the eruption that destroyed Pompeii and Herculaneum (Lobley, 1889). The years AD 203 and 472 were faced with eruptions that destroyed new cities built over Pompeii and Herculaneum (Gasparini, Giacomelli and Scandone, 1992). Over the next 600 years, the only eruptions took place in AD 512, 685, and 993 (Lobley, 1889). They were recorded in Procopius' *History of the Wars: The Gothic War* where he wrote, "If you peep in [Mount Vesuvius] you may see fire, which ordinarily keeps in, not troubling the people … soon after it casts out far away a large quantity of cynders … [man] hath no means to save his life" (Procopius, 2015). In AD 1036, lava flows reached as far as the sea. After this time, three minor eruptions occurred in AD 1049, 1138, and 1139 (Lobley, 1889).

An eruption of Mount Vesuvius in 1631 was the next major horror in this region; the estimated death toll was 6000 (Gasparini, Giacomelli and Scandone, 1992). At this time, the crater of Vesuvius had become home to wild boars and cattle. It was observed that the crater became filled with volcanic matter level with the brim (Rolandi, Barrella and Borrelli, 1993). Witnesses described that the mountain appeared to liquefy, flowing away like water. After 10 minutes of continuous ash movement, a tsunami hit the shores. The only survivors were those in elevated areas (Lobley, 1889). The lava emitted from this eruption now forms the substratum between Italian regions Resina and Torre del Annunziata (Lobley, 1889).

Before the 1631 eruption, artistic representations of Naples did not include Mount Vesuvius. This was partially because many Vesuvians were unaware that the mountain was in fact a volcano. After many years of quiescence, the cone was covered in large trees. However, after the large eruption, paintings of Naples began to include Mount Vesuvius (Gasparini, Giacomelli and Scandone, 1992) (Figure 1.3). This reflects how Vesuvius became a widely-recognized landmark of public interest and concern.

In the 1700s, James Hutton introduced the concept of uniformitarianism (Sigurdsson et al., 1999). His claims regarding natural laws and geological processes shed light on the mechanisms by which the eruptions at Mount Vesuvius occurred. Volcanoes, according to Hutton, "… should be considered as a spiracle to the subterranean furnace" (Sigurdsson et al., 1999). Mount Vesuvius, it seemed, existed as a testament to the hostile, molten nature of the Earth's core.

The volcano continued to garner intrigue from the surrounding communities. In 1844, Ferdinand II – the new monarch of the Kingdom of the Two Sicilies – established the Royal Vesuvian Observatory. It was the first ever permanent volcanic monitoring station and, in the mid-1860s, its importance in the advancement of volcanology was affirmed. In 1865, seismological equipment at the observatory (including a Lamont's apparatus, designed to detect changes in the magnetic field caused by ground motion) began to detect an increase in subterranean shocks (Giudicepietro et al., 2010). The tremors culminated in a prolonged eruption in 1867 where Mount Vesuvius spewed lava for an entire month (Hoffer, 1982). Luigi Palmieri, the director of the observatory at that time, is now recognized to have conducted the first organized scientific inquiry into the behaviour of the volcano. Palmieri kept careful records of the lava flows, noting that every 12 hours the flow increased while the ash and steam clouds were more forceful. He corresponded these periods to the tidal cycles, and concluded that Mount Vesuvius was influenced by the gravitational pull of the moon (Hoffer, 1982).

Palmieri would later describe his theory of cyclic volcanic activity, proposing a three-stage model: a period of dormancy following an eruption, lava flows which build up the cone, and finally another explosive eruption (Hoffer, 1982). He proposed tentative time scales between four and thirty years as the periods for these cycles, revising and adjusting his predictions following subsequent eruptions in 1872 and 1906 (Hoffer, 1982).

By the turn of the century, volcanology began to emerge as an increasingly prominent field in the earth sciences. Scientists at the Vesuvian Observatory measured lava flows and seismic activity using newly engineered equipment. During the 1906 eruption, observations noted conditions which bore a striking resemblance to those claimed by Pliny the Younger nearly two millennia prior. Even in this period of technological and scientific advancement, many of the techniques used for the collection of data were still quite dangerous for researchers. Dedicated volcanologists often had to risk their own safety by ascending the volcano during eruptions in displays of seemingly foolhardy bravery reminiscent of Pliny the Elder (Hoffer, 1982).

In 1936, the physicist Giuseppe Imbò became the director of the Vesuvian Observatory (Schick, 1999). Imbò's scientific contributions arose from his strong interest in the relationships between seismology and volcanology. Using entirely non-electronic seismographic equipment, he meticulously recorded the subterranean activity near the volcano over prolonged periods of time. It was concluded that volcanic tremors arose from the rhythmic pulses of the magma column against the walls of the volcano. Imbò also progressed an understanding as to the roles of pressure and buoyancy of magma during an eruption (Hoffer, 1982).

The most recent eruption to date occurred in 1944. At this time, Imbò was still actively studying the volcano despite the recent occupation by the U.S. Army and Air Force who had taken over most of the observatory with their radio-receiving equipment. The military presence eventually benefited Imbò when he managed to convince one of the U.S. Staff Sergeants to drive him up Mount Vesuvius in a military jeep during the eruption. Imbò managed to measure the temperature of the flowing lava, which he later used to gauge its composition and speed (Hoffer, 1982).

Ongoing inquiry continued regarding Mount Vesuvius, despite its decades of silence. A 1979 study suggested the possibility of a 17000-year Vesuvian cycle (Bonasia et al., 1985). Other publications in 1982 and 1990 attempted to reconstruct the processes which likely occurred during the AD 79 eruption by analyzing the deposits found in Pompeii (Sigurdsson, Cornell and Carey, 1990; Sigurdsson, Cashdollar and Sparks, 1982).

The analysis of every Vesuvian eruption has furthered an understanding of volcanic processes. Knowledge, experience, and recorded observations have built upon each other to help the entire society – historians, earth scientists, and local citizens alike – in understanding these previously hidden volcanic mechanisms.

Modern Methods for Eruption Prediction

Mount Vesuvius is a somma stratovolcano, meaning that it was built gradually up as numerous small lava flows solidified on the surface of the cone. Modern potassium-argon dating methods indicate that Mount Vesuvius is at least 300 000 years old, based on lava drilled from the base of the volcano (Jashemski and Meyer, 2002). Even after hundreds of thousands of years, the intricacies of its subterranean processes continue to elude volcanologists. It is essentially impossible to definitively predict the occurrence of eruptive events. Nonetheless, researchers have developed various methods to monitor volcanic activity and attempt to spot changes which may be indicative of eruptions to come. These methods seek to alert nearby residents of any possible dangers, issue timely evacuations, and minimize damages associated with eruptions.

Figure 1.4. Seismic monitoring devices such as the one pictured here provide continuous data about subsurface vibrations at Mount Vesuvius (Chouet, 1996).

Seismology

Volcanic seismology is the study of vibrations resulting from flowing magma, hydrothermal movement, and other mechanical processes (Chouet, 1996). The goal is to understand the physical and dynamic properties of magmatic systems, and to observe changes over time. This field is an essential component in the monitoring of Mount Vesuvius, which began in the 19th century when Luigi Palmieri first installed seismic monitoring equipment (Hoffer, 1982). Since then, the Mount Vesuvius seismological monitoring station has expanded to include 18 seismic stations and 7 infrasound microphones (Orazi et al., 2013). These stations cover the area near the volcanic edifice and attempt to record seismic events greater than M1 on the moment magnitude scale (Dobran, 2006).

Seismic monitors aim to provide continuous snapshots of subsurface structure. This is done by collecting data in the form of reflection (cross-sectional views of dip and strike directions), shear wave (compression waves, lithology and fractures in rock) and refraction (tectonic movement) (Badley, 1985). The data is transmitted using technological solutions based on radiomodem and Wi-Fi radio links (Orazi et al., 2013). The Italian National Seismic Network also collects seismic information in addition to that collected from Mount Vesuvius, compiling both sources into a large database called 'EarthWorm' (Giudicepietro et al., 2010).

Elemental Analysis

Magma is mainly composed of oxygen, silica, and aluminum at varying concentrations, but many other secondary elements contribute to our understanding of volcanic function. Radon is of particular interest, as its concentration is affected by fracturing in volcanic surfaces at the caldera and summit faults (Cigolini et al., 2001). The release of radon tends to be observed as a precursor to volcanically-induced earthquakes, which commonly precede eruption events. During incipient fracturing of porous media, fluid pressure builds up, releases, and radon migrates to the surface (Cigolini et al., 2005). These radon anomalies are carefully monitored at stations located near Mount Vesuvius (Cigolini et al., 2001).

Monitoring Ground Deformation

When magma moves through chambers below a volcano, changes in pressure result in subtle deformations of surrounding rocks near or on the surface of the Earth (Sparks, 2003). Changes to magma movement can often foreshadow eruptions; monitoring these deformations are thus indicative of activity and can help researchers to predict eruptions, allowing for early evacuation.

Ground deformations can be monitored using GPS satellites, measuring ground tilt, or by using electronic distance measurements (EDM) (Sparks, 2003). There are multiple ways by which EDM can be employed. One method involves the recording of time taken for the transmission and return of a light signal (commonly infrared) in order to determine the distance between a set location near a volcano and a measurement station (Rüeger, 2012; Sparks, 2003). Minute changes in distance caused by ground deformations are easily detected by this approach.

Generally, ground deformations cannot be used as a sole metric for eruption prediction. Deformations have previously been known to occur due to magma movements unrelated to eruption. Similarly, some volcanoes have been observed to erupt without any preceding deformation (Sparks, 2003).

Measuring Volcanic Gases

Monitoring volcanic gases is an effective way of not only understanding subsurface chemical reactions, but additionally identifying a potential eruption. Gases, such as sulfur dioxide and carbon dioxide, are dissolved in high pressure magma chambers (Williams-Jones et al., 2006). As magma ascends, the gas pressure increases past that of the overlying rock – this is what causes an eruption (Giggenbach, 1975). These gases are emitted at the surface, which can be dangerous for any people or animals nearby and can leading to climate change in the surrounding environment (Giggenbach, 1975). Gas geochemists collect data via direct sampling, remote sensing and measuring dissolved volatiles in magma (Williams-Jones et al., 2006). The technology of remote sensing is another new method for monitoring gases. Remote sensing equipment, such as correlation spectrometers, were initially developed for measuring industrial pollutants, but now can be employed for the measurement of sulfur dioxide concentrations in volcanic plumes (Williams-Jones et al., 2006).

The Future for Mount Vesuvius

Since the tragic demise of Pompeii and Herculaneum, the future safety and prosperity of Vesuvians has been a top priority for the Italian Government. Currently, the city of Naples (located 12 km away from the volcano) has a population of over 3 million people, over 600 000 of whom live in the red zone (less than 10 km away from the crater) (Government of Italy, 2007). Both regions would be in the direct path of deadly pyroclastic flows (Figure 1.5). Inhabitants of these areas rely on technologies that can identify signs of an eruption.

With the advent of advanced monitoring systems comes the risk of false alarm (Dobran, 2006). False alarms are detrimental to the communities as they encourage popular distrust and may contribute to slower responses to real calls for evacuation. Approximately 80% of citizens in the area are unaware of how to react during an eruption, and are ignorant to the significance of indicators such as smoke or seismic activity (Dobran, 2006). Changes in public education are underway to alter the perceptions of Mount Vesuvius.

Figure 1.5. Urban development at the base of Mount Vesuvius would likely be destroyed by lava flows in any future eruptions.

Recent estimates expect that the severity of the next eruption would be of Volcanic Explosivity Index (VEI) 4, compared with the VEI 6 eruption that destroyed Pompeii and Herculaneum (Suzuki, 2017). These indices ensure global standardization and help researchers determine severity and appropriate response measures.

Evacuation instructions are available to the public, detailing alert levels and relocation measures. To accurately make evacuation decisions while preserving the wellbeing of the nation, Volcanic Risk Metrics (VRMs) can be used. This set of cost-benefit mathematical equations consider individual and societal risks involved when deciding to evacuate a region. Financing the re-establishment and rehabilitation of the Mount Vesuvius region in the aftermath of an eruption would be extremely expensive. Drastic decisions about infrastructure changes may enable engineers, politicians and scientists to compromise the historical integrity of the region in an attempt to remedy the situation. Even more so, they would have the capacity to destroy a populated area that is not easily alterable economically, socially, or ecologically (Dobran, 2006). It is hoped that with the extensive monitoring and measuring techniques, the infrastructural changes can be minimized.

The Government of Italy is now establishing a national park around the volcano to prevent further red zone development, and offers a financial incentive for the relocation of current residents. Still, many citizens remain in their hometowns despite the imminent threat of Mount Vesuvius. Hopefully ongoing advances in volcanic monitoring systems will continue to improve the accuracy with which eruption precursors can be detected in order to safely evacuate nearby residents.

17th Century Geomagnetism: A Dynamic History

Much like the phenomenon itself, the study of geomagnetism has a very dynamic history. Ranging from philosophical views to experimental methods, the scientific approach to geomagnetic study has evolved dramatically over time. A magnetic field is present in any region of space which contains charged particles in motion (Serway and Jewett, 2014). The Earth is surrounded by a magnetic field, called the geomagnetic field, which acts as an essential defence against cosmic radiation (Serway and Jewett, 2014). As a result, human beings at every moment are immersed in observable evidence of magnetic phenomena. So unsurprisingly, long before we understood the true dynamic nature of the field, magnetic materials and their sources were a topic of wide debate.

Figure 1.6. The ferrimagnetic mineral magnetite, commonly referred to as lodestone.

Early human interest in geomagnetism revolved around compasses, which were formed of the mineral lodestone, also known as magnetite (Serway and Jewett, 2014). As seen in Figure 1.6, a lodestone is a ferrimagnetic substance which attracts small pieces of iron (Serway and Jewett, 2014). Between the first and sixth century floating compasses appeared in China, consisting of a floating magnetized needle sitting inside a hollow straw on water (Courtillot and Le Mouël, 2007). Jonkers (2000) attributes the introduction of the dry compass in Europe to approximately the mid-twelfth century. Though it still remains a topic of debate, it is the opinion of many historians, including Smith (1992) that the use and design of compasses probably evolved and were invented independently in both China and Europe during these early years.

Origins of Magnetic Philosophy

It is well agreed upon that the earliest dated mention of the lodestone in ancient literature was by Thales of Miletus in c.624-548 BCE (Roller, 1959). His ancient remarks, referred to by Aristotle (384-322 BCE) reference the attractive nature of iron in the presence of the lodestone and appear incidental in the discussion of a greater topic. Although Aristotle and Plato were similarly unconcerned with the nature of the lodestone, they used its known power in analogies to support their philosophical theories (King, 2010). Despite Plato's rejection of the idea that the lodestone and iron exhibited attraction, the modern use of this term to describe magnetic phenomena is thought to derive from his writings (Roller, 1959). Plato compared the force between the lodestone and iron to the circumstances where a primitive man may feel he is being pushed, pulled, and urged towards a fundamental need (Roller, 1959). In his writings *Timaeus* (c.360 BCE), Plato records that magnetic matter contained no drawing power, and thus something else must be at work, though he clearly had no interest and formed no hypothesis regarding the source by which these forces were derived (Roller, 1959). The men mentioned above were a few of many natural philosophers before the 15th century who discussed geomagnetic phenomena including Theophrastus, Pliny, and Dioscorides (Gilbert, 1600). Though our comprehension and documentation of the periods and men discussed above are sparse, we can confidently ascertain that the existence of lodestones and their attractive magnetic properties were widely known.

Up until the turn of the 16th century, natural philosophers attributed the observable magnetic phenomena on Earth, to divine, celestial origin. One of the first people to challenge these traditional methods of philosophy was a man by the name of William Gilbert. Gilbert, an accomplished physician and member of the Royal Society, sought to revolutionize natural philosophy, and in 1600 published *De Magnete* (Roller, 1959). Gilbert's publication provided the driving force behind the isolation of the field of magnetism from the broader philosophical context used by the men before him (Thompson, 1903). He writes in the author's preface (Gilbert, 1600, p.xlix), "To you alone, true philosophers, ingenious minds, who not only in books but in things themselves look for knowledge, have I dedicated these foundations of magnetic science - a new style of philosophizing."

Beginnings of Modern Science

Gilbert introduces *De Magnete* (1600) by outlining his intention to not only share his theories and experiments, but to also offer a critique into the methods of scientific analysis his peers and other learned men of the time used. Gilbert gives credit to Plato, Aristotle, Theophrastus and Dioscorides (among others), for their contributions to the recordings of the lodestone's ability to attract iron (Gilbert, 1600). However, he discerned that these men indulged in fictitious theories which left them ignorant to the majority of the lodestone's properties. As revealed by Gilbert's words (1600, p.03): "[these men] write and copy all sorts bout ever so many things which they know naught." In *De Magnete*, Gilbert (1600) declares that where these men went wrong was their lack of practical research into objects in nature, and their neglect of magnetic experiments.

Gilbert was not the alone in his search for novel scientific methodology and approaches. Towards the end of the 16th century, the opinions of scientists and scholars took a significant shift away from the former philosophy of celestial magnetism and tended to conform with the concept of terrestrial magnetism (Gubbins and Herrero-Bervera, 2007). This shift established the concept of magnetic poles existing on the Earth's surface (Gubbins and Herrero-Bervera, 2007). One specific discovery that helped bolster this change in mentality was that of magnetic inclination, which describes the angle between the horizontal and the Earth's magnetic field lines (Gubbins and Herrero-Bervera, 2007). First theorized by German mathematician Georg Hartmann in 1554, it was around 1580 when the first quantifiable measurements of magnetic inclination were recorded using the first inclinometer, a rotating magnetic needle developed by a compass builder named Robert Norman, as seen in Figure 1.7 (Gubbins and Herrero-Bervera, 2007). The discovery of magnetic inclination offered a mathematical perspective of visualizing the Earth's surface, provided the first hints to the internal source of geomagnetic phenomena and inspired the idea of using measurements of Earth's magnetic field as a navigational aid (Gubbins and Herrero-Bervera, 2007).

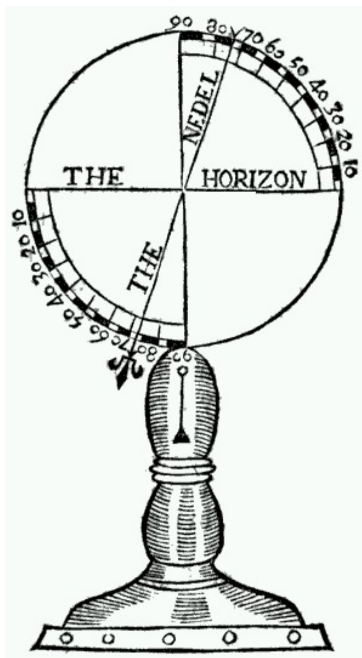


Figure 1.7. An illustration of a dip circle drawn by Robert Norman displaying angles of magnetic inclination between the horizon and a rotating magnetized needle.

In the late 16th century, these advancements caught the interest of an English mathematician named Henry Briggs. Briggs is regarded as one of the most renowned mathematicians of his time due to his conversion and invention of John Napier's original mathematical logarithms into the common base 10 logarithms used today (Nowlan, 2017). His work and writings on logarithms were one of the principal factors leading to the eventual widespread recognition and utilization of logarithms throughout Europe, with some of today's more famous scientists such as Kepler and Newton among those influenced by Briggs' work. Although Briggs is less renowned for his navigational work, his publications including *A Table to find the Height of the Pole, the Magnetic Declination Being Given; Tables for the Improvement of Navigation;* and *A Treatise of the Northwest Passage to the South Sea, Through the Continent of Virginia and by Fretum Hudson* all reinforced his position as a leading academic, bridging the gap between mathematical theory and practice in navigation (Faulkner and Hosch, 2017). Briggs' greatest contribution to the discovery and understanding of Earth's magnetic field, however, was his creation of a table of magnetic inclination, or dip, for each degree of Earth's latitude, assuming an axial dipole (Gubbins and Herrero-Bervera, 2007). The resulting effect of this work was the final persuasion that the origins of Earth's magnetic field came from deep within the planet, rather than on or above its surface.

Geomagnetic Earth Analog

Elaborating on Briggs' conclusions, in book one of *De Magnete* (1600), Gilbert further establishes the "terrestrial poles" as a place of importance. He introduces his method of experimental investigation, by imagining an analog Earth he refers to as terella; a strong, solid, uniform, and flawless lodestone that contained the same polar properties as observed on Earth.

Gilbert's terella is the key to his contributions in geomagnetism. In order to develop experimental evidence using this analog, Gilbert set a coordinate system for the terella, dividing it symmetrically with respect to the poles (Gilbert, 1600). This map provided one of the earliest semi-quantitative approaches to identifying the magnitude of magnetic phenomena at each point on the terella (Tauxe, 2010). Gilbert insisted that the region which surrounds a lodestone, what he called the "sphere of influence", as seen in Figure 1.8, is of intense interest. He noted in *De Magnete* (1600, p.305) that if a magnetic material is placed at a point near a lodestone, along a circle drawn concentric with the centre of the loadstone, it will behave as though it were on the surface of an imaginary lodestone bounded by the circle. Though Gilbert's concept of the sphere of influence is quite different from our modern conception of the magnetic field, his emphasis on the importance of the concentric region around the terella undoubtedly influenced the concepts of magnetic fields introduced by Faraday in the 19th Century (Roller, 1959).

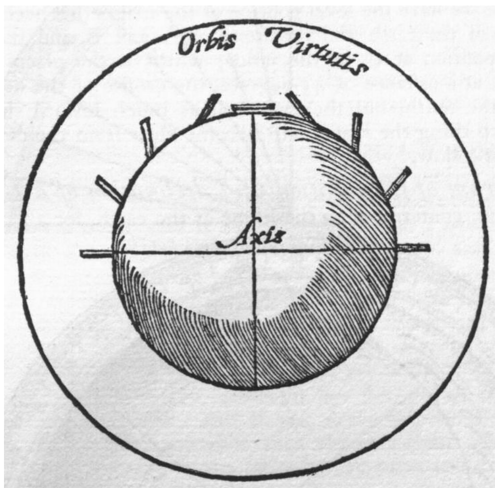


Figure 1.8. The "sphere of influence" about a spherical lodestone (terella) as described by Gilbert.

Like many of his predecessors, Gilbert subscribed to the notion of form; that which gives being to matter (Gilbert, 1600). He hypothesized that the majority of objects in the universe possessed a peculiar magnetic property which he referred to as magnetic form. Through induction, Gilbert concluded that if the pieces of Earth are lodestones, then the Earth itself is definitively a lodestone (Thompson, 1903). In this statement alone, Gilbert revolutionized the study of geomagnetism, being among the first to identify the source of magnetic phenomena as the Earth itself (Thompson, 1903).

Prominent Rival Theories

Gilbert's main prediction that the Earth is in fact the source and "mother" of all magnetic phenomena was highly controversial at the time in which he lived. Elaborating on his emphasis on the importance of terrestrial poles versus the so called "celestial poles", Gilbert introduces for the first time the notion that the Earth is in fact not the immovable centre of the universe (Stern, 2002). This in itself was a highly disputed and controversial theory, however it allowed Gilbert to extend his studies into the realm of cosmology. Using the small magnetized analogous model ball terella, Gilbert made a number of observations which he felt could be extended to the scale of the Earth and thus were pivotal to cosmological science (Roller, 1959). From these speculations, Gilbert provided theories of great interest to his contemporaries and successors (Stern, 2002). Gilbert's analogy of the lodestone Earth is recorded to have informed the physical framework which Johannes Kepler is rumoured to have used in his own studies of planetary motion (King, 2010). Galileo was highly critical of Gilbert's arguments, as he found them to be loose and lacking evidence. However, he saw in them some support for the Copernican world-system, in which the sun exists at the centre of the solar system and the Earth and other planets orbit around it (King, 2010).

Niccolò Cabeo, a Catholic priest and member of the religious order of the Jesuits, published his book *Philosophia magnetica* in 1629, in which he discusses and disputes Gilbert's theories and hypotheses. As a religious man, Cabeo held the belief that the Earth was the centre of the universe, and as such he repudiated Gilbert's hypotheses concerning Earth's motion and the cosmological implications which accompanied it (Gubbins and Herrero-Bervera, 2007). Although this may seem as if Cabeo held his theories and claims on top of religious bias, he was very interested in investigating the causal nature of phenomena. Much like Gilbert, Cabeo renounced the traditional Aristotelian style of natural philosophy, stressing his interest in the causes of natural phenomenon and the experimental evidence behind his claims (King, 2010). Though Cabeo's views and assumptions may have been partial, his use of mathematical tools and demonstrative approaches paved the way for our modern understanding of experimentation and evidence-based theories (Gubbins and Herrero-Bervera, 2007).

In the late 16th century, a mathematician named

Guillaume le Nautonier published *Mecometrie de l'eymant*; his own account of measuring the magnetic field of the Earth, a theory which rivaled Gilbert's *De Magnete* (Courtillot and Le Mouël, 2007). Inspired to help mariners navigate, le Nautonier's work contained approximately two hundred pages of tables of magnetic inclination and declination values as functions of longitude and latitude in both hemispheres (Courtillot and Le Mouël, 2007). However, unlike Gilbert's preference of the experimental method, le Nautonier favoured calculation and geometry from hypotheses as per Greek tradition (Turner, 2011). In his publication, he claimed that the Earth itself was similarly magnetized like a lodestone, however due to his lack of experimentation his claims were not perceived to be as legitimate and compelling as those found in Gilbert's *De Magnete* (Turner, 2011).

Le Nautonier disagreed with Gilbert's theories because he found that his arguments contained inconsistencies when trying to explain magnetic declination (Turner, 2011). Gilbert had described how the elevation of the topography of the Earth was miniscule in comparison to its overall size in his first book, however, he had used these same topographic parameters when evaluating substantial magnetic declination angles in his fourth book, thus contradicting himself (Turner, 2011). The biggest issue le Nautonier took with Gilbert's model was his assumption of Earth's magnetic field being parallel to Earth's rotational axis (Courtillot and Le Mouël, 2007). In his own work countering Gilbert's theory, he developed the first tilted dipole model, where the magnetic moment was tilted at an angle of 22.5°, which would have allowed mariners to navigate more effectively using his measurements of magnetic inclinations and declinations (Courtillot and Le Mouël, 2007).

The Great Debate on Variation

Gilbert's third induction concerning variation was likely where he began to deviate from his experimental technique of philosophizing and ultimately his argument began to collapse. Gilbert's weakness was his belief in empirical laws and his desire to derive theories based on order and simplicity (Roller, 1959). His understanding of the fundamental character and form of magnetic phenomenon lead him to prescribe to simple relationships between the angles of dip and latitude (Roller, 1959). He attributed the variation and declination of a needle compass to irregularities on the surface of the Earth (Stern, 2002). Gilbert believed that earlier writers and scientists were ignorant when observing and analyzing variation, and that compass needles deflected toward continents only because magnetic attraction was attributed to the mass of the Earth (Stern, 2002). He derived his theory of variation from his conceptual scheme of magnetism and data from seamen (Gilbert, 1600). His theory concluded that variation at a given place on the Earth's surface is unchanging with time, and that the source of variation from the meridian was ultimately the inaccuracy of data compilation (Stern, 2002). In regards to the variation from the horizontal, he made feeble attempts to account for declination as a source of reorientation towards conformity rather than failure (Roller, 1959). After Gilbert's passing, there was great debate by the early science community about the source and variability of geomagnetic variation. Many of Gilbert's successors were left unsatisfied with his theory of permanent magnetization, though no one disputed that which Gilbert lacked in field observations, he made up for in his rationale (Thompson, 1903).

In 1634, a number of years after Gilbert had passed, a man by the name of Henry Gellibrand published his own geomagnetic theory and observations which effectively disproved Gilbert's notions of permanent magnetization. Gellibrand was a successor to Edmund Gunter, a distinguished mathematician who spent his life's work measuring and observing magnetic declination (Courtillot, 1988). Unfortunately, Gunter passed before he was able to confirm any of his measurements. Gellibrand instead took it upon himself to validate the observations made by his predecessor. He intended to meticulously compile, verify, and duplicate previous measurements completed over the course of decades, by Gunter and other seamen, in order to provide substantiated evidence for this topic of intense debate at the time (Courtillot, 1988). Gellibrand's observations, published in his book *A Discourse Mathematical on the Variation of the Magneticall Needle* (1635), provided the first concrete evidence of secular variation, the deflection of the magnetic meridian from the terrestrial. Through precise measurement and observation, he deduced that the magnetic effect generated by the Earth could change over the course of decades (Courtillot, 1988). Though Gellibrand made no attempt to hypothesize on the source of this variation he found that the average variation was 4°05'E, and that magnetic declination occurs worldwide in random patterns (Gellibrand, 1635). This marked a firm end to Gilbert's notion of fixed magnetic declination and spurred a new era of geoscientific discovery, inspiring scientists to throw more energy into magnetic data collection, eventually leading to the identification of the nature and source of the phenomenon.

One of those scientists was Edmond Halley, a famous astronomer best known today for the comet named after him (Chapman, 1943). In 1696, Halley published his theory claiming that the Earth was made up of an inner and outer core, as seen in Figure 1.9, with both layers having their own magnetic dipoles (Chapman, 1943). In this theory, the behaviour of Earth's magnetic field could be explained with the movement and rotation of the inner core in a westward direction. Although this model was eventually discarded, it inspired many more similar theories that emerged hundreds of years later involving a molten, moving inner core undergoing complex magneto-hydrodynamic processes (Chapman, 1943).

Figure 1.9. A portrait of Halley proudly displaying his two-cored model of the magnetic field.

Halley's greatest contribution however, was his attempt to solve the longitude problem in nautical navigation. Although latitude was now relatively simple to calculate, determining a precise longitude measurement still evaded the brightest minds. Since knowing both latitude and longitude was essential in order to reduce loss of life and ships at sea, governments of maritime powers at the time offered significant rewards to anyone who could solve the problem (Chapman, 1943). Halley approached the problem by attempting to map lines of constant magnetic variation over Earth's surface and relate them to longitudinal lines (Chapman, 1943). After sailing across much of the Atlantic Ocean on more than one expedition, it was in 1701 when Halley was finally able to chart the world's first isogonic map, showcasing lines of constant magnetic declination across the Atlantic Ocean (Chapman, 1943). This map and future charts made by Halley proved utmost useful for navigators and were extensively used for a period of about 40 years, before more accurate marine chronometers were invented toward the end of the 18th century (Chapman, 1943).

The observations and evidence produced by these men in the 17th century, not only influenced the field of geomagnetism, but made huge contributions to scientific theory. Though many of their claims were flawed, these philosophers founded the very approaches by which their errors were corrected.

Modern Measurements of Secular Variation

As alluded to by Halley and Gellibrand, the geomagnetic field is a highly dynamic phenomenon; the field at Earth's surface at any moment deviates substantially from any geocentric axial dipole model or any known reference system (Brown, 2017). As a result of this continuously changing phenomenon, modern scientists are working on new and innovative ways to accurately measure variations in the magnetic field. Scientists have identified the main source of the geomagnetic field as the metallic liquid outer core of the Earth, where convection currents drive the geodynamo generating electrical currents in the mantle (Brown and Korte, 2016). More recent developments have determined a number of external sources of the magnetic field. There exist electrical current systems in the ionosphere and magnetosphere which generate rapidly changing magnetic fields on the ground and in the near-Earth environment (Chulliat et al., 2016). More generally, the concept that the geomagnetic field changes through time is referred to as secular variation.

Paleomagnetic Records

For over half a century, scientists have been studying paleomagnetism, the field of research interested in the properties of past geomagnetic fields. These studies provide both an empirical and theoretical basis for long-term geomagnetic field behaviour models using ferromagnetic materials, which exhibit magnetic moments (Butler, 2004). In an ideal environment, the local geomagnetic field at the time of rock formation influences the natural remanent magnetization of the minerals (Kristjansson, 2013). In other words, rocks which exhibit any of the primary forms of natural remanent magnetism, record the direction of the geomagnetic field at their time of formation, and can retain this information over geologic time (Kristjansson, 2013). Data from continental margin sediments is still often used for dating and extracting paleomagnetic records from widespread locations (Chulliat et al., 2016). The extraction of sedimentary cores and analysis of past paleomagnetic records has proved quite useful in allowing the reconstruction of a paleomagnetic secular variation record that spans thousands of years (Walczak et al., 2017). Having a paleomagnetic transcript of our past is extremely beneficial because it allows researchers to predict changes and variations that may occur in the magnetic field in the future, including phenomena such as pole reversals. Although the interpretation of these records is highly complex, as they can be greatly influenced by sedimentation rates, transport mechanisms, and lithogenic sources, the path to the future is always made clearer with a good understanding of our past (Butler, 2004).

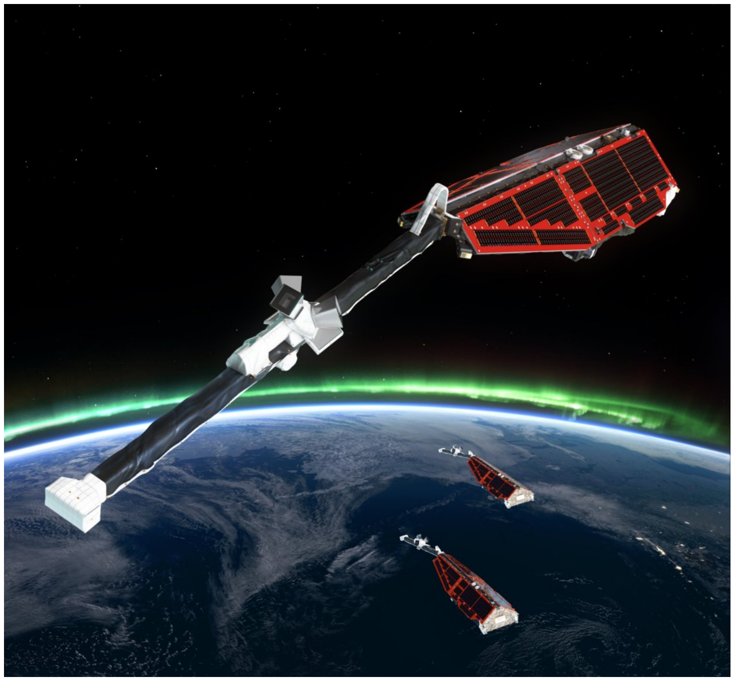


Figure 1.10. The ESA's Swarm satellites measure signals from both internal and external magnetic sources, allowing scientists to study the complexities of geomagnetic variation.

Space-based Observations

There has been a significant shift in recent years toward the use of satellites to model and categorize both internal and external geomagnetic sources. Space-based observations allow for improved modelling of the shape and intensity of the geomagnetic field through time, with models demonstrating the temporal and spatial variation of the field from the core's surface to the satellite's altitude (Chulliat et al., 2016). This drastically improves the modelling of several field sources, isolating the mechanisms responsible for the generation of the time-varying magnetic field. In 2013, the Swarm mission was launched by the European Space Agency, consisting of three satellites with an orbital configuration designed to improve the separation of geomagnetic sources, as seen in Figure 1.10 (Stolle, 2018). The main objective of this mission is to provide the best survey to date of the geomagnetic field and its temporal evolutions (Olsen et al., 2016). Ground-based observations have been phased out in recent years due to the evolution of the spacecraft era (Chulliat et al., 2016). However, modern magnetic observatories remain extremely important, providing a good portion of the data used in global models of the main core field (Love and Chulliat, 2013). Observatories use fluxgate magnetometers to measure the three components of the geomagnetic field vector with incredible accuracy in real time (Love and Chulliat, 2013). The compilation of ground and space-based observations provide better resolved data to improve models of secular variation and ultimately improve our understanding of the geomagnetic field.

The perplexing nature of secular variation has proven to be a challenging and highly debated phenomenon throughout human history. Measuring secular variation not only helps with navigation and the prediction of geologic behaviour as the philosophers of our past discovered, it also allows us a glimpse into the Earth's future. The journey doesn't end here; the application of recent advancements in modelling the magnetic field are not limited to our own planet. Since a magnetic field is essential to life on Earth, understanding its essence and history may just propel us forward in our goal of habitable exoplanetary discovery.

The Development of Gradualism by Ancient Greek Philosophers

Ancient Greece, a conglomerate of independent populations, is often recognized solely for its cultural successes and brilliant thinkers. Many think of Ancient Greece as one large empire, when in fact, it was a region made up of diverse city states with different systems of government and cultures (Martin, 2013). Athens, one of the most prominent city states, had large periods of unrest in its political history, but by 500 BC, it had reordered its political structure into a democracy. However, it was not until the Persian wars in the 490s and 480-479 BC that the Greek city states joined together, forming an unprecedented coalition to meet the military might of the Persian Empire (Martin, 2013). This led to what is now called the Golden Age of Athens, named for its period of heightened prosperity and its intellectual movement.

Figure 1.11 Portrait of Plato, a Greek philosopher and the founder of the Academy in Athens.

Preceding this Golden Age, great thinkers such as Anaximander, Pythagoras and Xenophanes began to challenge the polytheistic beliefs of the late 6^{th} and early 5^{th} centuries (Martin, 2013). They questioned the existence of the gods and proposed the counter-argument that nature was governed by rules instead of divine whims. The Golden Age led to the flourishing of the intellectual movement in Athens, and the migration of a group known as the Sophists, to the area in 450 BC (Martin, 2013). This group had explanatory theories on subjects ranging from the cosmos and atoms to natural phenomena. Members were impious with their questioning, which prompted fear from the general populace. Socrates, another great philosopher of the time, was opposed to the Sophists due to his conflicting ideas on how knowledge should be gathered and applied (Moore, 1925). This age of study was interrupted by the culmination of tension between Athens and Sparta, resulting in the Peloponnesian War in 431 BC. It was in this atmosphere of opposing views and tension that the first evidence of theories of gradualism appeared. Gradualism is a modern term used to explain theories which suggest that the Earth undergoes slow, incremental change by fixed processes that occur the same in the past as they do in the present (Simpson, 1970). This idea is also known as, and is now synonymous to, uniformitarianism. Theories of gradualism evolved throughout the time of Greece, one idea building the previous to form the beginnings of an explanatory framework for understanding the Earth's processes.

Plato: 428 – 348 BC

Plato, born in Athens in 428 BC, was a strong figurehead for Western philosophy, in particular, the natural sciences (Taylor, 2001). Quick-minded and with a passion for learning, he received his education as a student of Socrates at the age of 20. Plato continued to study under Socrates for a decade, until his teacher's death in 399 BC (Taylor, 2001). Inspired by Socrates' death, *Phaedo* emerged, a dialogue in which Plato discussed the events and controversy surrounding Socrates' execution which was carried out by the Athenian courts for crimes of impiety (Millett, 2005).

In *Phaedo*, supplementing discussions on death, the immortal soul, and myths concerning the afterlife, Plato provided novel ideas concerning calamity through volcanism (Plato, 360 BC a). Volcanism, believed to be a cataclysmic event, was a recurring phenomenon that was used as validation for the idea of periodic catastrophes, which Plato thought were designed to cleanse the Earth (Plato, 360 BC a). This belief in intermittent, intense events is remarkably similar to the modern principle of catastrophism, a theory which posits that geologic time is marked by long periods of pause interrupted by fleeting and violent events (Baker, 1998).

In spite of an emphasis on sudden, intense events, which define catastrophism, Plato's investigation into slow-moving volcanic and subterranean mechanisms provided an indirect foundation for gradualism. Geological structures, such as volcanoes, were thought to have originated from vast, everlasting underground rivers of fire and mud that were distributed throughout subterranean tunnels (Plato, 360 BC a). These underground passageways were also used to explain the circulation of elements such as water, fire, and air through the Earth's interior. *Phaedo* described that as water moved, it took on the properties of the landmass it passed. This movement remained gradual, as time was required for elements to travel long distances, and accumulate to alter landmasses.

Plato's ideas concerning geology and prolonged change also implicitly indicate that the Earth's processes are dynamic rather than static. Plato alleged that bottomless waters shifted in a rhythmic back and forth lull from a Central Tartarus - a piercing channel through the Earth filled with water (Plato, 360 BC a). Similarly, subterranean water movement provided the origin of surface seas, rivers, lakes, and streams. This supplied visible, above-ground evidence for changes to the Earth, which could be used by observers to note the gradual changes necessary for the description of uniformitarianism. Many of these dynamic processes were described in Plato's *Timaeus* using 'vitalism' – a theory that paralleled anatomical processes of the human body and aligned them to processes observed on Earth (Plato, 360 BC b). Vitalistic descriptions divided the Earth into microcosms set within the universe that served as a macrocosm. The tides, a microcosm set within the macrocosm of the Earth, were described as moving to a continuous rhythm that mimicked human breath. This directly correlated to organicism – the belief that the universe was alive and well-structured, similar to a living organism (Coulter, 1976).

In the years following Socrates' death, by many accounts, Plato is reported to have travelled to neighbouring city states where he was exposed to different facets of knowledge through varying intellectual schools of thought (Bluck, 2013). In his later years, Plato moved to southern Italy where he studied with Orphic and Pythagorean systems and doctrines, which aligned with his later theories of vitalism and sphericity (Cornelli, McKirahan and Macris, 2013). Plato taught for 40 years prior to his death in 347 BC, emphasizing order in the world provided by a knowing rational god (Martin, 2013). Rationality and logic were both attributes incorporated into theories provided by Aristotle, a student of Plato.

Aristotle: 384 – 322 BC

In 384 BC, Aristotle was born in a Macedonian town known as Stagira (Wheelwright, 1935). He grew up in the royal court of Macedon and became friends with Philip, who would later become King of the Macedonian Empire and father to Alexander the Great. When Aristotle was 18, he moved to Athens to join Plato's Academy until the death of his teacher (Wheelwright, 1935). It was then, in 343 BC, that Aristotle was invited to become Alexander's teacher (Moore, 1925).

During this time, influenced by Plato's doctrines, Aristotle wrote some of his most famous works. Of interest for the foundation of gradualism are his writings on what he called 'meteorology' and 'natural sciences.' Aristotle believed that nature was defined by both motion and change, which were continuous processes (Wheelwright, 1935). In *Meteorology,* Aristotle expressed the thought that many theories suffered because they examined processes on a small scale, but when looking at the bigger picture, it was clear that everything was connected (Aristotle, 350 BC a). Aristotle used this point to explain his theories about the global exchange of water.

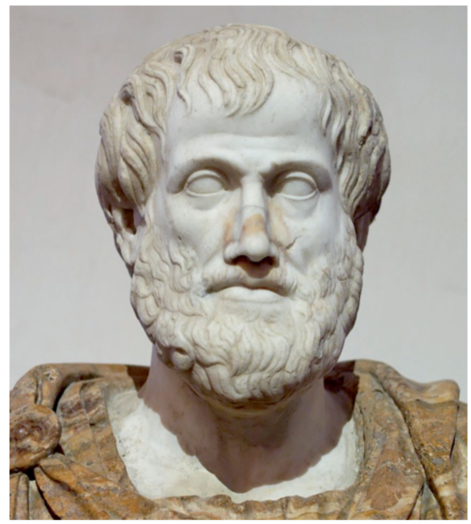


Figure 1.12 Roman marble sculpture of Aristotle, a Greek philosopher, reproduced from the original sculpture chiselled in 330 BC by Lysippos, a bronze sculptor.

According to Aristotle's *Meteorology*, areas that were land and sea had not always been so (Aristotle, 350 BC a). Throughout Earth's history, areas that were wet had been dry and those that were dry, at one time had contained seas. Aristotle concluded that these processes were cyclic and extremely slow. Particularly, *Meteorology* explained that the time over which this cycle took place was so vast that "before their course can be recorded from beginning to end whole nations perish and are destroyed" (Aristotle, 350 BC a, Book 1 Chapter 14). Using the example of Egypt, Aristotle explained the exchange of moisture by stating that the whole region was consistently getting drier. This area was a sediment deposit from the Nile River, but this development was not recorded due to gradual settling of the land. Therefore, the gradual processes were not accurately documented.

Not only was the idea of slow, consistent processes important for theories of gradualism, but Aristotle took this concept one step further. In attempting to explain why the sea was salty in *Meteorology*, Aristotle disregarded many explanations because he believed it illogical to assume that different principles occurred in the past than the ones that existed at the time (Aristotle, 350 BC a). This early, rudimentary theory bears a startling, if not as directly stated, resemblance to the uniformitarianism principle theorized by James Hutton centuries later.

Figure 1.13 Map of the Roman Empire in 44 BC, the extent of which is indicated by the salmon colour. This map was modified to highlight several key regions of the time: Macedon, Athens, and Sparta.

Towards the end of Aristotle's life, King Philip II of Macedonia won a victory over the Greek city states in 338 BC (Martin, 2013). He then preceded with an invasion against the Persian Empire. Although Philip was not successful in accomplishing his goal to conquer the Persian Empire, it was his son, Alexander (later to be known as Alexander the Great), who succeeded in this mission. As Alexander conquered vast areas of land, he sent back many of his findings and animal specimens to Aristotle, opening up the flow of information between the East and West (Draper, 1896). However, it was the foundation of the city Alexandria in Egypt, and the death of Alexander in 323 BC, that really instigated another intellectual revolution.

Eratosthenes: 276 – 194 BC

The period after Alexander's death is now known as the Hellenistic period of Greek history (Martin, 2013). Due to his sudden death, Alexander left no successor. Therefore, his vast kingdom was claimed by many of his previous generals who named themselves kings of different regions of the empire (Martin, 2013). Scholarship became a founding principle of this period. Learning and investigation was promoted not just by the spirit of the times, but by the Hellenistic kings who gave royal patronage to great thinkers (Martin, 2013). Alexandria was a city located between the great civilizations of the East and West, where scholars gathered and exchanged ideas (Draper, 1896). Philosophy began to reach a wider audience, spreading through what was once the Macedonian Empire. The growing diversity of religion may have also contributed to further freedom, as no one group could impose its view on scientists, especially those who were free in the metropolis of Alexandria (Martin, 2013).

Figure 1.14 Italian Baroque painting by Bernardo Strozzi of Eratosthenes of Cyrene teaching in Alexandria.

Under the influence of this intellectual environment, Eratosthenes, a Greek intellectual, geographer, and mathematician, was able to make keen qualitative observations of geological structures (Gow, 2009). Although much of his work was lost, Eratosthenes is credited with explaining slow-moving processes. Eratosthenes said that the world was in constant motion, as evidenced by the expansion of continents, geological submersion of lands, elevation of ancient sea-beds, and the opening of Dardanelles - a natural strait (Draper, 1896). Although these qualitative observations may be elementary to modern geographers, they bear a strong resemblance to opposition towards catastrophism and support for slow changes, as described by Charles Lyell in the 19th century in *Principles of Geology* (Secord, 1997).

Eratosthenes is also credited with inquiring about the causes responsible for the accumulation of large quantities of mussel-shells, oyster-shells, scallop-shells, and salt marshes large distances away from their source points (Jones, 1932). He observed build-up of these shells two thousand to three thousand stadia (370-555km) from the sea (Jones, 1932). At the time, depositional processes were attributed to deities, resulting in Eratosthenes' findings being discredited by authoritative figures in theology. Today, only fragments of Eratosthenes' most influential piece of work, *Geography,* exist. However, this did not limit the impact of his work as scholars at the time, such as Strabo, had records of *Geography* to use as a reference.

Strabo: 64 BC – AD 24

Strabo, a Greek philosopher and geographer, was a prominent figure during the transitional period between the Roman Republic and the Roman Empire. Julius Caesar, a renowned leader of Rome's military and government, was barred from future leadership after a major victory, prompting him to march his army into the capital of the Roman Republic and declare himself the dictator (Everitt, 2012). He was assassinated in 44 BC, a major transitional event which led to the Roman Empire. It was in this same year that Strabo served as a student of geographers Tyrannion and Xenarchus, who followed the Aristotelian school of philosophy (Dueck, 2002). This transitional period was also the time at which Strabo converted to stoicism – a philosophy concerning personal ethics, which involves viewing the natural world through logic (Funk, 2011). This gravitation towards logic also aligned with Strabo's indifference towards theories based in religion. Strabo believed that religion was for the ignorant who required the structure and guidance religion provided. Rational thought founded Strabo's early geographic theories that involved political, physical, topographical, and mathematical explanations. This was in significant contrast to the public thought at the time, as Roman society was deeply rooted in religious practice and rituals that relied on the supreme power of the gods (Everitt, 2012).

Strabo's observations resulted in the volume *Geography,* a set of historical works. His work covered the geography of northern Europe, southern Africa, India, and Ceylon, while providing weaker accounts of the Baltic region, Scandinavia, and the British Isles (Jones, 1932). Understanding various geographic regions allowed Strabo to make broad qualitative observations that contributed to the concept of gradualism in structure formation.

Similar to Eratosthenes, Strabo questioned the cause behind the discovery of large quantities of marine shells found at high elevations and long distances from the sea. Using marine evidence, he found that seas were once extensive and had afterwards, partially dried up (Jones, 1932). This was similar to Aristotle's ideas of the land and sea exchanging places over time. In providing a response to the question of transport of shell fragments, Strabo used information from Strato, a philosopher who devoted himself to the study of naturalistic elements. Strato discovered that the quantity of mud brought down by rivers into the Euxine, an inland sea, was large due to sediments gathered from erosion of rising landmasses (Lyell, 1858). He conceived that the Euxine became elevated to the point where it 'burst its barrier,' causing marshy ground to form (Lyell, 1858). Rivers continued to pour, keeping water levels equal. Strato's discoveries eventually led Strabo to the conclusion that elevation of landmasses was not due to sea coverage at different altitudes, but rather, by the transgression and regression of water (Jones, 1932). Strabo's explanation implied that flooding of land may have been responsible for the movement of shell fragments and their discovery far from the sea. The same landmass rose and was depressed, returning to its original state. In *Geography*, Strabo claimed that it was necessary to derive explanations from things which were clear and a daily occurrence to be able to explain other phenomena such as deluges, earthquakes, and sudden swelling of the land beneath the sea (Jones, 1932). This use of observable, daily processes as an analogue to understand the mechanism behind other processes is a slight departure from gradualistic theory. Instead of slow, incremental changes as an explanation behind all phenomena, Strabo started to recognize that there were other processes which have immense impact on the formation of the Earth.

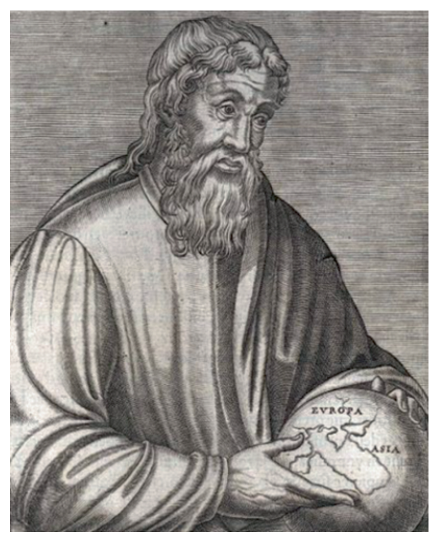


Figure 1.15 Portrait of Strabo, a Greek geographer and historian who completed much of his work during the transitional period of the Roman Republic.

Throughout Ancient Greek history, many philosophers gave additive contributions to theories of gradualism. From Plato, it can be understood that the world does change and that time is required for this change to occur. Aristotle took this idea further by stating that the world was changing at a gradual rate. He even decided to reject hypotheses that suggested that explanations of the past could use different laws than those found at the time, a notable foreshadowing of uniformitarianism. Eratosthenes supported this understanding of gradual events with clear evidence of natural phenomena that could be observed in his time. Finally, Strabo built on the work of Eratosthenes to explore the question of how marine organisms were preserved so far from the sea. It is with this question that he progressed further than the strict adherence to gradualism.

Applications and Limitations of Actualism

The desire to understand processes that shaped the Earth did not stop after the Ancient Greek period. Instead, the debate between theories of uniformitarianism and catastrophism has continued, yielding a merged concept, providing a stronger understanding of past geological events. Actualism is this combined geological theory which amalgamates the fundamental tenets of catastrophism with major ideas from uniformitarianism. It is the current accepted method to approaching geological quandaries. The all-encompassing modern theory of actualism is often argued to be more logical and intuitive than the black and white views provided by uniformitarianism and catastrophism. Another primary reason that actualism remains a popular modern theory is due to the fact it considers the mechanisms behind certain events rather than solely focusing on identifying and classifying geological structures (Baker, 2013).

Definition and Usage

The principle of actualism states that processes which have occurred in the past continue to occur today (Altermann and Corcoran, 2009). By this logic, events from the present have corresponding analogues in the past, suggesting that the ability to reconstruct the geological past lies in observations from the present. In addition to supporting recurring geological processes, actualism also implies that physical and chemical laws have remained constant throughout time (Simpson, 1970). The single changing variable remains the rate of change at which geological processes proceed (Levin and Jr, 2016).

Advantages

Currently, actualism proves beneficial in providing clarity to geologists. By relying on the present to shape an understanding of the past, geologists are able to find structures and processes that exist as proxies for past geological formations. Actualism is one of the first concepts applied by scientists when trying to analyze evidence from the past. In many cases, ancient evidence has clear parallels to modern day specimens and formations. One example is the analysis of ichnofossils found at Mistaken Point, Newfoundland, which are remarkably well-preserved but no less confusing (Martin, 2012). Liu, McIlroy and Brasier (2010) determined that the traces found in the rocks in this area were created by organic instead of inorganic processes. They achieved this by looking at the regular intervals and ridged division of these traces. Due to different orientations of these equally spaced ridges, unidirectional current can be ruled out as a formative factor (Liu, McIlroy and Brasier, 2010). Additionally, due to modern understanding, striae caused by glacial activity and bedding cleavage caused by tectonic activity can be eliminated as possibilities for causing these marks. Other abiotic features are too irregular to cause these evenly spaced ridges, confirming through actualism that these traces are in fact abiotic (Liu, McIlroy and Brasier, 2010). This entire process of reasoning and careful observation of phenomena is one that traces its roots back to Ancient Greece. However, actualistic analysis of the ancient organism traces at Mistaken Point was further applied using modern laboratory testing of different marine organisms to determine the tracks they made. From these studies, it was determined that extant anemones, particularly Urticina, make very comparable trails with nearly identical ridged patterns. Liu, McIlroy and Brasier (2010) therefore determined that an organism with a similar locomotion pattern to the modern anemones could have made this pattern, successfully utilizing the concept of actualism for narrowing hypotheses surrounding ancient evidence.

Another such example in which modern processes, particularly chemical ones, can be used to determine past geological processes is in studying the Cambrian Burgess Shale (Caron and Jackson, 2006). This area of well-preserved organisms, first discovered in 1909, is important for the study of the evolution of early animals and their body plans. However, one limitation to any fossil analysis is the preservation bias present (Caron and Jackson, 2006). Despite thorough analysis of a site, one can still come to incorrect conclusions regarding the reality of life in that area due to an incomplete picture generated when some fossils are preferentially preserved over others. The problem of insufficient and fragmented evidence could have affected the analyses generated by Ancient

Greek philosophers, who used marine fossil records preserved on land to further ideas of gradualism. In order to determine what preservation biases may have been present, Caron and Jackson (2006) used laboratory experiments to study decay rates of many taxa of modern invertebrates. They determined that polycheates are some of the quickest organisms to decay (Figure 1.16). Therefore, if polycheates are preserved, it can largely be assumed that a high representation of the diversity was conserved in a site. This enabled a much greater understanding of how representative the Burgess Shale fossils are in terms of the actual diversity of species at the time. Further advantages include researchers being able to consider geodynamics and incorporate mechanical and physical observations into their models (Jacoby, 2001). Interrelations between events can also be identified, as there is an innate dependency and lack of mutual exclusivity implied when events mimic each other. Parameters affecting geological processes can also be studied through inductive reasoning, as the presence of similar physical events enables geologists to extrapolate by assuming progressive processes.

Figure 1.16 Polycheates are modern invertebrates that were used to determine decay rates, which helped researchers understand preservation bias of Burgess shale fossils.

Limitations

However, despite numerous advantages, actualism is not considered a universal technique that is consistent in providing complete knowledge about the past. Comparing geological phenomena from the more recent past to modern processes is a useful utilization of actualism which yields more applicable results. The reliability of present geological structures decreases for longer elapsed time periods, making modern day processes an impractical application for the distant past, its radically different environment and unique processes (Kowalewski, 1999). Understanding the limitations of this technique is of vital importance for providing reliable explanations of the past. Providing accurate explanations of the past often requires the willingness to set aside common, well-accepted ideas, whether these be modern scientific theories or historical religious values. The limitations of actualism can be illustrated by the large differences between extant and extinct species of Xenarthra, a broad class of organisms that includes current species such as armadillos, sloths, anteaters and elephants (Vizcaino, Toledo and Bargo, 2017). However, in just the example of sloths, the ancient equivalent of the modern species - known as Megatherium americanum - were ground sloths that were roughly the size of elephants. Further than just their size differences, bone structure and morphology suggest large differences in modes of life, making it near impossible to use the modern analogue to make inferences about past life (Vizcaino, Toledo and Bargo, 2017). Many of the extinct species of Xenarthra studied had no close correlation in limb size and shape to any extant organisms. Therefore, instead of actualistic comparisons, it may be more useful to use non-biological models of these organisms, such as the application of biomechanics, to obtain useful information about the mode of life, motility and niche of these ancient organisms.

The failure of actualism to explain past events can be a helpful metric, a null hypothesis, against which to test possible hypotheses (Kowalewski, 1999). For example, modern understanding of fossilization can explain the degradation of Cenozoic and Mesozoic records of brachiopods, a marine organism. However, the fossil record of the Paleozoic does not agree with these modern estimates, suggesting a change in preservation during this period (Kowalewski, 1999). Modern ideas and processes cannot necessarily predict the past and new theories are needed with greater recognition of differences between our modern environment and the unique conditions that had once existed. Theories are constantly evolving from the time of Ancient Greece to the present. Although gradual processes may have provided vital knowledge for understanding many of the Earth's mysteries, recognition of rapid change and the idea that modern processes do not reflect all possible conditions that occurred on early Earth are also vital to further understanding of the still elusive concepts from our past.

Tectonic Plates and Continental Drift

The existence of plate tectonics and convection currents has been an important aspect in explaining the similar habitats around the world as well as the movement of continents. The topic however, is accompanied by numerous theories and the actual causes for the continents reaching their current locations getting to where they are today has been hotly debated over time. Many scientists have shed light on their respective theories that contribute to the science behind tectonic plate movement. Much debate and controversy has taken place, encompassing multiple scientific fields and leading to situations where proposals made by many scientists were not widely accepted yet developed after further investigation.

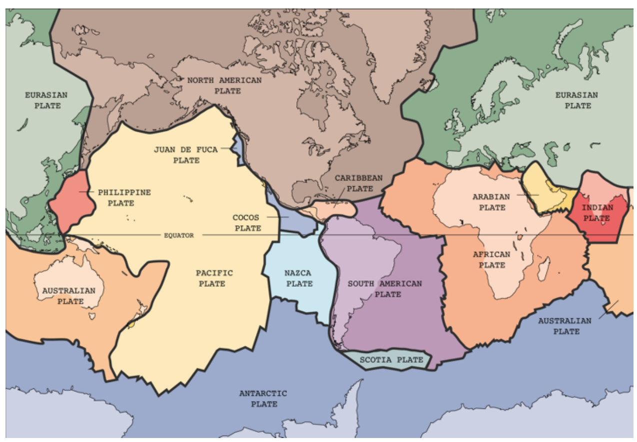


Figure 1.17. The tectonic plates of the world. Composed of the lithosphere, these plates are motile and collide with one another, forming geological features seen on the Earth's surface.

These aforementioned scientific theories revolved around explaining the movement of the Earth's continents relative to one another, paving the path for the concept of tectonic plates and the convection currents that drive its movement. Tectonic plates compose the Earth's lithosphere, making up the crust and the solid component of the upper mantle (Stern, 2007). There are seven major plates and several minor plates that move relative to one another. These plates are rigid rock layers floating atop the asthenosphere, which is the fluid component of the upper mantle, and its motion is generated by mantle convection. Plate motion is miniscule, however these motions explain the geological processes and features that are visible on the Earth's surface (Stern, 2007). The Earth's crust is divided into either continental or oceanic crust, with the main difference between the two being their sediment composition. The continental crust is composed of granite rocks whereas the oceanic crust is formed from a denser basaltic composition. The collisions involving these two types of crusts contribute to the movement of continents.

The first idea that there were movements of continents, assuming they were once unified, came from Antonio Snider-Pellegrini, a geographer, in 1858 (Gohau, 1990). Snider-Pellegrini had observed similar features seen on the coasts of Africa and South America, and how the two continents seemingly fit together, almost like puzzle pieces. This characteristic can be seen in Figure 1.17. Believing that the two landmasses may have moved from their original positions, Snider-Pellegrini published his observation of the movements of Africa and South America in the book, "La Création et Ses Mystères Dévoilésas", as an illustration of the world before and after the separation of the two continents (Gohau, 1990). However, this theory was not well supported as his argument was based solely on the shapes of the adjourning coasts. Snider-Pellegrini believed that both continents had similar triangular shapes but at the time, fossil records were not considered when comparing the corresponding coasts (Gohau, 1990). Similar to this proposal, two geologists, Marcel Bertrand and Eduard Suess, focused on conducting research on two regions, India and Africa. They believed these two landmasses were once together, forming the supercontinent of Gondwana (Gohau, 1990). The reasoning that they used to support the idea was that the same flower fossils in carboniferous rocks were found in both regions. However, this theory was initially criticized as he did not initially have a mechanism as to how the similar organisms would be able to travel across the expansive oceans separating the two continents (Gohau, 1990).

Land Bridges

To combat the criticism he received, Suess proposed the possibility of a land bridge, a connection between two regions. His main idea was that the Earth's crust is constantly collapsing and reforming, allowing for the formation of a strip of land between two established continents (Nome and Us, 2018). As a result of this, continents in the past must have been larger compared to the ones currently and the collapsed fragments settled at the bottom of the ocean. Suess was not alone in his observation, as the general belief in the early 1800s was that at some point in the past, the continents were joined together through various land bridges (Nome and Us, 2018). Scientists initially proposed this idea as an explanation as to how humans and animals could have possibly managed to populate both North and South America when they had originated in Africa. The presence of these bridges would explain the similar fauna found on continents separated by water (Nome and Us, 2018).

The first proposal of the land bridge theory was the written record by Fray Jose de Acosta. He believed that humans and animals had migrated to North America from Asia through a land bridge, which started in Northern Asia and crossed the Pacific Ocean (Nome and Us, 2018). Jose de Acosta's idea differed from many of his peers in the field as he believed that the land bridge connecting the two continents still existed while he was alive (Nome and Us, 2018).

Further research from the 1600s to early 1800s, including several voyages led to the confirmation of what is now known as the Bering Strait, a waterway connecting present day Canada and Russia (Nome and Us, 2018). This discovery fueled interest in a potential area of land which previously connected the two areas as depicted in Figure 1.18, but which, contrary to Fray Jose de Acosta's theory, still did not exist (Nome and Us, 2018).

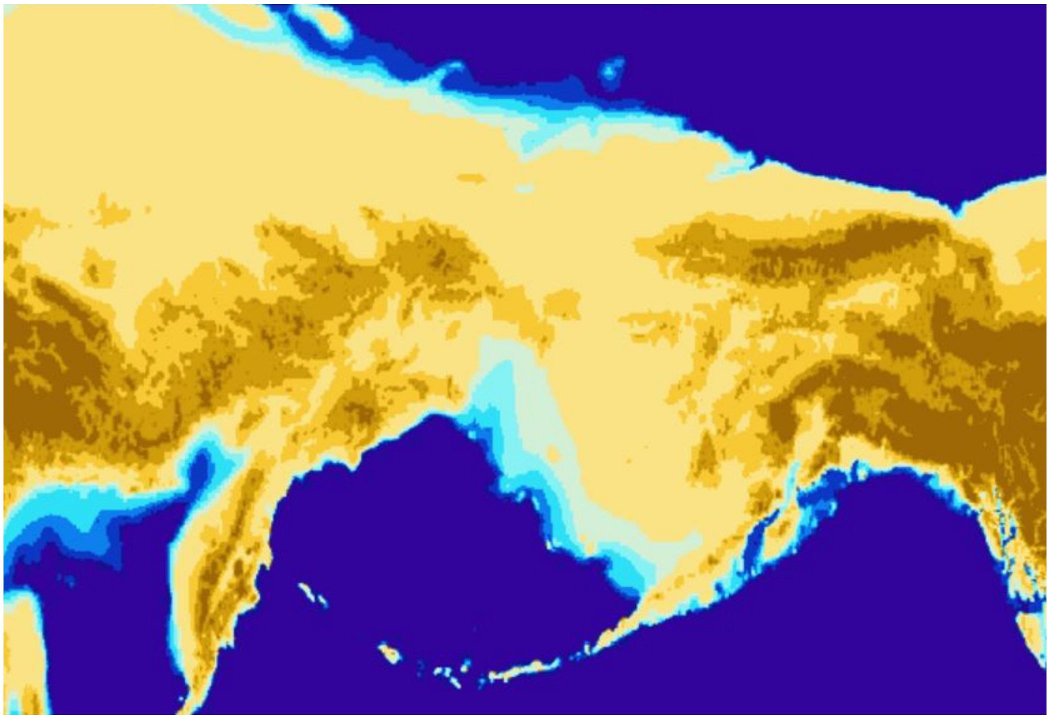


Figure 1.18. An artist rendition of a proposed land bridge between what is now present-day Asia (left) and North America (right).

At this time, there was also confirmation that humans originated not in North America but in another, at the time unconfirmed. The possible existence of land bridges provided an explanation for how humans most likely migrated from their original location (Nome and Us, 2018).

There is some evidence that supports the theory of land bridges (Nome and Us, 2018). The similar environments and fossil records observed on separate coastal regions such as those formed between the South American and African coasts provides evidence of these connections. However, evidence was later found to the contrary, illustrating that the theory of land bridges may not have been feasible (Nome and Us, 2018).

Arguments Against Land Bridges

While the theory of land bridges was popular for some time, evidence found in the mid-1800s led to criticism and controversy (Eshagh, 2017). The theory of Isostasy was developed based upon observations made in the 19th century, and the term "Isostasy" was officially coined in 1889. Initially proposed by an astronomer, George Biddel Airy, the theory stated that the Earth's crust and mantle system followed what was known as Archimedes' principle. This concept explains that the system behaved much like if one were to place a rock in water (Eshagh, 2017). The amount of water displaced would depend on the weight of the rock in the liquid. The theory of Isostasy hypothesised that the crust is floating on top of denser materials, ultimately displacing an amount of mantle proportional to the weight of the crust (Eshagh, 2017). This theory was heavily debated in terms of whether the crust or the mantle was the denser material. An astronomer, John Henry Pratt, refuted Airy in 1859, claiming that the crust was denser (Eshagh, 2017). Moreover, the early 20th century validated the hypothesis by establishing that the oceanic and continental crusts had different densities. These findings also challenged Suess' hypothesis, as the crust could not be interchanging and constantly collapsing into itself if it is composed of different densities (Eshagh, 2017). If two landmasses with different densities collide, the denser one should subduct. By the early 1900s, a new theory was proposed that would later go on to become the more widely accepted theory in the community, as the theory of land bridges became more obsolete (Eshagh, 2017).

Figure 1.19. Alfred Wegener (1880-1930) was a German geophysicist who proposed the idea of continental drift, a theory that opposes the idea of land bridges and would go on to be the generally accepted theory by the 1960s (Gohau, 1990).

Alfred Wegener

These proposed theories of land bridges was opposed by Alfred Wegener. Wegener was a geophysicist born in 1880, who made one of the most important contributions to the development of plate tectonic theory (Gohau, 1990). To support his opposition of the theories proposed in his field of work, he developed his theory on continental drift. Wegener claimed that large pieces of land such as land bridges were impossible by geophysical standards (Gohau, 1990). In addition to his opposition, he indicated that various parts of the land bridges, which stretched across long distances, would have had different climate and weather conditions. In that case, any animals traveling across the bridge would have had to endure the wide range of weather conditions (Gohau, 1990). Though the fossils found on either side of the land masses were similar, the animals should have adapted to survive in unfamiliar regions. If the animals were capable of migrating to the adjoining continent, they had to have changed either anatomically, behaviourally, or physiologically in order survive in the climate present in the land bridge regions (Gohau, 1990).

A theory was also proposed that mountains were formed because of the high temperatures exerted from the Earth's core (McKenzie and Richter, 1976). As a result, this would create a series of wrinkling and unwrinkling on land. However, Wegener opposed this proposition too, claiming that the radioactivity in the Earth's crust prevented the heating or cooling of the crust because it was in a state of thermal equilibrium (McKenzie and Richter, 1976). With no heat flow or transfer, there should not have been wrinkling or folding to shape the mountains currently seen today (McKenzie and Richter, 1976). One of Wegener's most important contributions was his proposal of the theory of continental drift. He looked at previous works, referencing the similar coastal shapes of several continents, as well as the similar fossil records to ultimately propose his own theory (Gohau, 1990). Wegener placed viable evidence behind the idea of a past supercontinent and even proposed a mechanism as to why the continents were no longer together. His theory stated that the continents were previously together as supercontinents but soon after, they "drifted" apart over the ocean floor like rafts over water until they finally reached their present positions (Gohau, 1990). The reasoning behind his proposition was that he realized the different

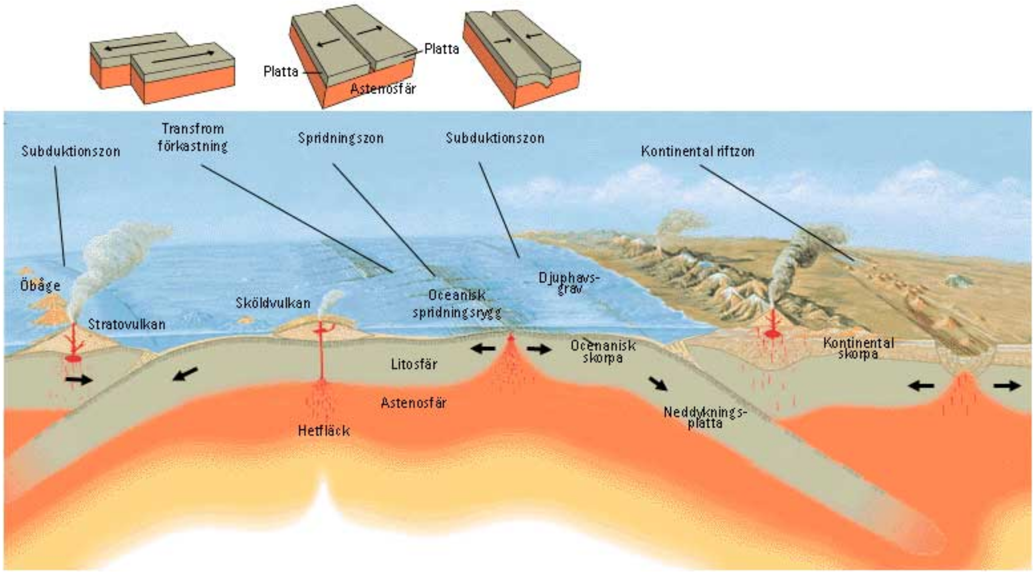


Figure 1.20. Plate collisions within the Earth. Convergent margins are observed on land (right), divergent margins are seen in the middle of the sea (middle), and transform boundaries split the rift valley (left).

land masses almost perfectly fit together. Specifically, the continental shelf of the Americas is fitted with Africa, Europe, and Australia (Gohau, 1990). Wegener's theory was supported by an earlier proposal in 1910, which interpreted mountain ranges and mid-oceanic ridges as evidence of the separation and collision of continents. Wegener first presented to the Geological Association at Frankfurt am Main and was called "Die Entstehung der Grossformen der Erdrinde". The idea was later published in the book "Die Entstehung der Kontinente und Ozeane" in 1915, with revised editions being released periodically as Wegener continued his work, until his sudden death in 1930 while on a research trip (Gohau, 1990).

However, Wegener's theory was flawed. The main issue at the time was that the theory was initially proposed with no mechanism to explain how the continents were able to migrate to their current locations (Gohau, 1990). Wegener's initial proposal was that there was movement away from the poles through tidal friction, and that this force pushed the continents and created mountains through force. At the time, Wegener openly agreed that his proposal had little viability (Gohau, 1990).

One of the main studies that supported Wegener's theory was published by Frederick Vine and Drummond Matthews in 1962. The two geophysicists observed a pattern of magnetic bands at the edges of ridges, which alternated between regular and reverse polarity (Vine and Matthew, 1963). Vine and Matthews hypothesized that these bands were the Earth's polarity that was captured at the time during the lithification of the crust. The study was a large step towards it becoming generally accepted that the oceanic crust was not in fact the same as it was in the past, as was previously believed (Vine and Matthew, 1963). With concrete evidence supporting their theory, the idea of an ever changing crust, as well as possible movement in the crust became more widely accepted (Vine and Matthew, 1963).

The mantle's convective process allows for the movement of plate tectonics and therefore, their motion exhibits the features that are observed on the Earth's surface: divergent margins, convergent margins, and transform boundaries (Pirajno, 2016). Divergent margins occur when two tectonic plates separate from one another, creating mid-ocean ridges. Exposure in the crust allows the magma from the mantle to escape through the crust, lithifying into new crustal material on either side of the rift (Pirajno, 2016). The driving force behind the uplift of magma are the convection currents and the seeping of magma beneath the crust causes a further separation in the rift. This phenomenon is known as sea-floor spreading. In addition, the collision of two tectonic plates form a convergent margin, forcing the other to subduct into the mantle depending on its density and composition (Pirajno, 2016). When there is a convergence between a continental and oceanic crust, the oceanic crust enters the subduction zone due to its high density compared to the continental crust. Subduction zones are subject to volcanism where the subducting crust melts because of its close proximity to the Earth's mantle (Pirajno, 2016). As a result, magma is formed and travels through the crust, generating volcanic eruptions. On the other hand, the collision of two continental crusts form mountain ranges due to the same density and in this case, neither one subducts. Both plates crumple upon exerting a force onto one another and create the mountains observed today (Pirajno, 2016). Lastly, transform boundaries are where tectonic plates grind past one another and is a conservative process because material is neither created nor destroyed. The sliding between the adjacent plates commonly offset visible ridges and trenches. The accumulated strain between the two plates can release and the forceful impact can translate into earthquakes (Pirajno, 2016). The different types of collisions explain the movements that Wegener hypothesized.

The limitations in Wegener's theory, otherwise sound argument led many to criticize him and develop alternate theories to explain what Wegener's theory could not. Starting in 1923, there was a meeting at the Geological Society of France where scientists such as the president of the society, Paul Lemonie and Leonce Joeaud, acknowledged several flaws in Wegener's theory (Gohau, 1990). Their criticism included Wegener's justification on how continents were able to move. Wegener claimed that the crust melted at a lower temperature than what was previously hypothesized in the literature, allowing the crust to "glide over" the lower layer of the crust called the sima (Gohau, 1990). However, this was disproven through experimentation and therefore without much concrete evidence, Wegener's argument was not widely accepted (Gohau, 1990).

After Wegener

J. Tuzo Wilson proposed a model that summarizes Earth's evolutionary processes where the continents undergo a cyclic process involving amalgamation and break-up (Morra et al., 2013). The cycle begins with a peneplain craton and enlarged continent that begins to swell upward and split into two due to the rising of a hot spot from below. The rifting creates divergence between the two novel continents and opens a new ocean basin (Buiter and Torsvik, 2014). On the edge of the divergent continents, sediments begin to accumulate as the ocean basin widens. This newly developed wedge accumulated with sediments becomes a subduction zone, forming in the ocean basin. The two continents begin to collide where the convergent plate boundary subducts under one of the landmasses, initiating the closing of the ocean basin (Morra et al., 2013). The collision of the two continents generate igneous magma to pierce through the surface and form volcanoes and mountain ranges. After the collision, the newly developed features seen on land is eroded down to sea level, creating a peneplain and the cycling process begins again (Buiter and Torsvik, 2014).

Exploration of Convection Currents

Presently, the mechanisms of Wegener's theory is being expanded upon, and the idea of plate tectonics in general, is being used for novel applications such as determining the habitability of a planet. Research is currently being focused on refining the model of the convection current process. There are two main hypotheses that hope to develop on the information of what is already known about convection currents. In particular, the first theory proposes that there are at least two layers of the mantle present, and that several but not necessarily all are convecting simultaneously (Sankaran, 2002). The second model hypothesized that convection currents run through the entirety of the mantle (Sankaran, 2002).

Convection currents in the mantle allow the movement of tectonic plates by inducing stress on it (McKenzie and Richter, 1976). Mantle convection is driven by heat coming from three main sources: the magma originating from the formation of the Earth's core, radioactive decay of elements present, and a portion of the heat is from the tidal friction exerted by the Moon's pull on the Earth. Ultimately, these energy sources generate mass amounts of heat and the moving of tectonic plates (McKenzie and Richter, 1976). Floating on magma, tectonic plates are in a semi-liquid state (Katakami et al., 2017). The heat generated from the inner core increases the temperature of the material above it. The liquid is heated to the point where it diffuses and a critical temperature gradient is reached. Point currents are generated, causing it to rise from the bottom of the mantle to the crust as it becomes less dense (McKenzie and Richter, 1976). While ascending, the magma begins to cool and as it reaches its apex, the material becomes dense again, spreads horizontally and sinks back down. The process is driven by the differences in temperature and follows a pattern of convection circulation (McKenzie and Richter, 1976). Furthermore, the constant circulation of hotter and cooler molten rock are also believed to heat the Earth's surface.

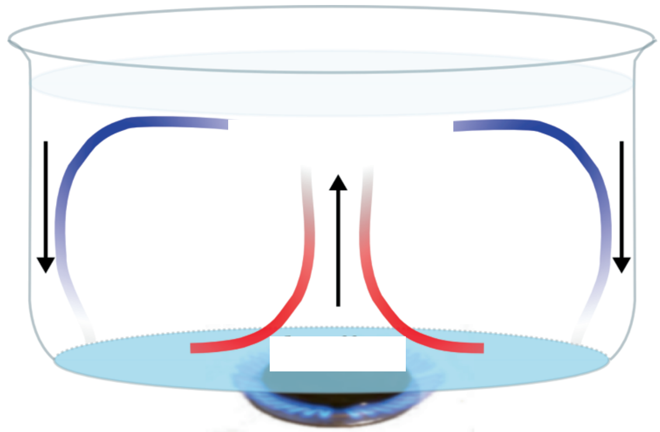


Figure 1.21. A model representing the convection currents in the Earth's mantle.

The main support for the layered mantle hypothesis is that seismic activity contains discontinuities at certain depths in the mantle, suggesting that there were multiple, discrete layers. The 1970s saw support for the latter theory, wherein seismic tomographic techniques demonstrated that penetration through multiple layers was possible, implying that there was intermixing between mantle layers (Sankaran, 2002). At this time, it was proposed that the seismic discontinuities may have been caused by partial melting, leading to viscosity changes at certain depths. However, the full-mantle convection hypothesis also came under scrutiny (Sankaran, 2002). A study conducted in 1999 found that the observed penetrating slabs between layers was actually part of a process known as "down welling", where higher density material of a specific layer would sink beneath lower density material (Sankaran, 2002). Therefore, there was no material being transferred between the colliding layers. Currently, there is still debate over which hypothesis is correct.

In 2002, Don L. Anderson published two papers detailing a new possible explanation as to how the plates move. This new theory flips the logic of previous theories by suggesting that it is actually the movement of the plates and continents that contribute to the currents in the mantle. He proposed that the surface tension between the crust and mantle also plays a role (Sankaran, 2002). His proposition was not that the movement of plates drive the currents, but rather organizes the current flow. The colder area of the mantle closer to the Earth's crust leads to a temperature gradient being created (Sankaran, 2002). The instability that comes from this temperature difference is what drives convection in the mantle close to the surface. As there is less of a gradient closer to the core which is emanating heat, there is less of a convection in that region (Sankaran, 2002).

The Earth's interior is at a very high temperature as a result of the three heat sources. The heat generated from the convection currents escapes the Earth and dissipates into space (Nicholson, Carter and Horner, 2018). This creates a temperature gradient between the layers where the mantle beneath the crust is lower in temperature in comparison to the core. Without plate tectonics, the difference in temperature would be smaller and convection currents would cease. The disappearance of convection would in turn cause the magnetic field to weaken and ultimately, disappear (Nicholson, Carter and Horner, 2018). This process is believed to be what was once happening on Mars however, the red planet is smaller than Earth. Therefore, the interior heat dissipated into space at a faster rate whereby, the convection currents were not maintained and magnetic field could not be supported. The tectonic plates on Mars were not recycled and there was no drive for the magnetic field. Due to the loss of this, Mars became uninhabitable. Ultimately, the speed of convection currents and tectonic plates contribute to the presence of a magnetic field, which is vital for shielding and building of a thick atmosphere (Nicholson, Carter and Horner, 2018). Currently, scientists are investigating for these specific components on other terrestrial planets to determine whether or not they are habitable. As the investigation continues, researchers believe that Earth would not have tectonic plates if water was not present on the planet (Nicholson, Carter and Horner, 2018). Though this idea is heavily debated, water acts as a lubricant within the Earth's mantle, between tectonic plates as it increases fluidity and allows for the occurrence of convection currents. Without water, the movement of tectonic plates would seize due to the dry environment and convection currents would come to a halt (Nicholson, Carter and Horner, 2018).

The Emergence of Modern Seismology: The Great Lisbon Earthquake

In the mid 17th century, natural philosophers and scientists held a wide variety of beliefs when it came to the explanation for the cause and mechanisms of earthquakes. Prominent hypotheses included the occurrence of chemical reactions in underground caves, or the involvement of electric charge, resulting in trembles which shook whole countries and continents. Meanwhile, most of the general population and religious leaders were convinced that these natural disasters were an act of God; a divine punishment (Livingstone, 1999). So naturally, when the Great Lisbon earthquake of 1755 hit Portugal with death and major destruction, curiosity of its cause became the spark that ignited what we now know as modern seismology.

Figure 1.22. Painting depicting Lisbon in ruins during the 1755 Great Lisbon Earthquake.

Nuns, priests, and devout Christians alike had woken up in Lisbon, Portugal on November 1st, 1755 ready for All Saints Day. Little did they know that during their morning prayers, a natural disaster of a scale so large would hit their city that it would be felt all the way up to Sweden and down to the West Indies three resultant tsunamis, this event was an estimated 8.2-9.4 earthquake on the modern Richter Scale. This undoubtedly had a significant impact on the cultural, socioeconomic, and philosophical aspects of Portugal and its neighbouring countries (Mendes-Victor et al., 2008). The sheer effect of this earthquake was not limited to a loss of a third of Portugal's population or the fact that it left the country in ruins. It also called for urgency in understanding the mechanisms of earthquakes and for the development of post-disaster planning.

Early Beliefs

The theories that accumulated to the body of knowledge and hypotheses on earthquakes started long before the year the quake struck Lisbon. Early understanding of earthquakes was based on folklore and mythology. Whether it was the activity of a large elephant beneath India or the movement of an oversized catfish under Japan, these stories all shared one common idea: earthquakes were caused by restless gods or giant creatures existing and lurking beneath the earth's surface.

The ancient Greeks believed the movement and interactions of the four elements (air, wind, fire, and water) were the cause of all natural phenomena. Being surrounded with these understandings, Greek philosophers postulated theories on earthquakes moving away from the influence of mythology and the supernatural. Democritus (460 BC - 371 BC) was one of the first to suggest an explanation for this natural disaster (Kapur, 2010). He believed that the earth was full of water and its combination with the event of heavy rainfalls resulted in the overcapacity of fluid within the earth. This would cause the planet to tremble, leading to an earthquake (Kapur, 2010). Furthermore, Greek philosopher Aristotle (384 BC - 322 BC) believed that two types of air existed: humid vapour and dry air also known as pneuma (Kapur, 2010). He hypothesized that fire within the earth made subterranean water boil and produce vapour which in turn pushes pneuma through the earth's crust resulting in a quake (Kapur, 2010). Although these postulations, as we now know, are not entirely accurate, they inspired scientific thought and analysis on these topics.

Centuries later, beliefs progressed from the four elements to the consideration of other factors such as chemical interactions. French philosopher and scientist René Descartes (1596-1650) proposed an Aristotelian-influenced theory from a chemical perspective. He viewed the earth as being star that had become a cold planet with a central fire (Good, 1998). Descartes believed that exhalations originating deep within the earth reacted in various mechanisms to produce Thick and dense fumes trapped within cracks and cavities in Earth's uneven surface. When a spark of fire is struck in these areas, the fumes ignite in a combustion reaction (Good, 1998). An immense amount of pressure is exerted on the walls of the cavity and the explosion causes an earthquake. Descartes explained different degrees of violence based on how much inflammable material is present in the cavities and the extent of unevenness in the earth's surface (Good, 1998). Descartes' work and well-outlined propositions created a new direction when considering the movement and interactions within the earth.

In the mid-eighteenth century, a different approach to the development of earthquake theory began as a result of new findings in the field of electricity and magnetism. One theory in particular proposed by William Stukeley (1687-1765) was supported by many scientists studying electricity independent of earthquakes (Kapur, 2010). He hypothesized that clouds discharge their contents to different parts of the earth. When this charge rises, the resultant vibrations cause an earthquake (Good, 1998). Overall, it was with all of these ideas circulating between scholars of Europe when the earthquake shook Lisbon.

John Michell

John Michell (1724-1793) was one of the many natural philosophers who picked up a curiosity on the causes of this great earthquake. The British geologist (Figure 1.23) already had a keen interest and works published on cosmology, magnetism, and strata by 1755. It was imagined that his room in Queen's College, University of Cambridge was filled with apparatus to conduct his own experiments and rock collections from his travels (McCormmach, 2011). So naturally, with the advent of the Great Lisbon earthquake, Michell became more interested than ever to more accurately record and understand earthquakes. By 1760, he had formulated his paper describing a general theory for earthquakes, done using publications of data collected on the Lisbon earthquake while building upon his natural philosophy and postulations on strata (McCormmach, 2011). While others such as Kant were significant in their method of reasoning, Michell's importance includes the fact that some of his postulations were correct.

Steering away from theories suggesting that earthquakes were a result of underground caves and chemical reactions, Michell understood the idea that earthquakes were propagated as elastic waves through a solid medium rather than through empty space (Michell, 1759). This allowed him to explain the noise heard with the tremblings of an earthquake as wave energy reached the earth's surface and continued on to the atmosphere as sound waves. Along with this postulation came the idea that this wave energy is radiating outwards from a small source whereas past theories did not acknowledge the specific location from which the earthquake originated.

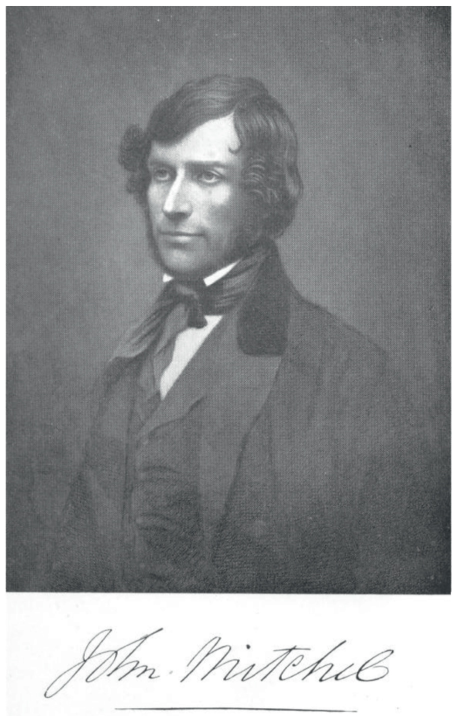


Figure 1.23. Portrait of natural philosopher John Michell (1724-1793).

Michell also formed a method to locate the focus of the earthquake by using human observations at two different point sources and crossing the lines pointing to the direction in which the sound appeared to originate. Pioneering seismologists Charles Davison and Robert Mallet later built upon this method to further derive techniques for taking non-instrumental data of earthquakes (Musson, 2013). While Michell's other theories such as that for the causes of earthquakes echoed those of philosophers before him, Michell's application of his knowledge of strata allowed him to suggest original ideas. This became the seedlings for the theory of plate tectonics and their relation to earthquakes that we know today (National Research Council (U S.) Committee on Seismology, 1969). Albeit being briefly mentioned, Michell suggested an observation of strata being unaligned along a crack, what we now know as fault displacement, to have a potential effect in inducing some earthquakes.

It is important to note that the significance of Michell's paper also lied in how he explained the formulation of his theories based on his observations. He introduced past hypotheses on earthquakes and then persuasively explained his own with sequential steps, analogies, and inviting the reader to conduct their own exercises to understand his concepts. He approached his questions with Newtonian mechanics rather than relying on writings of past philosophers which many other scientists followed (National Research Council (U S.)

Committee on Seismology, 1969). Michell additionally succeeded in staying focused on his paper to geological phenomena related to earthquakes, rather than connecting this natural disaster in any way to religious or social matters. Due to the multiple branching theories of earthquakes and its related phenomena (i.e. tsunamis), Michell's work was overlooked by geologists. This resulted in many scientists reaching similar conclusions as him, but 80 years later (McCormmach, 2011). However, this is not to say that his contributions were not well-recognised. Robert Mallet, the 'Father of Seismology', later stated that Michell's contributions were, at the time, "by far the most important and remarkable work upon the subject" (McCormmach, 2011).

Immanuel Kant

Immanuel Kant (1724-1804) was another enlightenment philosopher who became quite intrigued in the causes of earthquakes following the 1755 Lisbon Earthquake and the attention it received. In fact, he jumped on the opportunity right away, releasing a short essay by January the next year. By March 1756, Kant had released a series of detailed articles on both his philosophical perspective and scientific hypotheses on the processes contributing to earthquakes (Gulyga, 2012). Kant's immediate efforts in contributing to the scientific work related to earthquakes had both positive and negative repercussions.

Fortunately, the optimal timing of the release of his articles facilitated the communication of his information to both 'natural philosophers' and equally important, the general public (who could read German, the language his work was written in) . In fact, there was so much interest on understanding the reasoning behind the Lisbon Earthquake, that Kant's papers were being sold individually as they would come out of the printer (Gulyga, 2012**)**. In this way, Kant was able to communicate his ideas to a substantial population size. The scientific content of his papers built upon Descartes' suggestions that earthquakes were the result of chemical reactions occuring in underground caves. More specifically, Kant used several secondary sources for seismological data in different parts of the world and to build upon the ideas of scientists such as French chemist Nicolas Lemery (Reinhardt and Oldroyd, 1983). Although Kant's work on earthquakes was largely derived from second-hand accounts and reflected already proposed theories, his attention to detail revealed analyses on what we now know at seiches. Seiches are standing waves in encompassed bodies of water in contrast to tsunamis. By focusing on accounts of movement of water in lakes and rivers, Kant alluded to how tremors in the Earth caused by tilted plates can result in seiches (Kant, 1756). However, Kant's work overall was important in its deductive reasoning in geology and for efforts in what he called a "Universal Natural History" (Kant, 1755**)**. The fact that his work was in demand during the mid 1700s is also important as it excluded any mentions of divine intervention despite Kant being a devout Christian. He understood and neglected the widely held belief that earthquakes were a consequence of sin, rather than emphasizing the natural processes of the Earth as a separate system; simply "the work of nature" (Kant, 1756**)**. Along with his well-articulated explanations in Kant's essays, he was also able to communicate the scientific processes he proposed by suggesting experiments to conduct at home for the public.

The only negative consequence which resulted from Kant's quick actions and use of secondary sources was in fact getting incorrect information on the events that took place. One example of this is the assumption that a lake in Switzerland disappeared and reappeared as a result of the Lisbon Earthquake (Reinhardt and Oldroyd, 1983). Reports and observations of this lake strongly suggest against this occurrence. Kant's acquisition of data through personal accounts during the Lisbon earthquake led to a small amount of events being inaccurately recorded (Reinhardt and Oldroyd, 1983).Thus his explanations for these events could be considered invalid. In this sense, the validity of scientific data, even in the works of a popular and reputable philosopher such as Immanuel Kant, was not highly emphasized in a developing field such as seismology during the 18th century.

A True Leader: The Marquis de Pombal

Following the earthquake of Lisbon, it is very important to note the swift and resourceful actions of Sebastião José de Carvalho e Melo, the Marquis de Pombal. He sent out a questionnaire to parishes across the country to collect information from the citizens of Portugal about the earthquake and its effects (Fréchet et al. 2008). This large scale inquiry served to create a remarkably detailed account of the the macroseismic effects of the 1755 Lisbon earthquake and capture its effect over a large geographical area. The Marquis' questions were later noted as the first scientific quantification of earthquake damage in history (Mendes-Victor et al., 2008), rightfully along with Fernando VI of Spain who had sent out a similar and equally detailed questionnaire to his country. His motives for this questionnaire were for the betterment of his country in the form of post disaster planning and prevention for the future. The scientific importance of these questions remain in their concise formulation, which resulted in answers that gave information on aspects of the earthquake. This includes but are not limited to: wave propagation, soil liquefaction, and the movement of buildings (Fréchet et al., 2008**)**. Furthermore, by understanding any precursors such as rumblings and earthworms coming out of the ground (as was noted in Cadiz), the questionnaires brought to light some earthquake identifiers which could help reduce the damage done.

The Marquis of Pombal's initiatives following the earthquake was not limited to this questionnaire and post-disaster planning. Another very important step towards the development of modern seismology during that time was his explicit and assertive support towards 'natural' or scientific explanations for the earthquake. The catastrophic nature of one of the largest recorded earthquakes taking place on All Saints Day brought about hysteria amongst and between different religious groups (i.e. Protestants, Catholics, Anglicans) (Araújo, 2006). This was largely due to the fact that the earthquake considered an act of God and moreso, a consequence. It was under public and political distress, and strongly against many theological beliefs around the earthquake, that the Marquis spoke out and promoted progress in the natural sciences and seismology (Fréchet, Meghraoui, and Stucchi, 2008). Contradicting the Marquis was Gabriel Malagrida, a Jesuit with an influential voice in Portugal and in the politics of the Lisbon Royal Court. Malagrida was not only strongly against the explanation of such phenomena as natural processes, but against the rehabilitation and rebuilding of Lisbon since "the Lord [was] still shaking the Earth" as a consequence of Lisbon's supposedly reprehensible sins (Mostefai and Scott, 2009)**.** Marquis de Pombal took the event of an assassination attempt against King Jose I as a chance to execute Malagrida and related Jesuits under conspiracy in 1761 (Tyszczuk, 2017). Despite the fact that this event was largely driven by the Pombal's personal vengeance against Malagrida, it allowed not only continuation of reconstruction of Portugal but also facilitated a shifting mindset referring to the cause of natural disasters.

The After Effects

Figure 1.24. Statue of the Marquis de Pombal in honour of his heroic efforts in reconstructing Lisbon following the 1755 earthquake.

The amount of interest and work that had originated as a result of the 1755 Lisbon earthquake had started intensive efforts in the field of seismology. Scientists and natural philosophers started to focus on the movement in the earth and their correlation to natural disasters, especially without religious influence.

The data collection done by the Marquis de Pombal of Portugal proved to be extremely important due to the lack of earthquakes on a scale as large as the one that hit Lisbon in the following years. For this reason, the 1755 Lisbon earthquake was extensively studied with the use of seismic data originally collected through the citizens of Portugal. Creations of isoseismal maps and observation of fractures allowed scientists to observe the spread and damage that can be done by such an earthquake when it hits the land (Frechet et al., 2008). Furthermore, the work of scientists who theorized the cause of earthquakes allowed for the discussion and advancement of knowledge of the Earth. Michell's work was used for analysis and raised questions of whether his postulations of earthquakes was possible. As scientists such as Mallet understood more about the thickness of the Earth's crust by the 19th century, they discredited his postulation that earthquakes are a sudden release of a large quantity of gas (Good, 1998). Furthermore, British geologist and mining engineer David Milne extensively studied data collected from the Lisbon earthquake and Michell's derivations for locating the origin of the earthquake. Through this, he understood that it originated by the movement of seabeds and its vibrations in the Atlantic Ocean (Musson, 2013). Overall, it was due to the many theories and suggestions made by scientists such as Kant and Michell, which allowed the pioneers of modern seismology to have postulations and data to test, analyse, build upon, and disprove.

The idea that waves travel through the Earth's surface, as was discussed by Michell, had made significant progress by the 19th century. The analysis of waves in seismology has led to the discovery of the structure of Earth's core. In the late 19th century, seismologists began to use P- and S-waves much like an X-ray in an effort to determine Earth's interior composition. In 1914, Beno Gutenberg used this technique to conclude that the earth's core was semi-liquid (Lee et al., 2002). He came to this conclusion by studying data collected by seismometers placed around the world. The data showed that S-waves were only detected up to a distance of approximately 104° from the source of the quake (Lee et al., 2002). On the other hand, P-waves also could not be detected after 104° but then once again appeared at approximately 140°. This resulted in a 'shadow zone' between 104° and 140°. Gutenberg therefore argued that that this wave behaviour was due to the existence of a molten semi-liquid core (Lee et al., 2002). S-waves could not travel through the liquid whatsoever whereas P-waves could but their pathway was deflected in the process.

This model of the earth's interior was inaccurate as some P-waves were detected in this shadow zone following the 1929 earthquake near New Zealand (Lee et al., 2002). For years, seismologists had assumed this was due to the use of faulty seismometers. However, Inge Lehmann was intrigued by this phenomenon especially since these P-waves were detected in the network of seismometers she had helped install in Europe (Lee et al., 2002). After analyzing multiple sets of data, she finally came to the conclusion that Earth's interior consists of a solid inner core enclosed within a molten outer core all surrounded by the mantle in 1936 (Lee et al., 2002). The presence of a solid inner core explained why some P-waves were reflected into the shadow zone. Other data collected in the decades to follow has supported Lehmann's hypothesis.

As major earthquakes, tsunamis, and natural disasters alike continue to cause destruction and leave civilizations in ruins, there is a call for earth scientists to understand why. More importantly, there is an urgency to engineer and innovate methods to minimize the damage done by utilizing details known about the Earth. As these developments occur, the field of seismology continues to grow and evolve.

Modern Developments in Seismology for Disaster Preparedness

Seismology has advanced significantly since the 1755 Lisbon earthquake. It is true that it is impossible to prevent natural earthquakes from occurring. With that being said, after every destructive earthquake (Figure 1.25), more and more efforts are made towards disaster prevention. Recently, the advancement in modern seismology have come to the point of trying to scientifically detect earthquakes before they occur.

Predicting Earthquakes

Earthquakes are predictable to a certain extent, based on a location's proximity to active fault zones. Some regions are more-likely to be shaken than others based plate tectonic activity. However, the timing of an earthquake is unexpected. Moments before they occur, propagating vibrations below the earth's surface can be detected using a seismograph but there is not enough time for people to evacuate or take safety precautions (Maldonano et al., 1998).

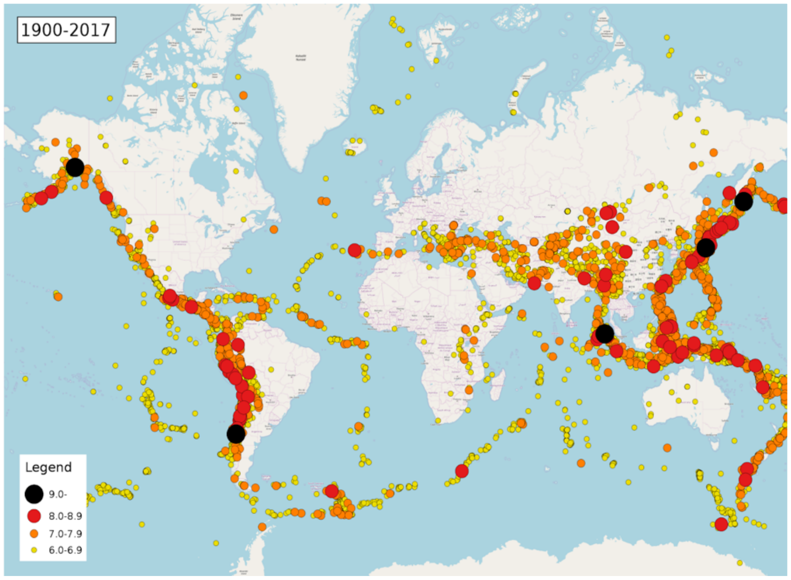


Figure 1.25. History of Earthquake Incidents: Earthquake incidents are prevalent throughout history and continue to occur today.

Seismologists now have the challenge of finding an effective method for predicting earthquakes so the appropriate measures can be taken before the disaster hits. Over the past three decades, as a result of long-term data collection initiatives, numerous seismologists have observed the changes in gaseous ^{222}Rn (an isotope of radon) concentration in soil. Major global earthquake regions such as the city of Kobe located in Japan have long-term ^{222}Rn monitoring programs (Baskaran, 2016). This has allowed seismologists to discover the correlation of its concentration changes to the occurrences of earthquakes (Maldonano et al., 1998). ^{222}Rn is formed from the decay of 238U which is very abundant in the earth's crust. Furthermore, ^{222}Rn can easily be detected in rocks since it undergoes α-decay and has a half-life of 3.8 days (Maldonano et al., 1998). Some seismologists hypothesize that the straining of the earth's crust in the days prior to an earthquake result in the imperceptible shift of the underlying tectonic plates. This theory, which has been developing over the last few decades, suggests that this negligible movement crushes subterranean rocks releasing trapped radon gas from cracks and cavities below Earth's surface (Maldonano et al., 1998). This would result in a temporary spike in ^{222}Rn concentration prior to a quake.

In the last few years, active devices have been developed for the constant measurement of radon gas in soil (Immè and Morelli, 2012). The gas can either enter the detection chamber through a pump at a fixed flow rate or the device can be placed directly in the soil and the gas enters the detection chamber via diffusion (Immè and Morelli, 2012). These devices would require a continuous supply of power which is not always available in active fault areas. Fortunately, this problem was solved by implementing solar panels in the detection system (Immè and Morelli, 2012). The more frequent use of subsurface radon detectors could provide more information on the correlation between ^{222}Rn concentration and earthquake activity. If there does appear to be a relationship between the two factors, it could potentially help predict earthquakes days before they occur due to the accumulation of radon gas underground over time.

The Use of Articial Intelligence in Seismology

The increase in induced seismicity in central United States in the past several years called for explanations and warning detections of seismic activity on any scale (Perol et al., 2018). The volume of seismic activity data has increased exponentially over the last few decades facilitating more effective and reliable techniques detecting and locating earthquakes. ConvNetQuake is a form of artificial intelligence that has been very recently developed as a result of this increase in data (Perol et al., 2018). It blocks out ambient seismic noise to find and locate seismic activity of magnitudes as low as zero or minus one on the Richter scale. This technology is currently being used to study the induced seismicity in central United States, specifically Oklahoma. It has been proven to detect more than 17 times more earthquakes than older methods done by the Oklahoma Geological Survey (Perol et al., 2018).

With the increase in usage of ConvNetQuake in Oklahoma, the exact cause of recent seismic activity can potentially be revealed. In addition, with further development and application of this system, it can eventually be used to predict small-scale tremors in the earth before they occur.

The Isthmus of Panama and Its Implications in Biodiversity in the Americas

The Isthmus of Panama is the narrow land bridge situated in Panama that connects North and South America. Although there are various schools of thought on when the isthmus was formed (O'Dea et al., 2016; Montes et al., 2015; Murdock, Weaver, and Fanning, 1997), there is a general consensus that its formation had massive implications on climate, geology and life all over the Earth (O'Dea et al., 2016). The isthmus blocks the flow of water between the Atlantic and Pacific Oceans, which forces the Atlantic oceanic current northward into the Gulf Stream. This results in warmer Caribbean currents travelling to Europe, leading to changes in oceanic and atmospheric circulation patterns (O'Dea et al., 2016).

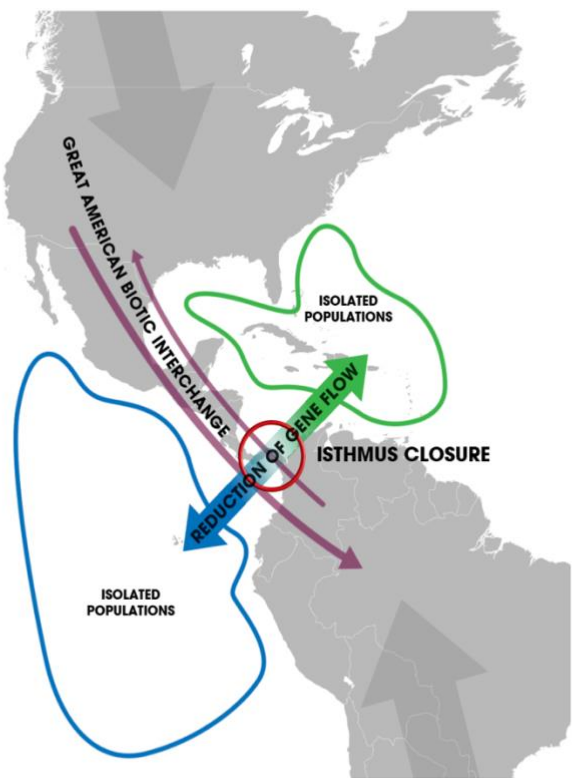


Figure 1.26. The formation of the Isthmus of Panama separated the Atlantic and Pacific Oceans, causing species on either side of the isthmus to evolve independently. The isthmus also allowed terrestrial species of the Americas to interchange.

Additionally, the formation of the Isthmus of Panama had two major implications for biodiversity in the Americas, depicted in Figure 1.26 (Leigh, O'Dea, and Vermeji, 2013):

1. It separated the Atlantic and Pacific Oceans, forcing the marine life in each ocean to evolve independently.
2. The isthmus allowed previously segregated land animals to migrate from North America to South America and vice versa. This event is known as the Great American Biotic Interchange, and it played a major role in biodiversity in the Americas.

Over the past 530 years, several key figures contributed to the understanding of the formation of the Isthmus of Panama and its effects on biodiversity. These scientists formulated and continue to formulate new theories based on the amalgamation of past ideas and current evidence, ultimately leading to greater knowledge on the topic.

The Land Bridge Theory

The concept of a land bridge was first developed by the Spanish Jesuit missionary José de Acosta in 1589. At age 32, Acosta travelled to work in the Americas as a missionary, spending time in Panama, Peru, and Mexico (Wunder, 2013). While he was there, Acosta began to assemble a variety of scientific and anthropological data of the Americas, making notes on geology, life, and the living practices of the Incas and Aztecs. Upon returning to Spain in 1587, Acosta compiled his findings into a seven-volume work titled *The Natural and Moral History of the Indies* (Wunder, 2013). The work was revolutionary, increasing scientific and cultural awareness of The New World in Europe, as well as challenging then-contemporary ideas on the development of the American peoples and life.

Many of Acosta's contemporaries believed in very differing theories that explained the origin of life in the Americas. Some people believed that the Incas and Aztecs had spontaneously been generated from mud, while others believed that they were Plato's lost Atlanteans (O'Neill, 2009). During his travels, Acosta had noted the differences in life between the islands and mainland of the Indies. The mainland was populated by a diverse collection of animals, both large and small, while the islands contained fewer and smaller species, many of which were birds (Acosta, 2002). The peoples of the Indies also were not technologically advanced in navigation and the building of ships. Acosta attributed the low species diversity of the islands to the inabilities of the people and terrestrial mainland life to travel there (Acosta, 2002). Coupled with the great distance between the Old and New Worlds, Acosta reasoned that the people of the New World had migrated there via a land bridge. He theorized that these early migrators then spread out across the Indies to inhabit different geographic regions that developed their own cultures (Acosta, 2002). Acosta also postulated that the land bridge was responsible for depositing mammals and other terrestrial species to the Indies. Given that no known land passage connected the Old and New Worlds, Acosta predicted that a land bridge to northern North America, an area unexplored at the time, was the ancient route of migration (Acosta, 2002). His hypothesis would later be proven correct by the discovery of the Bering Strait in 1729 (O'Neill, 2009). Unbeknownst to Acosta, his land bridge theory had laid the foundations of land bridge development and terrestrial species migration.

The Father of Biogeography

Alfred Russel Wallace (Figure 1.27) was a highly respected British scientist most famous for his contributions to the theory of evolution by natural selection (Gunell, 2013). In fact, he is considered by many as Darwin's antagonist, even though Darwin used ideas proposed by Wallace. Wallace developed his ideas on natural selection while researching the biodiversity of plants and animals in Southeast Asia from 1854-1862. Before studying in Southeast Asia, he conducted field studies on the biodiversity of South America from 1848-1852, where he learned of the significance of physical barriers such as mountains and water bodies on organism distribution (Gunell, 2013). From this line of research, Wallace contributed to preliminary ideas on the distribution of animals caused by the formation of the Isthmus of Panama. In 1876, Wallace published a two-volume set detailing the biogeographic distribution of animals he observed from his travels, called *The Geographical Distribution of Animals*. In this set, Wallace noted two main geographic principles that led to the observed distribution of animals. The first principle was that parts of modern, subaerial land were submerged in previous epochs due to Earth's domination by deep oceans (Wallace, 1876). The second principle was that changes in the distribution of land have likely taken place through additions to or modifications of existing land due to the extremely slow upheaval of continental land (Wallace, 1876). Wallace claimed that these principles led to two observations in the distribution of animals: the lack of migration of organisms despite ability to migrate, and the occurrence of similar or identical species that are separated by great physical barriers (Wallace, 1876).

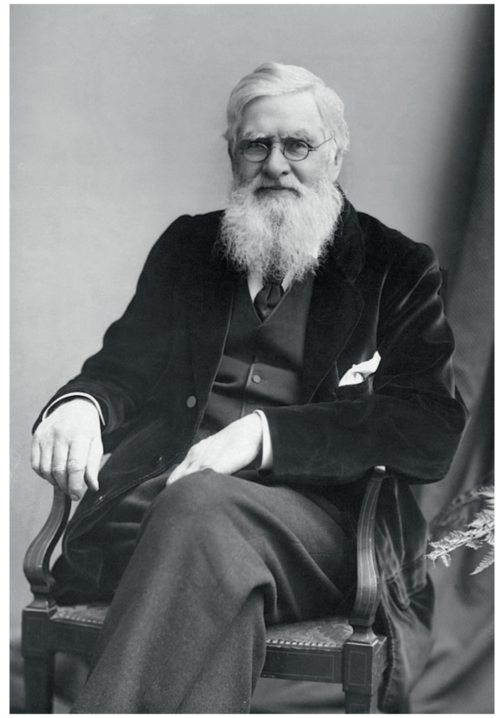


Figure 1.27. Portrait of Alfred Russel Wallace in 1895.

Wallace noted the curious fact of the almost perfect continuity of all the great continents (i.e. their proximity) and suggested that this was a result of the previous principles mentioned (Wallace, 1876). He stated that this led to a greater uniformity in the distribution of life than if the continents were more completely isolated from each other. Wallace used the Isthmus of Panama as an example of an "effectual union". This means the isthmus' wet climate and expansive vegetation allowed, and continues to allow, animals to cross the isthmus. As a result, Wallace noted that "we accordingly find that the main features of South American zoology are continued into Central America and Mexico" (Wallace, 1876).

Wallace was the first to explicitly propose that the Isthmus of Panama was not always present (Wallace, 1876). His evidence was as follows: firstly, the marine shells and corals on either side of the isthmus were generally of distinct species, but some were identical or very closely related. For example, the West Indian fossil shells and corals of the Miocene epoch were identical on both sides. Additionally, while most fish in the Atlantic and Pacific were very distinct, Wallace noted the discovery of a significant number of species inhabiting both oceans that were identical. From these two facts, Wallace concluded that there was a large channel between North and South America during the Miocene epoch, and a series of elevations and subsidences had taken place, uniting and separating the land masses in different epochs. He claimed that the most recent submersion lasted a short time, allowing locomotive fish to travel between the Atlantic and Pacific oceans, but not allowing for much change in the relatively stationary molluscs (Wallace, 1876).

Ideas of the Early 20th Century

In the early 1900s, several scientists were attempting to date the formation of the Isthmus of Panama based on living and fossilized animals. Namely, the succession of research compiled by Robert Thomas Hill, William Diller Matthew, and Henry Fairfield Osborn significantly contributed to this effort. Although none of them focused their research exclusively on the Isthmus of Panama, each of them indirectly contributed ideas to the chronology of the formation of the isthmus, which paved the way for future research on changes in biodiversity caused by the isthmus.

Robert Thomas Hill was an American field geologist who was fascinated by the geologic evolution of North America (Alexander, 1974). He conducted field studies of the West Indies and Isthmus of Panama because he believed they were significant to North American geology. In 1899, Hill published a periodical called *The Geology and Physical Geography of Jamaica: Study of a Type of Antillean Development*. While clearly focused on Jamaican geography, Hill also discussed the formation of the Isthmus of Panama. He stated that there was a land barrier that existed as early as the Jurassic period (206 - 144 Ma) which lasted throughout the Cretaceous period (up to 65 Ma) (Hill, 1899). Then, this land bridge opened and closed again at the end of the Oligocene (24 Ma). He based his ideas on geologic, paleontologic, and biologic evidence.

William Diller Matthew was a successful Canadian paleontologist of the early 20th century (Watson, 1932). In 1906, Matthew wrote the book *Hypothetical outlines of the continents in Tertiary times*. Here, he attempted to map the changing Earth between 65 - 2 Ma (Matthew, 1906). In order to accurately construct the map, including the Isthmus of Panama, he used some of Hill's ideas regarding the chronology of the isthmus. However, he critiqued Hill for not accounting for evidence from land vertebrate fossils. Matthew argued that vertebrate evidence showed that animals from South America appeared in North America (and vice versa) starting in the Pliocene era (5 - 2 Ma), and at this time a large interchange of terrestrial life took place (Matthew, 1906). Thus, Matthew believed that the two continents remained separate for a longer period of time than Hill had posited (Figure 1.28).

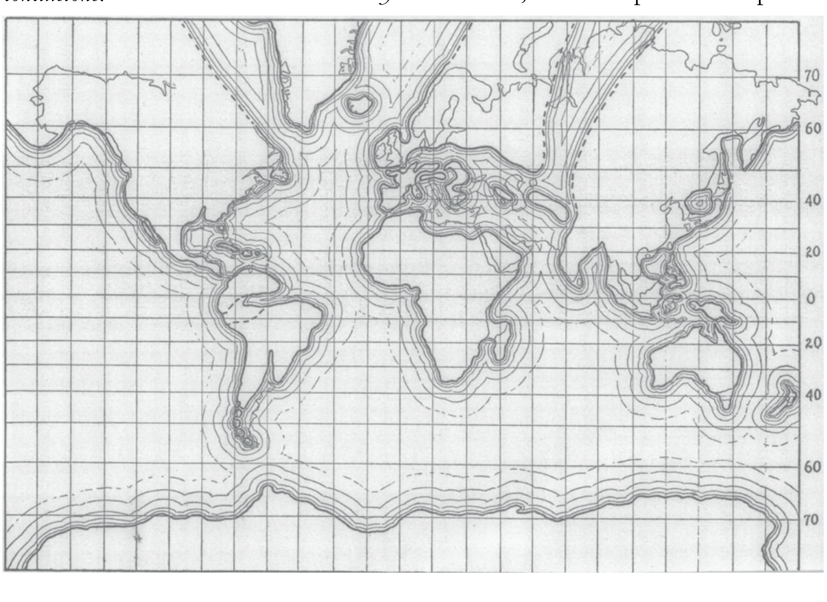


Figure 1.28. Matthew's postulated map of Earth during the Oligocene epoch (34-24 Ma), in which the Isthmus of Panama did not yet exist, as opposed to Hill's conclusions.

Henry Fairfield Osborn was an American geologist and president of the American Museum of Natural History from 1908-1933 who had an interest in evolution (Figure 1.29) (Gregory, 2013). In his book, *The Age of Mammals in Europe, Asia and North America,* published in 1910, he discussed the land connection between North and South America. He acknowledged Hill's conclusion that the land bridge formed in the Miocene era, but argued that it formed in the Pliocene era (Osborn, 1910). However, Osborn recognized that additional research needed to be conducted to more conclusively determine the exact date of formation. He also based the maps he produced in this book on Matthew's maps from 1906 (Figure 1.28) who, interestingly, was one of Osborn's Ph.D. students (Gregory, 1996).

Osborn based his conclusions primarily on the interchange of mammals between North and South America (Osborn, 1910). Due to the lack of fossil evidence of an interchange in the Miocene era, he believed there was no connection between the two continents at the time. Conversely, he stated that some physical, climatic, or biotic barrier which existed from the Upper Cretaceous was removed in the Pliocene. However, he admitted that there was not enough evidence to conclude that this land separation was at Panama. Here, he again cited Hill's conclusions that the separation was at Panama, but also acknowledged work done by other scientists who believed that the separation occurred where the current Amazon River exists (Osborn, 1910).

Osborn's research focused on the migration of mammals between the Americas (Osborn, 1910). Specifically, he discussed the invasion of edentates from South America to North America in the Lower and Middle Pliocene periods. Edentates were an order of mammals distinguished by their lack of incisor and canine teeth. Additionally, giant sloths and glyptodonts (an extinct type of armadillo) also invaded North America but later went extinct in the Pleistocene (Osborn, 1910).

Additionally, Osborn discussed fish fauna that supported the theory of a long prevailing separation of North America and South America in Cenozoic times (Osborn, 1910). He mentioned two South American fish families, the Characinidae and Chichlidae, which appeared as far north as the Rio Grande River in northern Mexico. Osborn also stated that several members of North American fish fauna travelled as far south as the Isthmus of Tehuantepec in southern Mexico. He suggested that this fish fauna interchange was a result of a long separation of the two continents (Osborn, 1910).

Despite his presented evidence, Osborn actively acknowledged the shortcomings of the observations. He stated that "... knowledge of the mammals of the Pliocene epoch in America is very incomplete and still awaits the more active exploration and exact research which have so nearly solved the mammalian succession of the Miocene and earlier periods" (Osborn, 1910). The work of Hill, Matthew, Osborn, and others provided a basis for future scientists to conduct this more detailed research into the chronology and biotic interchange pertaining to the Isthmus of Panama.

Biochronology and Fossil Indicators

In order to understand the migration of animals over time, and thus how the Isthmus of Panama influenced biodiversity in the Americas, one must first develop an understanding of biochronology. Biochronology is a branch of science which uses fossils to determine the history of geologic events and can be used to determine the appearance and extinction of species (Lucas, 2013). The field was first developed by the American geologist Henry Shaler Williams in 1901 (Williams, 1901). Williams was an educated zoologist who had left the scientific world to work in business in 1872 (Weller, 1918). Upon his return to science eight years later, he joined the faculty of geology at Cornell University, applying his zoology background to study fossils (Weller, 1918). Williams believed that fossils could be used as markers in division of time. He reasoned that due to evolution, the morphological characteristics of organisms were temporary and would change over time (Williams, 1901). Thus, each fossil had a time-value corresponding to its age of preservation and represented a specific point in geologic history. Williams invented the unit of the biochron, which measures the length of the presence of an organic character (Williams, 1901). However, the biochron, which is a temporal entity, was confused with a stratal entity by the geologic community, causing it to be forgotten (Lindsay, 2003; Teichert, 1958).

Figure 1.29. Henry Fairfield Osborn (right) and paleontologist Barnum Brown (left) in Wyoming conducting field work in 1897.

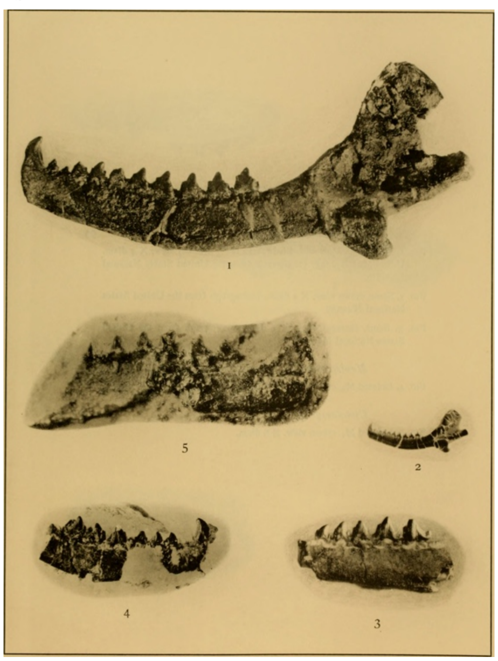
It was not until 1958 that biochronology was further developed. At this time, the concept of isotopic dating was emerging (Lindsay, 2003). Despite this, geologist Curt Teichert chose to focus on the use of fossils as means of dating instead (Teichert, 1958). The 53-year-old Teichert, a German-born paleontologist, was well on his way through his career when he published his paper *Some Biostratigraphical Concepts* (Reinemund, 1997). Teichert revisited and refined Williams' ideas and added his own opinions on the use of fossils to correlate time periods. However, Teichert's work did not sufficiently differentiate biochronology from chronostratigraphy, the dating of rock strata, causing his and Williams' ideas to practically be abolished from literature (Lindsay, 2003). Their ideas resurfaced in 1974 when paleontologists William Berggren and John van Couvering argued that correlations between the marine and terrestrial worlds could be made by utilizing biochronology and "datum events", which are chronostratigraphic markers (Berggren and van Couvering, 1974). Ultimately, the ideas of Williams, Teichert, Berggren, and van Couvering led to the development of the usage of fossils to correlate periods of geologic time between different areas, setting the stage for the study of the migration of terrestrial species.

Dissecting the Interchange

From a young age, George Gaylord Simpson was a bright and enthusiastic boy, graduating from high school at the age of sixteen in 1918 (National Academy of Sciences, 1991). Simpson and his family spent much of their time outdoors and their frequent adventures in the Rocky Mountains gave Simpson keen observational skills that would prove to be very useful to him later in life. He then set off for the University of Colorado, later transferring to Yale upon realizing his interest in geology. Simpson earned his Ph.D in paleontology in 1926 and worked in what is now known as the National Museum of Natural History (National Academy of Sciences, 1991). Though the museum collections were vast, Simpson was itching to conduct paleontological work in the field. He began traversing western North America, examining the stratigraphy and fossil deposits of Montana and New Mexico. His work here familiarized him with life in the early Tertiary period in North America (National Academy of Sciences, 1991).

During Simpson's time, it was known that South America had previously existed as an island continent, causing its native species to evolve in isolation for the majority of the early-to-mid Cenozoic period (National Academy of Sciences, 1991). Scientists had uncovered the fossils of carnivorous marsupials and herbivorous mammalian species in South America. Some of the species appeared to be related to North American mammals, while other species were entirely unique. These discoveries raised many questions to paleontologists. What relationship did the Americas have during the Cenozoic period, and why was it that deposits of bones of both South and North American mammalian origin only appeared during the Miocene? How did evolution rates differ between the two continents? Intrigued by the mysteries of South America, Simpson travelled to Patagonia in Argentina (National Academy of Sciences, 1991).

Figure 1.30. Some of Simpson's American Mesozoic mammalian fossil specimens.



In Patagonia, Simpson began research on the history of land animals in South America by examining fossil specimens and applying biochronological techniques (Figure 1.30). He found that the sedimentological and fossil record of the Andes during the Pliocene, Pleistocene and Recent epochs was well-preserved. This aided in his analysis of land mammal migration, as a land bridge was hypothesized to have developed during that time (Simpson, 1980). He compared the fossil records of North, Central, and South

America to identify common and unique species of the geographic regions over time in an effort to pinpoint how terrestrial mammals had travelled. He used species such as the members of the cricetid family to justify his hypotheses (Simpson, 1980). Based on his observations, Simpson placed faunal species into one of two categories: of North American or South American origin (Simpson, 1980). He then reasoned that not all species were participants in the biotic exchange, due to the differing ecological conditions of the Americas that would define the success of migrating species. Simpson reasoned that the isthmus and the surrounding area would serve as a large "filtering" zone, allowing only the passage of terrestrial life suitable for habitation in both Americas (Simpson, 1980).

Applying his hypothesis, Simpson discovered that prior to the joining of the continents, North America had about 27 land mammal families and South America had 29 (Simpson, 1940). Upon the formation of the isthmus, 22 families (14 of North American origin, seven of South American origin, and one of inconclusive origin) were common in both regions. The interchange had profound effects on the biodiversity of the Americas. As some species invaded their non-native continent, they filled new ecological niches or out-competed their native counterparts. This tug-of-war between the expansion and contraction of the migrating species eventually led to the extinction of all native South American carnivores and ungulates (Simpson, 1940).

The research compiled by Acosta, Wallace, Hill, Matthew, Osborn and Simpson, as well as the biochronologial techniques developed by Williams, Teichert, Berggren, and van Couvering, have led to the current understanding of the consequences of formation of the Isthmus of Panama. Their contributions straddled the boundaries of geology and biology, and have inspired further research to be conducted.

Dating the Isthmus

In the past few years, scientists have vigorously debated the exact age of the Isthmus of Panama. Before 2015, it was generally accepted, based on faunal fossil evidence, that the isthmus was formed about 3 Ma in the Pliocene epoch. Additionally, deep-sea cores taken in the 1970s also suggested that the isthmus formed around 3 Ma (O'Dea et al., 2016). However, several scientists have recently contested this timing.

The chronology of the formation of the Isthmus of Panama is important in multiple disciplines of science. Until the controversy is resolved, it is impossible to determine the precise consequences of the formation of the isthmus and the closure of the seaway between the Atlantic and Pacific Oceans. In climatology, it is thought that the closure of the seaway between the Atlantic and Pacific Oceans caused warm Caribbean currents to flow northward to parts of Europe, warming the European climate around 3 Ma (Murdock, Weaver, and Fanning, 1997). However, if this 3-million-year estimate is inaccurate, climatologists will have to consider another line of reasoning for the climate change. Additionally, the formation of the isthmus segregated marine life, forcing them to undergo divergent evolution in response to different environments. Scientists use the formation of the isthmus as a temporal marker of evolutionary divergence to calibrate rates of molecular evolution (O'Dea et al., 2016). Also, an entirely new explanation for the Great American Biotic Interchange would be required. If the 3-million-year estimate is in fact inaccurate, current understandings of the timing and causal relationships in the environment and climate must be reconsidered.

In April 2015, Camilo Montes and colleagues suggested that the isthmus likely formed 13 to 15 Ma in the Middle Miocene (2015). They based this off of evidence that showed that a river transported zircon rock crystals from Panama to the northern Andes 13 to 15 Ma, indicating that the Central American Seaway had closed by then. The researchers looked at evidence from eight boreholes and two surface stratigraphic sections in the northern Andes. They found a "zircon fingerprint", a unique crystal formation from Panama, in the shallow marine layers of the northern Andes, which formed around 13 to 15 Ma (Figure 1.31). They concluded that the "fingerprint" must have been the result of a river connection between Panama and the northern Andes in the Middle Miocene, thus indicating an absence of a large seaway (Montes et al., 2015).

However, a review article written by O'Dea et al. in August 2016 argues that these crystals are not in fact unique to Panama. They assert that the exact same crystals could have been formed at other locations

Additionally, in May 2015, Bacon et al. published an article suggesting that the isthmus began to form as early as 23 Ma and was fully developed at some point between 10 and 6 Ma. They used molecular and fossil evidence in order to assess the rate of both the interchange of terrestrial life between North and South America as well as the segregation of marine life into the Atlantic and Pacific Oceans. They used the assumption that a well-developed land bridge would lead to widespread dispersal of terrestrial biota and the division of marine organisms into distinct lineages. Bacon et al. correlated observed waves of dispersal of terrestrial organisms at 20 and 6 Ma to separations of marine lineages between the Atlantic and Pacific oceans at 23 and 7 Ma (2015). Thus, the group concluded that the isthmus began to emerge around 23 Ma, corresponding to a surge in terrestrial animal dispersal at 23 Ma and marine animal divergence at 20 Ma. Additionally, they concluded that the land bridge was completed at some point between 10 and 6 Ma, corresponding to significant terrestrial animal dispersal rate at 6 Ma and marine life divergence at 7 Ma (Bacon et al., 2015).

Figure 1.31. Cognac-coloured zircon crystal on top of a calcite matrix.

The review article by O'Dea et al. (2016) argued against this paper, stating that the group mistakenly used a "universal rate" of mitochondrial DNA divergence of 2% per million years. They claim that this is inaccurate because this rate is not in fact universal among organisms (O'Dea et al., 2016).

It is still quite unclear when the Isthmus of Panama was formed; it is an ongoing topic that will necessitate more research. Continuing collaboration and debate among scientists will be required in order to conclude this mystery and confirm previous thoughts on the impacts of the formation of the Isthmus of Panama.

The Evolving Theory of the Composition of the Earth

Human effort to demystify the origins of planet Earth is a decidedly ancient enterprise, spanning millennia. Ancient philosophers, the first to theorize explanations of the Earth's provenance, ascribed to a distinctly metaphysical school of thought involving the classical elements, and were often influenced by religious attitudes. These remained the prevailing theories for centuries, until the arrival of the Renaissance, and with it, the Scientific Revolution. New findings and methods of study would enable scientists to make tremendous strides in structural and compositional analysis whilst pursuing a more technical and methodological understanding of planetary structure. Indeed, the chronology of this evolution in human understanding of Earth's origins is a paradigm of general scientific development itself and is essential for comprehension of modern ideas surrounding the composition of the planet.

Figure 1.32. A portrait of one of the first Greek philosophers, Anaximander,

Anaximander and the Origins of the Earth

The pursuit of understanding the structure and composition of the Earth began with Anaximander, a Greek philosopher born circa 610 BC (Figure 1.32). Anaximander was fascinated with determining the origin of the cosmos and the universe and was considered by some to be among the first scientists. While his predecessor, Thales of Miletus, considered to be the father of philosophy, believed that the Earth floated on water, Anaximander was the first to suggest that the planet existed as an independent entity that floated freely in space - unsupported by any other object (Rovelli, 2009). Anaximander's ideas about the composition of the Earth also differed from those of Thales. Anaximander believed that the world arose from a homogeneous substance he dubbed *apeiron* or "the Boundless". The Boundless was not composed of any classic element such as earth, wind, fire or water, but rather something in-between that was "no more wet than dry and no more hot than cold" (Matson, 2013). The Boundless was an intermediated substance that was the root of all life. Again, this directly opposed the view of his predecessor and teacher Thales, who believed that the world originated from water, a belief very much tied to Greek gods and mythology. Anaximander's *apeiron* suggested that there was a unifying natural element that is at the essence of everything and can explain the existence of all things (Rovelli, 2009). This element was not divine, yet it was not visible in everyday objects.

While dismissing the idea that the Earth arose from the four elements, Anaximander did believe that these elements played a large role in atmospheric and Earthly processes. The attribution of natural phenomena away from the acts of gods and the divine can be credited to Anaximander's ideas. Anaximander believed that lightening, thunder, typhoons and hurricanes can be attributed to wind, rather than Greek gods such as Zeus (Gregory, 2017). He linked Earthquakes to crevices that existed in the fabric of Earth that would cause the Earth to shake when flooded with air rather than the work of Poseidon (Rovelli, 2009). Anaximander's ideas concerning the role the classical elements played in weather and natural disasters helped form the basis of early meteorology.

The Emergence of Life

Many believe that Anaximander was among the first to champion the theory of evolution. He believed that at the creation of Earth, there was no dry land and the planet was only composed of water (Matson, 2013). At this time, life emerged from the sea, or the "moist element" and humans existed as fish or sea creatures. As parts of the Earth began to dry due to the Sun, humans moved to the shore (Matson, 2013). While some relate Anaximander's theory to Darwin's evolutionary theories, others argue that Anaximander never explicitly stated that humans developed as a response to changes in their environment, and rather put forth this idea as general basis of how human life could have emerged (Barnes, 1979). Regardless, Anaximander was among the first to propose a theory for life on Earth that was "scientific" rather than rooted in religious belief.

While not much of Anaximander's original writings have survived, his influence and innovative ideas about the origin of the Earth can be seen through the work of later scientists and thinkers.

Empedocles and The Four Classical Elements

In the 4th century BC, nearly 200 years later, the Greek philosopher Empedocles put forward a theory of terrestrial genesis that stood in sharp contrast to Anaximander's. Reminiscent of early philosophical thought, the doctrine of the four elements, earth, air, fire and water, presented the focal point of his theory, describing with vivid imagery and poetic language, the transformation of the universe (Figure 1.33) (Wright, 1981).

Figure 1.33. The four elements; Earth, air, fire and water, as defined by Empedocles

Empedocles describes the four elements as entities coming together in unison through the uniting power of love and separating power of strife. Moreover, if the elements were completely separated by strife, there was no world in existence; but as love was brought into the picture, "its gracefulness was betokened by the unison of the different elements in varying combinations, forming an organic world" (Brush, 1980, p 35). Love was thought to be the entity that combined the elements into one, to formulate diversity amongst all existence on earth.

Empedocles was the first to bring forward a reasonable and logical explanation to the formation of the universe from the perspective of Greek philosophy. He proposed that if one were to trace the historical process of the formation of the Earth, the beginning would be the point at which all four elements are motionless and intermingled within one another in a sphere, under the domination of love (Wright, 1981). Strife, then entered the picture and split the elements into distinct masses that would seldom be able to coexist within one another. The cyclic relationship between love and strife was thought to be eternal, until love had progressed in power to overtake the nature of strife, allowing the elements to permanently intermingle with one another. This so called organic world contained a limitless number of individual existences, allowing for the mingling of the four Earthly elements into one (Trépanier, 2013).

As the elements progressed to coexist within one another, Empedocles believed that cosmogony had taken its toll to formulate life on Earth. As he describes in one of his famous passages, "the mass of the Earth was the center of all elements," (Wright, 1981, p 26). At the time, the formation of the Universe was a concept quite underexplored. The study of philosophy was up on the rise, and to many this was indeed the time of revelation.

Empedocles had also taken a step further to break down the formation of the Earth in its habitable zone. Water was the first layer surrounding the Earth, followed by the enclosure of air over top (Parry, 2016). Lastly, as fire was always placed in the periphery as a distinct entity, the Sun was placed farthest from the Earth. This belief in the geocentric placement had contributed to the study of the makeup of the cosmos.

At the time, the origin of life on Earth was also a field rather underexplored. Empedocles believed that trees were the first to form amongst the plants, much before day and night had parted and the Sun had spread its light (Parry, 2016). The plants were pushed up by the heat from the core of the Earth, as it was said to have been similar to an embryo within the womb (Kingsley, 1996). The physical makeup of the core was understood to be a very hot and dense center surrounded by a malleable layer on top. As claimed by Empedocles, the elements were initially mixed in ideal proportions, leaving no distinction between male and female. In essence, he believed, "Conscious life was given to plants, as to all of nature" (Trépanier, 2013, p 56).

Success in Theory

Approaching the end of the fourth century BC, Greek philosophers had advanced in their contributions to the fields of philosophy and science. The ideology claiming the properties of a substance becoming dependent upon its physical composition (i.e. the four elements) was at the center stage of philosophical and scientific inquiry (Rijk, 2002).

Greek philosophy was yet again on the rise, leaving people in awe of the study of the origins and composition of the Earth.

Aristotle and the Earthly Elements

Following the theory of the four elements brought forward by Empedocles, Aristotle, another Greek philosopher, became well-known for his findings within the fields of physics and astronomy in the third century BC (Maritain, 1947). A student of Plato and a teacher of Alexander the Great, Aristotle was a major contributor to the development of alchemy and philosophy. He published works that developed the process of deductive reasoning and logic, with one of his greatest achievements being syllogism.

Aristotle is said to have been the first to credit the works of Empedocles and support his idea on the four elements in Greek physical theory. He went on to develop Empedocles' theory of elements from his understanding of alchemy (Maritain, 1947). He found that elements were able to transform into one another through common qualities they possessed. For example, air could transform into water with the addition of moistness while fire could transform into air with the addition of heat (Maritain, 1947). This theory supported the idea that all the Earthly elements could undergo a repetitive cycle; from fire to air, air to water, water to earth and earth to fire.

Figure 1.34. A portrait depicting the Greek philosopher, Aristotle, 322 BC.

Later in his life, Aristotle published a treatise called *Meteorologica*, where he proposed his theory on the formation of the metals and minerals of the Earth (Rijk, 2002). His theory proposed that the interaction of the Sun's rays with water produces a cold, moist and vaporous exhalation. In Aristotle's *On the Heavens* he states that the exhalation is then imprisoned within the dry Earth, undergoes compression and is eventually converted to metal (Stocks, 1922). According to Aristotle, all types of metal, whether malleable or fusible, such as gold, copper, lead or iron, were all formed in the same way (Maritain, 1947). On the contrary, the formation of minerals had occurred when the Sun's rays hit the lithosphere. As the rays came in contact with the surface of the Earth, a hot, dry and smoky inhalation was produced, forming an abundance of heat, leading to the production of minerals (Rijk, 2002). Aristotle categorized the Earthly minerals into substances that could not be melted, including some rather odd substances such as sulphur.

Even though Aristotle was able to use Alchemy to take a novel approach to understand the composition of the Earth, his theories faded into the second century BC.

The Dark Ages, The Renaissance and The Scientific Revolution

Scientific inquiry in Europe was greatly halted after the fall of Rome in the fifth century AD. The period of history that follows is often referred to as the Dark Ages. While this time period was not completely devoid of scientific advancements, the Dark Ages are characterized as a time where much was not recorded, and thus provide little evidence of what intellectual progress happened during the time in all fields (Shuttleworth, 2010). If any developments towards finding the composition of the Earth did occur during what is estimated to be around 500 – 1500, there are no academic written records as there were for instance, during the times of Anaximander, Empedocles and Aristotle.

The resurgence of scientific ideas did not take place until after the middle ages during the European Renaissance beginning near the end of the Dark Ages.

Due to the development of the printing press, knowledge became more accessible to the masses. Along with this, came the rediscovery of many Ancient Greek philosophers as well as mathematicians. Mathematics became an avenue through which people attempted to understand the natural world (Henry, 2011). This rebirth of interest in scientific methods and questioning is responsible for the following time period beginning in about 1500 known as the Scientific Revolution.

Modern notions of science and academic writing can be attributed to the Scientific Revolution occurring between the 16th and 18th centuries. This phenomenon occurred mostly in Western Europe as the prevailing ideas about the nature of the universe were challenged and debated. Beliefs began to shift away from magic as well as the supernatural and turn towards scientific thought and knowledge. A re-emergence of interest into the origins and conformation of the Earth can largely be attributed to this time period, as scholars began to look away from traditional Greek thought to ideas which were more reflective of reality (Applebaum, 2005). As a result, new theories about the structure and composition of the planet began to emerge.

Modern Earth Theories

In the early 17th century, William Gilbert, through his studies of magnetism compared the polarity of Earth to a lodestone, a magnetized iron oxide (Wilson, 2000). Gilbert theorized that the Earth behaved as a magnet, while also suggesting that it could be composed of iron.

Another theory was that of Edmond Halley who was an English astronomer, notable for his contribution to the study of comets. Halley studied the magnetic variations in different parts of Earth. Through his knowledge of magnetic poles, Halley concluded that the Earth was hollow and published his finding in 1692 (Kollerstrom, 1992). Despite rekindled speculation into the subject, uncertainty still remained through much of the 17th and 18th centuries.

Confirmation of the elemental composition of the Earth did not come until the development of seismology. In the late 19th century, geophysicist Emil Wiechert developed a model of Earth consisting of a core surrounded by a rock shell, each of uniform density (Ben-Menahem, 1996). More notably, Wiechert speculated that density at the center of the Earth must be greater than the density in the crust, and that the earth was too dense to be composed of only rock (Rush, 1980). This led him to notice that these structures must be composed of different materials. As a result, in 1897, Wiechert reached the conclusion that the planet had a dense meteor-like core composed of nickel and iron (Badescu and Zacny, 2015).

Shortly after in 1906, Richard D. Oldham, another well renowned scientist, theorized through his study of earthquakes, that the center of the Earth may be liquid. Thorough experimental and mathematical inquiry, Oldham noticed that earthquakes travelled faster as they move deeper into the earth, until they slow down a depth of around 2900 km (Badescu and Zacny, 2015). From this, scientists theorized that the core must be made of a different material. Finally, in 1936 geophysicist Inge Lehmann concluded that there was in fact as solid inner core contained within this liquid layer, confirming Wiechert's original hypothesis.

Although scientists cannot obtain physical matter extending beyond the surface of the Earth, science has led to the development of new technologies that allow for the deduction of a great deal of information concerning what lies beyond the Earth's exterior. The perception and innovation of many philosophers, chemists, physics, astronomers and others was vital to arrive at today's understanding of the planet, and many more great minds will be needed to take scientific understanding beyond Earth.

Determining Planetary Composition Using Modern Methods

Though concepts of the Earth's composition were rooted in philosophical thought in ancient times, human understanding of these processes evolved over millennia to become deeply entrenched in the methods of scientific inquiry used today. Furthermore, the development of studies involving planetary structure have provided greater insight into the inner composition of other planets in the solar system. As the knowledge of these terrestrial processes continues to grow, so too will its applications, including a promising understanding of exoplanets and other planetary bodies.

Scientists from varying backgrounds such as Geophysicists, chemists, mathematicians and biologists are able to use techniques from their respective disciplines to predict and analyze the structure of other planets (Figure 1.35).

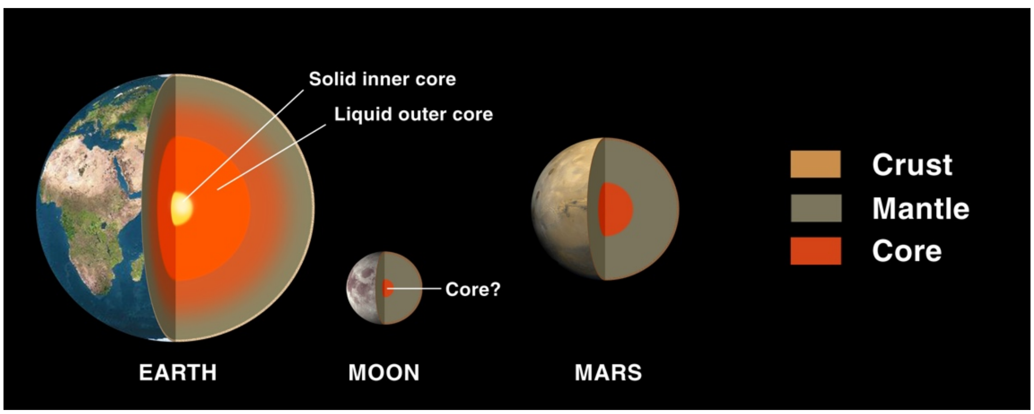


Figure 1.35. The inner structure of the Earth as well as other celestial bodies.

Spectroscopy

One technique scientists employ to study the chemical composition of planets and stars is astronomical spectroscopy. Spectroscopy analyses the electromagnetic radiation of planetary bodies, thereby allowing scientists to derive their physical properties. The atmosphere of Mars has been extensively studied through the use of molecular spectroscopy. Studies of bands formed by spectral analysis have revealed the presence of water vapour in the Martian atmosphere, giving researchers insight into the hydrological history of Mars (Rao, 1985). These analyses have also displayed clear variations in the ratio between H_2O and its isotope HDO, which is found in higher abundance across Mars, indicating significant proof of planetary water loss over time (Krasnopolsky, 2015). This could mean that water was present on the surface of Mars at some point in time. Isotopic variation also suggests the existence of a water cycle on the planet; high resolution spectrometers have shown that there is a lower deuterium-enriched water concentration in the atmosphere of Mars than there is in the planet's orographic depressions and polar ice reservoirs, signifying that water must cycle throughout a range of altitudes (Villanueva et al., 2015). Due to these developments, advancements in astronomical spectroscopy has been instrumental in proving insights into the history of Mars, as well as the planets potential to accommodate life.

The Understanding of the Composition of Mars

As scientists have put together various techniques that help deduce the composition of celestial bodies within our solar system, the composition of Mars is being well studied to this day.

Like Earth, Mars is a planet that has undergone various processes of differentiation, producing a dense and metallic core successively overlaid by less dense materials. The core itself is made up of iron sulfide, which is partially fluid, and is surrounded by silicate mantle that forms tectonic plates as well as volcanic hot spots on the surface of the planet (Mitchell and Wilson, 2003).

As geologists use stratigraphic mapping to formulate an understanding of planetary bodies, the principle of superposition is an important concept currently used to deduce the evolution of planetary surfaces. The principle of superposition states that a surface layer must be younger than any layer that lies underneath. Moreover, geologists have used the principle of superposition to investigate the controversial debate of whether liquid water had once existed on the surface of Mars.

As the Earth was originally believed to have been made up of four elements, geologists aim to find evidence of the existence of only one of the four elements on Mars; water. Furthermore, as the composition of Mars is currently well understood, scientists conclude that the interior seldom contains any form of elemental water (Mitchell and Wilson, 2003). As a result, they are left to study geomorphic evidence such as playa lakes and impact craters which provide further insight into historical processes that would have occurred on the planet.

Mass and Radius

Scientists can also predict the composition of other planets and celestial bodies by comparing them to planets of similar sizes whose composition is known. Planets that have similar masses and radii, and therefore similar densities are predicted to have similar composition. For example, the exoplanet Kepler-78b which has a similar density, mass and radius to Earth was shown to have an analogous composition consisting of an iron and rock interior (Howard et al., 2013). As well, high density exoplanets such CoRoT-7b and Kepler-10b are shown to have a rocky composition and a metallic core similar to Mercury which is also a highly dense planet (Valencia et al., 2013). However, this method is not always suitable as it cannot determine the composition of planets with no known analogs in dimension and is often combined with other techniques such as spectroscopy in order to ensure accuracy. Some exoplanets, such as those that are composed of 25% water ice by mass can be identified quite accurately due to the low density of water which allows for a distinguishable radius to mass ratio of the planet (Seager et al., 2007). However, planets composed of carbon or silicate are not as easy to distinguish. These planets often overlap with each other in their radius to mass ratios, so their compositions cannot be concluded as easily (Seager et al., 2007). Regardless, analysing the mass and radii of known planets allows for approximation of the compositions of planets that are out of reach and in other galaxies. .

Mathematical Modelling

Another technique is mathematical modelling, which is a novel approach taken by scientists to develop an understanding of the diversity of plants within the solar system. Similar to the previous method, a basic understanding of the composition of the planets can be obtained via analysis of the radius and radial velocity measurements. Both these parameters are used to formulate a graphical representation which displays planets with similar chemical compositions existing next to one another. Scientists then use planets with various common traits such as Uranus and Neptune (both belong to the family of "ice giants") to analyse their respective interior composition (Musielak and Quarles, 2017). A study recently conducted by NASA found that the mass-radius relationship of Neptune was indicative of a hydrogen/helium envelope as well as a core made up of ice and other gases such as ammonia and methane (Spiegel, Fortney and Sotin, 2014). Moreover, the rock : iron mass ration of the planet is taken which is then used to model the thermal evolution, providing a deeper understanding of the interior temperatures and the density of the core.

Seismology

One of the most common methods used to determine the composition of planets is seismology, as it was also previously used to find the composition of Earth. Seismology is the study of analyzing cosmic waves that travel through the interior core. Seismic waves are able compress rock and mantle to produce oscillatory waves at varying amplitudes. More specifically, these waves are produced when the planet's crust shifts, causing tectonic movement.

Seismometers, attached to a heat probe are placed on the surface of a planet by rockets to measure the specific temperature, density and pressure within the core and the surface (Tong and García, 2015). From these observations, astronomers can formulate and refine computer generated models of the interiors of planets. Computer models are then able to calculate the density between each varying layer of the interior and correlate appropriate temperatures with each layer until it reaches the core (Lognonné, 2005). Putting together these observations and calculations provides insight to scientists on the potential chemical makeup of the planet's interior.

New technologies are constantly emerging, allowing scientists to determine the properties of distant planets more efficiently and accurately. To maximize precision, these techniques are often combined and involve the integration of various scientific disciplines and individuals. In the future, science will continue to explore the universe, and push the boundaries of human understanding

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EXPLORATION IS CURIOSITY PUT INTO ACTION.

- DON WALSH

CHAPTER 2

New Frontiers: Exploring & Categorizing the World

In our efforts to understand our world, the acts of exploring and categorizing are so simultaneous that they might better be considered together a single process. The most human approach to understanding something wholly new is to compare this new experience with all that is already known and understood, and associate it with that to which it is most similar - i.e. put it in the box where it belongs. In science, these boxes are meticulously labelled and arranged, such that the level of order almost defines our level of understanding. And what enables this process of exploration-categorization is, ultimately, our ability to recognize similarities and patterns.

The matter of expanding our collection of boxes, or our knowledge, lies in communication and collaboration. Adequate description of physical phenomena is essential if future scientists are to reference the work of their predecessors in subsequent journeys of exploration-categorization of their own. We have not perfected this process, and as is discussed in the following chapter, the nature of our nomenclature and documentation influences our very perceptions of that which they are intended to describe.

The involvement of a vast number of individuals hailing from a diverse range of fields has led to an equally diverse variety of methods through which one may identify and document phenomena. As with any team effort, there exists the potential for conflict; across hundreds of years and entire continents, the collaborative process of exploration-categorization has encountered its fair share of disagreements involving misinterpretation or opposing methodologies. This has prevailed even as the nature of interpretation and comprehension has evolved from philosophical thought of the early natural sciences to empirical testing. As we will soon observe, the want for physical, irrefutable evidence, practicality and greater public interest marked the beginnings of the modern scientific method.

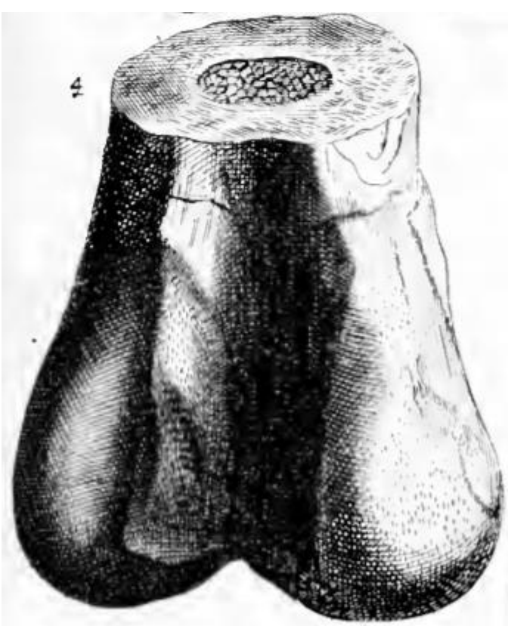
While the contents of this chapter, and book, are primarily rooted in the past, the process of exploration-categorization continues unimpeded today. If there is an upper intellectual limit, it must exist so far beyond our understandings that we may as well regard our pursuit of knowledge as an inexhaustible one.

Before There Were Dinosaurs

Dinosaurs have been influencing human stories even before the word "dinosaur" was conceptualized. Throughout history, fragmented remains of large fauna have been explained through myths and legends of dragons, giant humans (Weishampel and White, 2003), or mythological creatures (Brett-Surman, Holtz and Farlow, 2012). With the rise of Christianity, fossilized remains were kept in churches, connected to biblical figures or explained as rocks formed into the shape of human remains by God (Weishampel and White, 2003). By the 17th century, these views were challenged by the emergence of comparative anatomy and scientific analysis (Weishampel and White, 2003). This lead to four major discoveries and realizations.

Science Emerges

Figure 2.1. Plot's discovery of this femur segment began the discussion of the petrification of bones.



Robert Plot was a major figure in the transition from fossils being the product of "God's Grandness" to the remains of past life. This was initiated by his analysis of the lowermost part of a femur in 1676 (Figure 2.1) (Weishampel and White, 2003). This segment weighed 20 pounds (Delair and Sarjeant, 1975) and appeared to belong to a human or animal (Weishampel and White, 2003). However, the dimensions of the bone did not match anything that lived in the area where the fossil was found (Weishampel and White, 2003). This lead Plot's colleagues to think that the femur was not a bone, but a hollow rock in the shape of a bone that was then filled with material. The lack of hollow portions where bone marrow would have been supported their idea (Weishampel and White, 2003). This concept fitted the common belief of the time: that fossils were formed by the plastic nature of the Earth. Even though Plot agreed with this, he did not in regards to this femur (Delair and Sarjeant, 1975). Instead, he believed that it was in fact a real bone that had been petrified, and the hollow interior filled with rock (Weishampel and White, 2003).

Plot recognized that the dimensions of the bone were larger than those of animals in the area. He speculated that the bone belonged to a larger organism (Weishampel and White, 2003), specifically an elephant that may have been brought to Great Britain from Rome (Brett-Surman, Holtz and Farlow, 2012). However, when he had the opportunity to compare the femur to that of a living elephant, he discovered that the femur was too small. Plot then concluded that the bone belonged to a giant human (Weishampel and White, 2003).

Plot's idea that bones could be petrified shook the popular belief that fossils were Earth's replications of life, or a reminder of God's greatness. Furthermore, it prompted the scientific community to explore the possibility that fossils were remains of ancient organisms (Weishampel and White, 2003). This new comparison of fossils to life was seen in an explosion of fossil descriptions in the late 18th to 19th centuries including vertebrae, limbs, fish ribs, and teeth (Colbert, 1968; Delair and Sarjeant, 1975; Brett-Surman, Holtz and Farlow, 2012). Although these discoveries played a role in the development of science, many of these conclusions were incorrect. The major findings and descriptions that would advance the interpretation of ancient life would come from William Buckland and Gideon Mantell.

William Buckland

William Buckland was born in 1784 (Colbert, 1968) and became the first professor of Geology at Oxford University (Delair and Sarjeant, 1975). He was a fossil collector, commonly known as a Divine, and focused on sequencing sedimentary rocks and the fossils within them (Colbert, 1968). In 1818, he was elected into the Royal Society, and in 1824, he became the president of the Geological Society of London (Colbert, 1968). He wrote many papers and books on Geology and Mineralogy. However, Buckland is best known for his description of reptile fossils (Colbert, 1968), in particular those belonging to a large carnivorous lizard that lived on Earth long ago and was quite unlike the reptiles seen today (Colbert, 1968; Weishampel and White, 2003).

The date of Buckland's discovery for the described fossils is unknown, since he did not record this in his field notes. However, in a letter, Bargon George Cuvier stated that he saw Buckland's fossil collection in 1818 (Delair and Sarjeant, 1975), indicating that the fossils were found prior to their meeting. Buckland's small collection included teeth, part of a lower jaw, a section of vertebral column, two ribs, a femur, and a fibula (Weishampel and White, 2003). The most important of these fossils was the section of jaw (Figure 2.2), which contained blade like teeth set in sockets (Colbert, 1968), characterizing this reptile as a member of the Saurian family (Weishampel and White, 2003).

After describing the appearance of the *Megalosaurus*, Buckland went on to decipher its habits and the environment in which it lived (Weishampel and White, 2003). Buckland concluded that the *Megalosaurus* lived near a marine or lacustrine environment, since the rocks containing its fossils also contained shark teeth, fish bones, and shells, along with both terrestrial and laucustrine plants (Weishampel and White, 2003). Due to this environment, he rationalized that the *Megalosaurus* had amphibious tendencies, similar to those of modern day turtles and crocodiles (Weishampel and White, 2003).

This discovery and description piqued scientific interest in the fossils of large unfamiliar reptiles. Little did he know that his work, along with that of Gideon Mantell, would contribute to the creation of a new class of ancient reptiles.

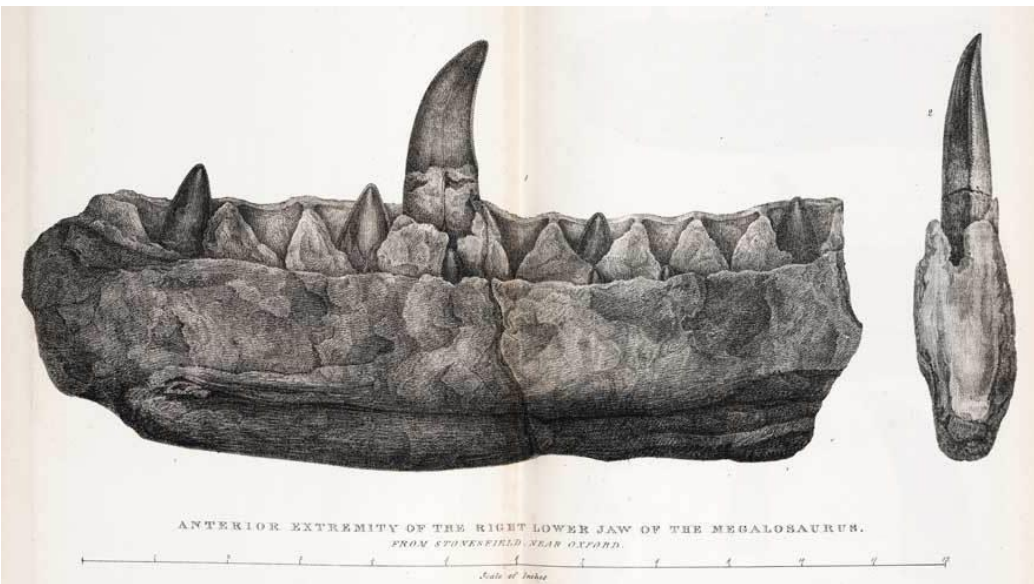


Figure 2.2. This tooth-in-socket jaw fossil was instrumental in the naming of the Megalosaurus (Colbert, 1968).

With help from Cuvier, Buckland determined this reptile to be 40 feet long and bulkier than an elephant (Colbert, 1968). However, when dimensions were predicted from the thigh bone, this carnivorous lizard was estimated to be 60-70 feet long and as tall as a modern day elephant (Weishampel and White, 2003). Sometime between late 1821 and early 1822, the name *Megalosaurus*, meaning "great lizard", was suggested to Buckland by W.D. Conybeare (Colbert, 1968). Finally, in 1824, with encouragement from Cuvier, Buckland presented his description of the *Megalosaurus* to the Geological Society (Delair and Sarjeant, 1975). Later that year, Buckland published this description with the hope that it would accelerate the accumulation of knowledge about the *Megalosaurus*, by making people aware that they possessed fossils of this great lizard (Weishampel and White, 2003).

Gideon Mantell

Gideon Mantell grew up in Lewes in the 1790s, and was fascinated by fossils even as a young boy (Colbert, 1968). He became a medical practitioner and planned to focus on fossils outside of his work. In 1816, he married Mary Ann Woodhouse, and over the next nine years, they had four children (Colbert, 1968). On his visits to medical patients, he looked for fossils, and his wife occasionally accompanied him (Colbert, 1968). In the spring of 1822, while Mantell was with a client near the Tilgate Forest, Mary Ann found a collection of strange teeth (Figure 2.3) among a pile of rocks at the side of the road (Colbert, 1968).

By then, Mantell had become an expert on extinct reptiles, with a strong interest in ancient reptile bones of the South Downs. When Mary Ann showed him her discovery, he did not recognize the teeth (Colbert, 1968). Upon inspection, he believed that they belonged to an herbivore, likely a colossal reptile since there had been no mammal fossils found in the area. Mantell returned to the site of her find, and unearthed more fossils which were included in his book, titled *The Fossils of the South Downs* (Colbert, 1968). This publication described several invertebrates and shells, and included 364 fossil figures drawn by Mary Ann.

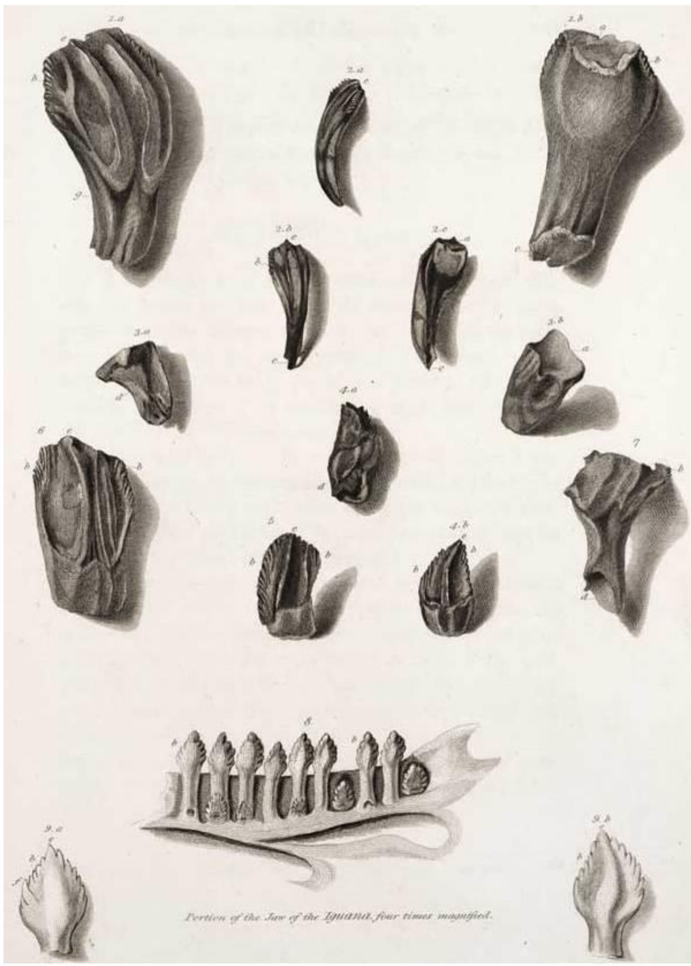


Figure 2.3. A jaw and various Iguanodon *teeth found by Mantell and Mary Ann near the Tilgate Forest (Colbert, 1968).*

Still puzzled about the origins of the teeth, Mantell sent them to Cuvier who hypothesized that they were the upper incisors of a rhinoceros (Colbert, 1968). This was supported by other Tilgate Forest fossils thought to be a hippopotamus and a rhinoceros. Neither the Geological Society of London, nor the emerging paleontologist William Buckland, showed interest in Mantell's find, believing the teeth to belong to a large fish or mammal (Delair and Sarjeant, 1975). This did not deter Mantell. He took the fossils to the Hunterian Museum but they did not resemble any of those in the museum's collection (Colbert, 1968). Mantell then met with Samuel Stutchbury, who found similarities between Mantell's teeth and those of iguanas in Central America. Both sets were worn, with flat surfaces for grinding fibrous materials (Delair and Sarjeant, 1975). This was Mantell's first clue in discovering the origin of his fossils (Colbert, 1968).

In 1825, Mantell published a paper, titled *Notice on the Iguanodon,* in the journal of the Royal Society of London describing his fossils (Colbert, 1968). *Iguanodon* means "iguana tooth", and was suggested by Conybeare. Mantell approximated the creature's length to be 60 feet and used clues from the fossilized bones to determine that it was a freshwater amphibian (Weishampel and White, 2003). He compared the *Iguanodon* teeth to reptile skeletons at the Royal College of Surgeons and described the similarities of the teeth-jaw joints (Weishampel and White, 2003). Initially, Cuvier disputed Mantell's claim that the fossils belonged to an ancient iguana (Colbert, 1968), but later Cuvier accepted the idea, bringing Mantell into the inner circle of the Geological Society (Weishampel and White, 2003).

Mantell devoted much of his life to his love of fossils, leaving him little time for medicine (Colbert, 1968). He expected to unearth more ancient remains at the site of Mary Ann's first discovery, which would need both an educated eye and perseverance (Colbert, 1968). As his collection of fossils grew, his house began to resemble a museum and attracted many curious visitors (Colbert, 1968). In 1833, Mantell and his family moved to Brighton to be closer to the Tilgate fossil beds in hope that his work with fossils and medicine would be appreciated by the nobles who frequented the town (Colbert, 1968). Unfortunately, this was not the case.

Life was difficult for the Mantell family since Gideon prioritized his fossils over his medical practice and his family (Colbert, 1968). In 1838, Mantell published his book *The Wonders of Geology,* sold his fossil collection to the British Museum, and with that money, moved and bought a medical practice (Colbert, 1968). The following year, his family left him. Before his death in 1852, he was an active member of the Royal Society of London, and was honoured with their Gold Medal (Colbert, 1968). Although his work on the *Iguanodon* was not supported by his family, his discovery would play a major role in Richard Owen's revelation of a new class of ancient reptiles.

Richard Owen

Richard Owen, like Gideon Mantell, was trained as a physician (Colbert, 1968). However, he applied his knowledge of anatomy to his work at the Hunterian Museum of the Royal College of Surgeons (Weishampel and White, 2003). Owen devoted much of his time to Natural History, and was active in displaying and describing the museum's fossil collection (Colbert, 1968). His views and ideas were widely accepted, making him a leader in science. Owen's interest in reptiles was piqued by the discoveries of Buckland and Mantell and would lead to his ground-breaking classification (Colbert, 1968).

In 1841, Owen identified the *Cladeidon* and the *Cetiosaurus* (Colbert, 1968) bringing the grand total of extinct reptile classes to nine (Colbert, 1968). He believed that these reptiles were worthy of their own order. Owen came to this conclusion due to his vast experience in comparative anatomy from cataloguing fossils in the Surgeon's museum and performing animal autopsies (Colbert, 1968).

With this realization, Owen was determined to develop a classification for these ancient organisms based on the *Megalosaurus*, *Iguanodon*, and *Hylaeosaurus* (Figure 2.4) (Colbert, 1968).

In his investigation of these reptiles, Owen confirmed that the *Megalosaurus* was a carnivorous lizard, since its teeth were similar to those of modern meat-eating lizards (Weishampel and White, 2003). Owen also re-calculated the length of this reptile to be 30 feet, using the size of its vertebrae and the anatomical ratios of crocodiles (Weishampel and White, 2003). Owen's inquiry into the *Iguanodon* lead him to discover that its tooth structure did not match anything he had ever seen (Weishampel and White, 2003). Owen also re-evaluated the length of the *Iguanodon* with the same ideas he used for the *Megalosaurus* (Weishampel and White, 2003). He determined the *Iguanodon* to be 28 feet long. In late 1841, Owen presented his new order of reptiles to the Geological Society of London (Delair and Sarjeant, 1975) and in 1842, he published his conclusions (Colbert, 1968).

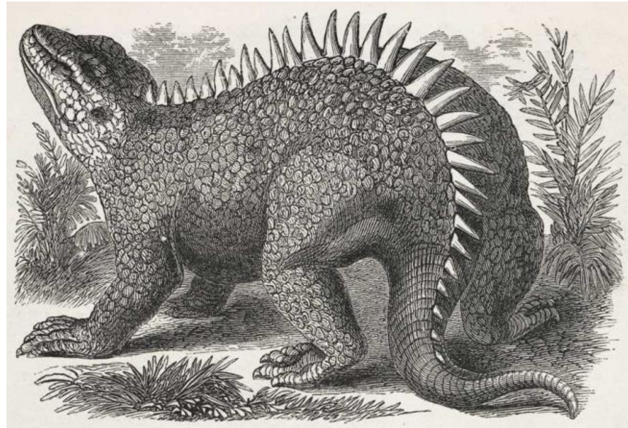


Figure 2.4. Illustration of the Hylaeosaurus*, an armoured reptile found in Southern England and described by Mantell in 1842 (Colbert, 1968). This was one of the three original* Dinosauria.

His new order of reptiles was titled *Dinosauria*, a term based on the Greek words *deinos* and *sauros* meaning "terrible lizards" (Colbert, 1968). This order contained ancient giant lizards with mammalian features (Weishampel and White, 2003). His paper described similar features among *Dinosauria* which included a large sacrum made of five immobilized joints, outward sculpting arches on dorsal vertebrae, ribs that attached to the vertebrae at two places, and bodies supported by four clawed limbs (Weishampel and White, 2003). The term *Dinosauria* was a turning point in the field of science and framed ancient life in a new way.

Owen was enthralled by the vast differences in *Dinosauria* bones and how these related to varying adaptations (Colbert, 1968). He began to imagine the outside appearance of these creatures. In 1854, his ideas came to life when he partnered with Mr. Waterhouse Hawkins to fabricate life-sized models of *Dinosauria* for a showcase at the Crystal Palace (Colbert, 1968). Hawkins used the fossils to make scaled drawings, which were edited and approved by Owen before construction (Weishampel and White, 2003). The most famous model in the display was the *Iguanodon* (Figure 2.5), which was shown as a dinosaurian rhinoceros (Colbert, 1968).

As an anatomist, Owen's interests extended beyond his work with *Dinosauria*, and he published numerous papers on his descriptions

Figure 2.4. Illustration of the

of vertebrate and invertebrate fossils (Colbert, 1968). Although his early scientific ideas were well accepted, he was not open to changes (Colbert, 1968). He opposed Charles Darwin's Theory of Evolution in 1859, and his credibility declined as his ideas were challenged by younger scientists (Colbert, 1968). Even though his career and reputation withered away, he will always be known for amalgamating the current ideas of ancient reptiles, and conceptualizing dinosaurs (Colbert, 1968).

The discoveries and realizations of Owen, Mantell, Buckland and Plot not only gave rise to the order of *Dinosauria* but also created a new field of science. These men changed the views of their time, providing a better understanding of ancient life and creating a foundation of knowledge for future paleontologists.

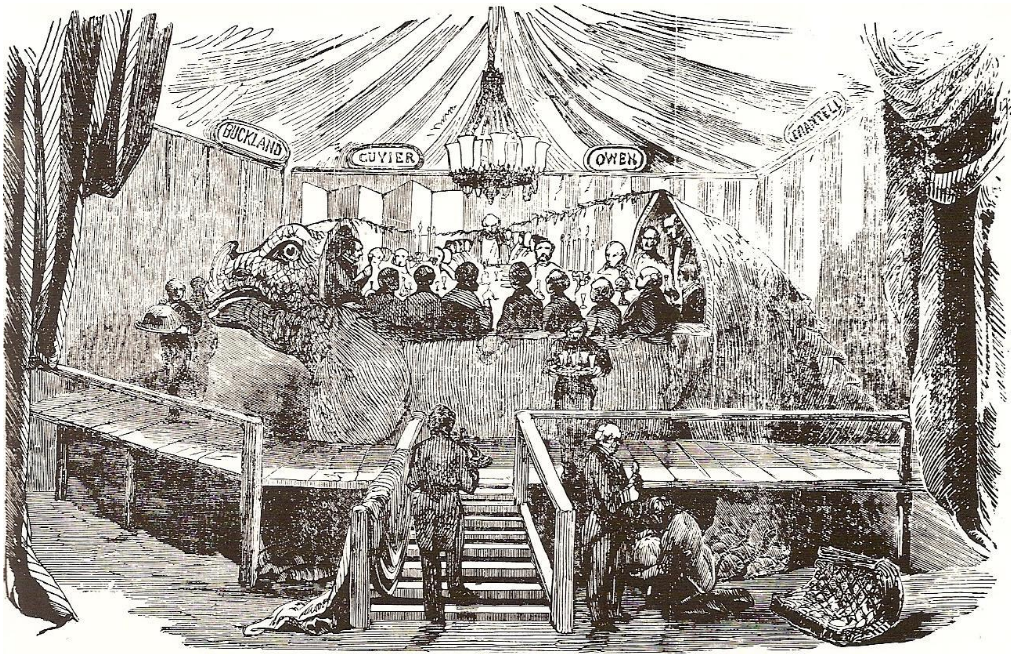


Figure 2.5. Illustration of the Iguanodon *display at the Crystal Palace. Before completion of the model, Owen hosted a dinner party inside the concrete replica (Colbert, 1968).*

Paleoreconstruction Using Amber

Although fossilization has provided tremendous insight into the macro-structures of dinosaurs, recent work with amber has allowed scientists to uncover the fine details of dinosaur anatomy, and their possible habitats.

Amber is fossilized tree resin (Penney et al., 2013), and deposits can be found in many locations, such as China, France, and Western Canada (McKellar et al., 2011). While dinosaurs fossilized in rock are usually disarticulated, fragmented, or compressed (Daza et al., 2016), amber preserves fine details and microstructures (Xing et al., 2017). Rock fossilization can also replace organic material with minerals, whereas amber preserves soft tissue, bones, and even pigmentation (McKellar et al., 2011). Amber can be translucent, but visualizing overlapping structures may require breaking the amber at specific points. This has the potential to harm the fragile structures (Perrichot et al., 2008). Although it is rare to find an entire organism encased in amber, even fragments of specimens can guide understanding of how organisms developed, behaved, and evolved in certain time periods.

To study specimens encased in amber, scientists use an array of technologies, such as X-ray micro-CT scanning, to render an image of the soft tissue and bone (Xing et al., 2016). Analysis of the Mesozoic specimens of the Late Cretaceous found in Western Canada have confirmed that birds in this era were adapted for both flight and underwater diving, due to similarities in their feather structure with that of modern marine birds (McKellar et al., 2011). Upon close examination of the feather filaments, cell walls, and the cuticular scales of other amber-preserved feathers, researchers have concluded that some dinosaurs were feathered (McKellar et al., 2011). The challenge lies in matching these feathers to known dinosaur species, because the fine details present in amber specimens are not seen on the more complete fossilizations (Xing et al., 2016). To overcome this, feather morphology is used to narrow the pool of likely species (Xing et al., 2016), but sometimes researchers must speculate based on fossils in adjacent strata (Perrichot et al., 2008).

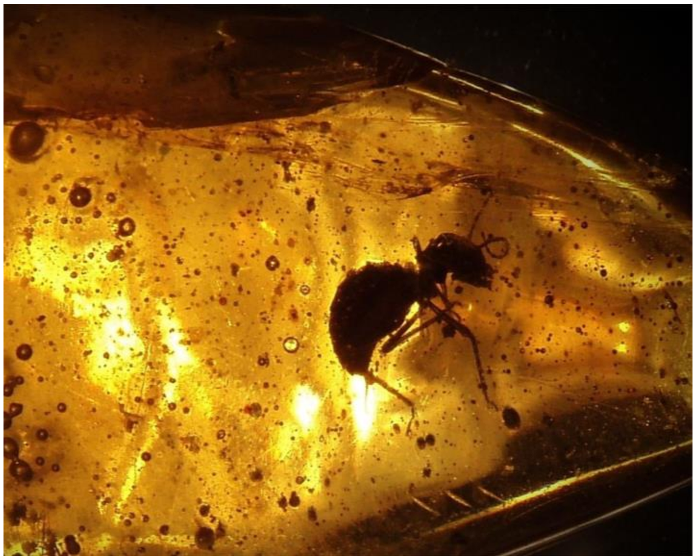


Figure 2.6. An ant encased in amber. Scientists use insect inclusions to predict past environments (Daza et al., 2016.

The elemental composition and other inclusions in amber also contain valuable information. An analysis of trace elements filling the cavities in the surrounding resin can identify the type of habitat in which the organisms lived, the amber's tree species, and possible ecological conditions (Davies et al., 2014). This can give researchers insight into the surrounding water sources, temperature and atmospheric oxygen levels of the time. Small organisms, such as insects (Figure 2.6), are often found in the amber as well (Daza et al., 2016). By identifying their modern counterparts, scientists can extrapolate today's environmental conditions to the past.

Even in amber, many tissues are degraded (Xing et al., 2016). This includes blood, as demonstrated by the high iron levels from hemoglobin decomposition. Futuristic movies and novels are optimistic that dinosaur DNA could be extracted from amber, but several reports, including a study in 2013 by Penney et al., state that this is highly unlikely. These researchers attempted to match a sequence of stingless bee nucleotides, from a specimen preserved in the amber precursor known as copal, to extant species of stingless bees and other sequenced organisms (Penney et al., 2013). The outcome was short, meaningless alignments with both bee and bacterial genomes, indicating that the extent of degradation in copal was too great to obtain viable DNA. This would also be the case for specimens in amber, since they are millions of years older (Penney et al., 2013).

Amber specimens and inclusions are indicative of life at the time the organism was encased. The rarity of amber-preserved fauna, and the lack of detail in lithified structures complicates correlating specific microstructures to known species. However, amber may hold the key to major dinosaur discoveries. Although replicating a live dinosaur is highly unlikely, specimens preserved in amber may reveal more about dinosaur colouring, their use of feathers, and evolutionary timelines. As paleontology progresses, amber analysis will be an important tool to further understanding of ancient life.

The Badlands of Alberta: A Glimpse into the Late Cretaceous Period

The distinct badlands of the region now known as Dinosaur Provincial Park (Figure 2.7) in Alberta act as a lens into the Earth as it was during the Late Cretaceous Period, an era that was radically different from our current home. Approximately 66 million years ago, this Park more closely resembled the Everglades of Florida than its currently dry, scarce, and eroded landscape. Flash-forward to the badland vista of the present day and Dinosaur Provincial Park and the genera of the Cretaceous Period have been preserved in abundance underground, making the Park the single richest site for dinosaur fossils and remains in the world (Spalding, 2000). As of 2017, the Park has brought forth more than 250 dinosaur skeletons of over 50 distinct species (Alberta Parks a, 2018). The question then arises of how the evidence was pieced together to reveal this bygone era and the role it played in the establishment of Dinosaur Provincial Park.

Figure 2.7. The badland landforms of Southern Alberta. The Dinosaur Park formation is exposed in the landscape.

The Paleontological Richness of the Region

It is important to understand the geology of the region now known as Dinosaur Provincial Park in order to comprehend how it has become a world-renowned epicentre for paleontological discoveries. This entails having a knowledge of the geologic formations that were deposited during the Late Cretaceous Period - a task that has, historically, not been simple. The region boasts three different eologic ormations that contain fossils; the Oldman, the Dinosaur Park, and the Bearpaw (Longrich and Currie, 2009). The delineation and distinction between each of these formations has evolved over time. These modifications were integral in creating a more precise record of past depositional environments in the region and therefore will be described in the following section.

In 1885, the ground beneath the region that is now the Park was characterized as one unit - the Belly River series by - George Mercer Dawson, a Canadian geologist and surveyor during the late 1800's (Currie and Padian, 1997). Dawson noticed differences in colouring between the upper and lower beds of the series. The lower section was a dull yellow colour and the upper was paler; subsequently, he subdivided the series into the Yellowish and Pale beds. Donaldson Dowling, one of Canada's permanent geologists and a topographer for the Geological Survey of Canada, agreed with Dawson's assertions about the Yellowish and Pale beds being distinct, yet arbitrarily renamed the lower bed Foremost in 1885 (Currie and Padian, 1997). Dawson's characterization of the Belly River series became problematic as evidence suggested that there were more than two depositional environments present within in the grouping. Therefore, a definitive report was published in 1940 by L.S Russell and R.W Landes, who were well published topographers for the Geological Survey of Canada, in order to rename and subdivide the series. The formations were renamed to eliminate the Pale bed classification denoted by Dawson as the Milk River, Pakowki, Foremost, and Oldman formations (Russell and Landes, 1940).

The Dinosaur Park Formation itself was defined and named in 1993 by David Eberth and Anthony Hamblin who were documenting the compositional variation of the Belly River series (Eberth and Hamblin, 1993). The Belly River series was still a general term used to classify formations in the greater area surrounding southwestern Alberta despite being the name being dismantled in 1940. Eberth and Hamblin were examining core and well logs in southwestern Alberta, western Saskatchewan, and northwestern Montana when they discovered a regional discontinuity within the Oldman Formation (Currie and Padian, 1997). As a result, they suggested dividing the Oldman Formation into two separate lithostratigraphic subunits: the underlying Oldman Formation and the Dinosaur Park Formation. The latter formation was named after the region (presently Dinosaur Provincial Park) to which it was well exposed (Figure 2.7) (Currie and Padian, 1997).

The marine Bearpaw Formation overlays the aforementioned formations (Currie and Padian, 1997). George Dawson and Joseph Tyrrell (whose importance will be further discussed in the following sections), referred to the formation as the Pierre Formation when they were studying the then Belly River series in 1885 (Allan, 2018). The name was later changed in 1903 after Hatcher and Stanton defined a series of exposed beds in the Bearpaw mountains of northern Montana (Allan, 2018). They also recognised that this formation was continuous across the vast majority of North America, including the land covering the region of the Park (Allan, 2018). It is important to note that the Bearpaw Formation has an important exposed section along the Red Deer River (Figure 2.8) which paleontologists used as a landmark to navigate towards the fossil-rich badlands of the Park (Allan, 2018).

The historical significance of classifying such formations has helped geomorphologists understand and describe the landscape of the ancient depositional environments in the region. As each formation was more properly characterized, mammals (preserved in the Oldman Formation), dinosaurs and smaller vertebrates (of the Dinosaur Formation) were believed to roam a coastal plain comprised of meandering rivers, the ancestral Rockies (Longrich and Currie, 2009). Aquatic organisms (of the Bearpaw Formation) inhabited the neighbouring shallow Bearpaw sea and species-rich cypress swamps (Mychaluk et al., 2015).

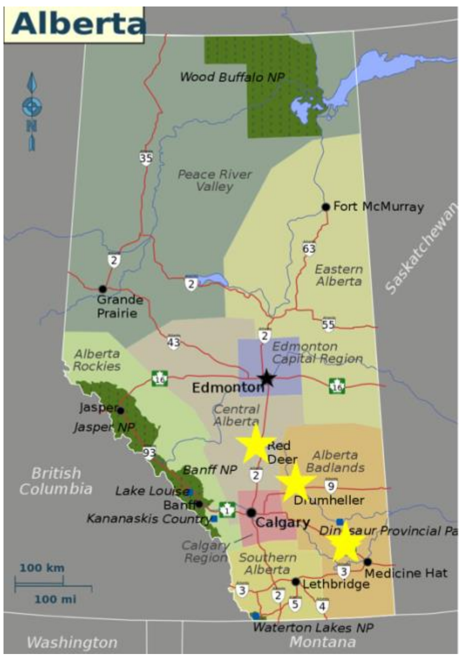


Figure 2.8. A map of Alberta, areas of interest are marked with a yellow star. Note the locations of Red Deer (river), Drumheller, and Dinosaur Provincial Park.

The remains that have helped to interpret life during the Late Cretaceous period are held within these geologic formations. David Mickelson, an expert on glacial deposits and shoreline processes, theorized the mechanism of how these traces from the ancient era were pieced together (University of Wisconsin, 2018; Mickelson and Colgan, 2003). In 1983, Mickelson hypothesized the distinct badland landforms that are exposed in the region were eroded by the Wisconsin Glacial event. The Wisconsin Glacial event was a meltwater event that occurred in Southern Alberta off of the Laurentide ice sheets approximately 10,000 years ago (Beaty, 1975). The history regarding late Wisconsin Glacial events has been refined several times as radiocarbon dating becomes more advanced, yet the details regarding the retreat of the ice described by Mickelson remain well accepted (Mickelson and Colgan, 2003).

Pre-Paleontological Discoveries

Long before the official establishment of what is now known as Dinosaur Provincial Park, the land was territory to the Peigan Nation of the Blackfoot Confederation. During the end of the 19th century, the Blackfoot Confederacy occupied the southern half of Alberta (which includes a region currently occupied by the Park), Saskatchewan and the northern portion of Montana (Sheposh, 2017). The first record of ancestral fossils came from the One Tree Creek area, a member of the Red Deer River system (Spalding, 2000). Jean Baptiste L'Heureux, a Jesuit Priest seeking refuge with the tribe, and a Peigan came across fossilized bones among "erratic boulders". In 1871, he documented these fossils as being colossal vertebrae that measured 20 inches in circumference. What was most interesting about L'Heureux's account was the local people identified the site as the grave of the "grandfather of the buffalo" (Currie and Koppelhus, 2005). This conclusion corresponded with Blackfoot culture, as their lifestyle was heavily based on buffalo hunting and the buffalo were the largest animals they had encountered (Sheposh, 2017). Accordingly, they would honour these remains by offering presents to aid them in their hunt (Spalding, 2000). This early account of dinosaurs foreshadows the discoveries to come.

The Great Canadian Dinosaur Rush

Joseph Burr Tyrrell unintentionally launched the Great Canadian Dinosaur Rush in 1884 close to the town that is presently known as Drumheller (Figure 2.8) (Currie and Koppelhus, 2005). Tyrrell was studying the coal seams and mapping the region of the Horseshoe Canyon Formation (Edmonton Formation) on the Red Deer River for the Geological Survey of Canada when he encountered a huge skull (Currie and Koppelhus, 2005). It is interesting to note that Tyrell was left partially blind by scarlet fever at a young age, and his partial blindness meant he quite literally came face to face with a fossilized dinosaur head (Spalding, 2000). E.D Cope, an American paleontologist, was the first to classify

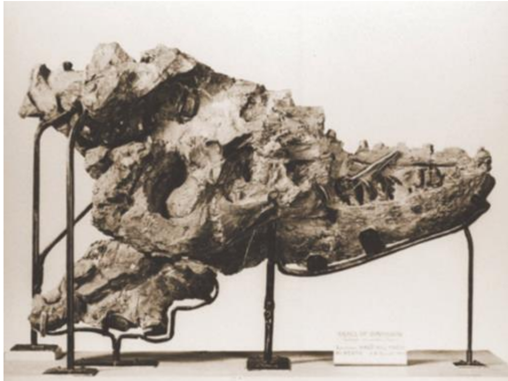


Figure 2.9. Albertosaurus sarcophagus *discovered by Joseph Tyrrell.*

the skull as *Laelaps incrassatus*. The name of the species was changed once more before being called *Albertosaurus sarcophagus* in 1905, in recognition of the place for which it was discovered (Currie and Koppelhus, 2005).

It could be argued that Thomas Chesmer Weston was the true initiator of the enthusiasm surrounding dinosaurs in Southern Alberta. Weston was the Geological Survey of Canada's only fossil collector from 1858 to his retirement in 1894, and thus the person tasked with following up on Tyrrell's finding (Spalding, 2000). In 1888, four years after the first *Albertosaurus sarcophagus* skull was discovered, Weston travelled down the Red Deer River by boat and recovered a second theropod skull from the Horseshoe Canyon Formation (Currie and Koppelhus, 2005). Weston's team continued down the Red Deer River for six days and passed by the Bearpaw Formation, where they realized it was comprised of different dinosaur-bearing layers than the Edmonton Formation where Tyrell had made his discovery (Spalding, 2000).

Next, they entered Dead Lodge Canyon, well into the badlands of what is now Dinosaur Provincial Park. There, Weston recorded the first official fossils in present Park territory. Weston's party also tried to recover the leg bone of a carnivore at this time; however, their techniques were not adequate and it "crumbled into a thousand fragments" (Spalding, 2000). Despite this, he recognized the region had an abundance of fossils, and he went on to theorize the fossils in the sand landforms of the landscape would eventually be exposed due to erosional processes (Spalding, 2000). While Weston never returned to explore Dead Lodge Canyon further, he can be credited with the following: (1) establishing an effective method of travelling the Red Deer River, (2) making the distinction between formations and thus fossils of different eras, (3) collecting many dinosaur samples, and (4) most importantly, revealing the importance and need for future work. In one of Weston's papers, *Reminiscences among the rocks: in connection with the Geological Survey of Canada*, he described the Dinosaur Provincial Park region as "the most important field in Canada, so far as bones of extinct animals is concerned" (Spalding, 2000).

Such discoveries garnered much excitement in the paleontological community. Renowned fossil-collectors and scientists flocked from around the world to see the richness described by Thomas Weston (Edmonton Journal, 1948). In 1902, Lawrence Lamb, a Canadian geologist and paleontologist, detailed many new species, thus adding more diverse fauna to help in the understanding of the Upper Cretaceous Period (Currie and Koppelhus, 2005). Lambe's discoveries added to the excitement and popularity of Weston's original comments, bringing forth more notable people of the industry such as Dr. Benjamin Arthur Bensley in 1908. Bensley, a zoologist from the University of Toronto, further contributed to the rising awareness of the region by publishing work that detailed the area's potential for valuable dinosaur fossil discoveries (Currie and Koppelhus, 2005). Such recognition brought private collectors and money to Steveville (a small-town close to fossil sites), as well as international attention to the southern badlands of Alberta, some of which was unwanted (Edmonton Journal, 1948).

To elaborate, Barnum Brown, an American paleontologist, caught wind of the land's richness and spent four years collecting specimens from the region between 1909-1913 (Currie and Koppelhus, 2005). Brown sparked controversy in the Park as he exported all of his scientific findings to be studied and displayed in the American Museum of Natural History in New York (Currie and Koppelhus, 2005). In an attempt to keep discoveries in Canada, the Geological Survey of Canada hired an accomplished paleontologist named Charles Hazelius Sternberg in 1912 to search for new dinosaur fossils (Currie and Koppelhus, 2005). This decision can be associated with the beginning of bitter competition and rivalry between Canadian and other fossil collectors from around the world.

Issues pertaining to the exportation of specimens obtained in southern Alberta by foreign collecting parties erupted periodically between 1930 to 1960. This resulted in heightened tensions between the provincial legislature and external institutions (Benson, 2017). Eventually in 1963, a conference was held in Edmonton to encourage the foundation of vertebrate paleontology programs in Alberta. The conference was attended by many vertebrate paleontologists, including many international notables such as Björn Kurten and Edwin H. Colbert. Both men were famous for their vertebrate discoveries, and their authorship of paleontological books written to target the general public (Wilkinson, 1973). The presence of international paleontologists was one of the strongest indicators of the importance and richness of the Park (Currie and Koppelhus, 2005).

The Establishment the Park

In 1911, during the years of the Great Dinosaur rush, Winfred George Anderson moved to a homestead east of Steveville and north of Brooks. Shortly, after his arrival in dinosaur country, Anderson visited one of the Sternbergs' field camps (Spalding, 2000). The Sternberg's had experienced great success in the badlands near Steveville during this period (Figure 2.10) (Russell, 2018). After visiting the Sternberg's camp and realizing its potential, Anderson began campaigning for the preservation of the fossil-rich badlands that are now Dinosaur Provincial Park. The earliest record of Anderson's intentions for the protection of the land began in a local newspaper in 1914. He went on to lobby in Ottawa, but in 1930 the responsibility for natural resources was reassigned to the prairies. Anderson's efforts seemed to be working when Alberta passed the Provincial Parks and Protected Areas Act which included objects of geological interest within the same year (Spalding, 2000). Although this may have been a monumental moment in the Park's establishment, its preservation was labelled as a low priority project during the Great Depression.

In the meantime, Charles Sternberg had begun to map the dinosaur camps he had frequented in the Steveville area from memory (Spalding, 2000). By 1938, he had created a detailed map of locations where paleontological discoveries had been made. As a distinguished paleontologist and historical politician, the first official action was made to protect the Munson and Morrin ferry sites which were outlined by Sternberg. Despite this, the act was never enforced (Spalding, 2000).

Finally, after much deliberation, the land was declared a provincial park in 1955, 66 years after the importance of the Park had been acknowledged by Thomas Weston (Spalding, 2000). Upon its opening in 1959, Steveville Provincial Park was bounded by the Red Deer River and the Montana border and spanned 8936 hectares (Spalding, 2000).

Following the Protection of the Park

Compared to the relatively high activity within the Park between 1911 and the mid-1920's, the collecting activities of museums were considerably lower between 1930-1960. This was due to a combination of reduced museum funds and economic circumstances onset by the Great Depression and World War II (Currie and Padian, 1997). Even so, it was this period that set the stage for the incredible discoveries that would once again bring the Park into public interest.

The 1960's was a period that included many management changes in the Park. In 1962, the Park's name was changed from Steveville Dinosaur Provincial Park to the current Dinosaur Provincial Park. Steveville had previously been a location notable for many specimen discoveries, after the Great Dinosaur Rush ended, it became a ghost town and the resources of the Park could no longer be associated with just one area (Spalding, 2000). It was also during this time that, as a result of the previously discussed conference pertaining to the export of scientific material out of the Park, a paleontological program was included in the plans to build a Provincial Museum. The program was opened in 1965 through the University of Alberta, and the Provincial Museum of Alberta was founded in 1967 (Currie and Koppelhus, 2005). Although new programs and a desire by new local museums for fossils encouraged more in province collectors to utilize the Park, this shift was slow because of the recovering economy, and mainly consisted of graduate students and paleontological hires curating museums. The Parks Management also attempted to hinder the movement of fossils. Extremely protective of the Parks resources, they insisted that any "display-quality" specimens remain within the Park (Currie and Koppelhus, 2005). This regulation caused a major dispute when in 1969, quality *Centrosaurus* specimens were removed by helicopter and bulldozer and taken to the University of Alberta before the Parks personnel were aware of what was happening. Parks staff initially disputed the removal, but "possession is nine-tenths of the law" meaning ownership is easier to maintain when someone has possession of said object. The specimens have remained permanently catalogued in University Collections (Currie and Koppelhus, 2005). This period demonstrated a decrease in dinosaur hunting and discovery, but the low number and strict regulations of researchers prevented damage to the Park. By

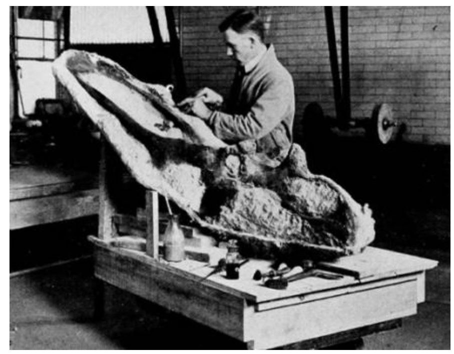


Figure 2.10. George Sternberg, son of Charles Sternberg, preparing the skull of Chasmosaurus belli *(collected from the Dinosaur Park Formation) in the badlands of Red Deer river, Alberta. A representation of the success of the Sternbergs in the region.*

contrast alone, this period of relative research disinterest made the following period of heightened discoveries all the more exciting.

The Dinosaur Renaissance

In the 1970's, public interest in dinosaur discoveries once again soared. This was largely due to research done by Robert Bakker, Peter Dodson, Jim Farlow, John Ostrom, and Dale Russell, a group of paleontologists who focused their research on structures called "bonebeds", which will be discussed in future sections (Currie and Koppelhus, 2005). This period, known as the Dinosaur Renaissance, resulted in increased funding from the Government of Alberta (Ostrom, 1974). A bigger budget meant that more resources were able to be utilized, and thus the number of discoveries increased. This lead to more funding and the pattern continued. With a heightened increase in public dinosaur interest, negotiations were underway to register the Park as a UNESCO World Heritage Site, and the Federal Government of Canada began the process of creating a motion (Currie and Koppelhus, 2005).

To promote active research in the Park, the Provincial Museum of Alberta was encouraged to become more involved in excavation. This resulted in a significant change in the treatment of discoveries. Previously, park procedures encouraged that findings remain in the Park, even if they were being damaged by erosional processes. As well, any fossils taken out of the Park to be cleaned and displayed were subject to recall. Strong museum and government influence eventually resulted in an impressive proposal package consisting of displayed and articulated fossilized evidence attesting to the richness of the Park that was not subject to recall. The motion was submitted in 1978 to UNESCO, and by 1979, Dinosaur Provincial Park became the first paleontological site registered on the UNESCO World Heritage List (Currie and Koppelhus, 2005). Being a World Heritage Site meant that the Park was protected by international treaties and recognized for its cultural and scientific importance (Centre, U., 2018).

Modern Day Dinosaur Provincial Park

Today, Dinosaur Provincial Park encompasses an area of 7929 hectares and attracts 100,000 visitors annually (Tourism, 2010). Many of the current procedures that exist in paleontology today can be traced back to the discoveries made before the Park was established. The influence of Dinosaur Provincial Park has also traversed academia and infiltrated social culture and media in ways that are still being shown today.

Societal Impacts

Dinosaur Provincial Park has had a major impact on not only paleontology in general, but also public interest and culture. The soar in dinosaur interest due to the discoveries within the Park are directly responsible for famous works of media and literature, an example of which being the incredibly successful *Jurassic Park* book and film series. The Dinosaur Renaissance changed public sentiment towards paleontology, and with increased interest came a surge of new paleontological programs and tourism opportunities. Dinosaur Provincial Park's role in initiating the dinosaur scientific revolution did not stop at starting the Dinosaur Renaissance. It continued to be an integral part in supporting a surge of new paleontological programs and contributing evidence to fast-track society's understanding of almost all aspects of dinosaur biology (Bakker R.T, 1987)

Change in Paleontological Research

Much of the research being done in the Park still revolves around bonebeds. As previously mentioned, the paucity of dinosaur discoveries enveloping most of the 1960's came to an end with the excavation of bonebeds. Bonebeds are notable accumulations of fossil bones and other structures from multiple individuals that occur in a geologic stratum or on the surface of the ground (Figure 2.11) (Ederth et al., 2008). They are prized by paleontologists for their unique ability to significantly add to the understanding of paleobiology and paleoecology. Dinosaur Provincial Park has a significantly higher number of bone beds when compared to other paleontological areas around the world. Earlier dinosaur hunters had focused most of their time on excavating only articulated skeletons from bone beds due to a lack of manpower and resources to properly excavate a full bone bed (Currie and Koppelhus, 2005). However, bonebeds pose such a rich opportunity for discovery that in the late 1960's, attempts began in earnest to fully excavate them out of the Park and strategically identify all specimen fragments. Since then, discoveries of bonebeds are treated with the utmost enthusiasm and are fully excavated. Some bonebeds take years and often multiple groups of researchers to be fully excavated, as is in the case of a bonebed in the Northern part of Dinosaur Provincial Park. This bonebed had been in an open excavation from the years 2009-2012, during this time most of the specimens within the bed had been recorded (Alberta Parks b, 2018). Afterwards, the bonebed was open to the public as a tourist attraction, where visitors could excavate it themselves. This attraction is now called the Bonebed 30 Tour and any new discoveries are sent to the Royal Tyrrell Museum (Alberta Parks c, 2018). Today, the Park uses bonebeds as both a means for new discoveries, as well as tourism opportunities.

The Park Today

Dinosaur Provincial Park is host to a broad range of programs for all degrees of paleontologists. Whether it be an integrative tour of key points of the Park for young children with a passion for paleontology or programs that offer students opportunities to obtain field experience, the Park offers something for everyone. Although, it was not always this way. The Parks first volunteer program started in 1977 by a young man named Patrick Harrop (Currie and Koppelhus, 2005). Patrick joined an expedition to the Peace River in order to aid in the collection of dinosaur footprints. Philip J. Currie, the lead paleontologist on the expedition was pleased with Patrick's work ethic and strength in the physically demanding expedition. As a result, he decided to continue the volunteer program another year and make it larger. Today, the program recruits a high number of graduate students with degrees in paleontology, biology, and geology, yet it also presents opportunities to young people with an interest in becoming paleontologists. Officially named the Field Experience program in 1994, participants are now required to pay a fee to cover their expenses, such as food and housing while they aid researchers in excavations as volunteers (Currie and Koppelhus, 2005). The program is run through the Royal Tyrrell Museum and University of Alberta (United Nations, 2018). The Royal Tyrrell Museum, named after Joseph Burr Tyrrell, is a hugely important museum established in 1985 and is another result of the Dinosaur Renaissance. It is one of the world's premiere palaeontological research facilities and Canada's only museum dedicated exclusively to paleontology. Today, the museum hosts a large public display gallery and is one of the major institutions funding scientific excavations and research programs (Alberta Parks c, 2018).

While Dinosaur Provincial Park continues to host an ongoing partnership with the Royal Tyrrell Museum that focuses on paleontological research and excavations, the Park has begun to involve itself with research in other ecological disciplines. As of 2017, current research in the Park includes the behaviour of bats in the winter, and road mortality of indigenous prairie rattlesnakes and bull snakes (Alberta Parks c, 2018). The bat research is being conducted by Dr. Cori Lausen and aims to increase understanding of both the habitat selection and the behaviour over winter of bats living in prairie provinces. Adam Martinson is conducting the research pertaining to snakes. Adam is a graduate student working towards his Master's Degree (Alberta Parks c, 2018).

Figure 2.11. An example of bonebeds found in Wilbarger county, Texas in 1908. One of the first bonebeds ever recorded.

Dinosaur Provincial Park has played one of the largest roles in the advancement of nearly all aspects of paleontology and geology. Protecting the Park in 1955 ensured preservation of its geological and paleontological resources by limiting un-regulated visitation and research. The protection and management of the property is enabled through a number of different statutes of the Province of Alberta, notably the previously mentioned Provincial Parks Act and the Historic Resources Act (Alberta Parks c, 2018). This act ensures land use activities are managed and impacts from visitors, facility operations, and livestock grazing are being controlled and monitored. Permits are required for any research program to gain legal entry to the Park, and visitors are allowed access to only some areas. While the high number of regulations decreases the likelihood of stumbling across fossilized remains as in the days of Joseph Tyrrell, these regulations continue to ensure that the Park remains preserved for as long as possible and that discoveries are properly taken care of.

Dinosaur Provincial Park has not only played an integral role in the cultivation of scientific discovery but also in the imaginations of people around the globe, and hopefully, it will continue to do so for years to come.

Discovering the Southern Ocean and the Antarctic Circumpolar Current

Several voyages conducted by great explorers of the 17th through 19th centuries were geared towards the discovery of the "unknown land of the south", otherwise known as *Terra Australis Incognita* or, today, as Antarctica (Cobbe, 1979). For centuries, the predominant theory was that the world was flat, causing those who desired to travel far distances and unknown paths to be warned about falling off the edge of the Earth or of vicious sea monsters that would likely await them (Brian, 2011). By the 16th century, when the belief that the Earth was spherical began to gain momentum, the intuitive and natural question began to arise: what must exist on the other sides of this sphere? A common thought was that the southern hemisphere must be a direct projection of the northern hemisphere, or at least quite similar to it (Cobbe, 1979 and Headland, 1989). That is, it must be one or more large land mass(es) surrounded by relatively smaller seas. Another thought was that of the Greeks and Romans, who, encouraged by the Alexandrian astronomer Ptolemy, believed that a southern continent was imperative to balance the northern land masses (Deacon, 1984). With the predicted existence of an unclaimed southern continent on their minds, various explorers, such as Captain James Cook (Figure 2.12) and Captain James Clark Ross, sought out the mysterious southern land by way of the sea. Although their voyages were unique in their motives, observations, and discoveries, what they had in common were the major routes they traveled along and the harsh natural conditions they experienced. Perhaps they, amongst others, did not realize that they were traveling through the foreign, uncharted, stormy waters of the Southern Ocean, affected greatly by the Antarctic Circumpolar Current.

Figure 2.12. Official portrait of Captain James Cook in 1776 from the National Maritime Museum in the UK. Cook is shown developing his revolutionary map of the southern hemisphere, with the focal point being the Great Southern Continent (Antarctica) (Dance-Holland, 1776).

Early Explorers

Some of the earliest explorers in search of the southern continent were those commissioned by the Spanish and the Dutch between the late 16th and mid-17th centuries, as well as those who travelled southward through the Strait of Magellan, in Argentina, between 1520 and 1522 (Cobbe, 1979). Despite their determined attempts, these endeavors were only able to confirm the areas where the southern continent could not be found. Discouraged by harsh weather and the lack of discovery in the seemingly endless icy waters, these expeditions were often cut short. It was not until the British, who were seeking areas for economic expansion and were enticed by the riches that the mysterious continent would likely bestow, began to fund expeditions that discoveries and scientific progress accelerated (Cobbe, 1979). The first known deliberate British expedition to the south was that of astronomer Edmund Halley in January of 1700 (Brian, 2011 and Deacon, 1984). On quest to map magnetic variation of the Earth, Halley sailed out on his small naval vessel, the *HMS Paramore,* across the south Atlantic Ocean. Upon the request of the British Admiralty, Halley simultaneously attempted to explore the coast of *Terra Australis Incognita*, proposed to be located somewhere between the Strait of Magellan and the Cape of Good Hope (Brian, 2011 and Deacon, 1984). In Halley's logbook, he noted that he had made it so far south so as to have spotted penguins, narrating that the waters of the south were inhospitable in comparison to those of the northern hemisphere (Deacon, 1984). To prevent further difficulties on the icy waters, cold temperatures, treacherous currents, and storms, Halley and his crew sailed back home.

Halley's voyage was just like any of the other, similarly motivated voyages that would soon follow, as they all began in the Pacific, Atlantic or Indian ocean basins (Walton, 2013). However, as explorers meandered further south in search of the southern continent, what they thought of as the southern extents of the aforementioned oceans was really a body of water that had yet to be defined as a unique ocean of its own. It was not until the 18th century, as Captain James Cook embarked on his early expeditions in search of the southern continent, that the name "Southern Ocean" was first used (Deacon, 1984).

The Endeavours of Captain James Cook: First Voyage

Cook concluded that amalgamating the southernmost regions of the world's oceans made sense due to their evident uniformity in the existing climate, winds, currents, and marine life (Deacon, 1984). He became quite familiar with these characteristics of the Southern Ocean as he was a part of three major scientific expeditions in the southern hemisphere. Each voyage generally departed from Plymouth, England and made stops in Tahiti or New Zealand (Cobbe, 1979 and Stonehouse, 2002). The three expeditions took place in the late 18th century, with the most significant observations regarding the frozen continent and the icy waters of the south having been made during the first and second voyages. Cook's first expedition was that of the *HMS Endeavour* and the second of two ships, the *HMS Resolution* and *HMS Adventure* (Cobbe, 1979; Stonehouse, 2002).

The first voyage was motivated by the viewing of the 1769 Transit of Venus, the advancement of astronomical theory, and other scientific studies, such as those surrounding climate, tides, winds, and currents (Cobbe, 1979 and Stonehouse, 2002). On August 26, 1768, Cook and his crew, including naturalist Joseph Banks, astronomer Charles Green, and naturalist Daniel Solander set sail from Plymouth on the *HMS Endeavour*. Although the expedition was mainly motivated by astronomical studies, Cook received secret instructions from the Royal Society to venture further southward to a latitude of approximately 40°S to try to catch a glimpse of the Great Southern Continent (Cobbe, 1979). The voyage occurred rather routinely at first, with the *HMS Endeavour* sailing across the South Atlantic Ocean towards Argentina, passing through the Strait of Magellan, and then traveling across the Southern Pacific in the direction of Tahiti. This path was followed to allow for the optimal observation of the much anticipated Transit of Venus. Following his instructions, Captain Cook, unbeknownst to the crew and scientists aboard, then turned in the southward direction. In his journal, Cook noted that he did not see the speculated continent, neither around the latitudes he was instructed to venture to, nor when he decided to surpass his instructions and travel as far as 60°S, southwest of Cape Horn (Cobbe, 1979). Thus, he decided to turn northwest towards eastern New Zealand before returning home in July of 1771. Unfortunately, the *HMS Endeavour* did not fulfill either of its known or secretive purposes; the Transit of Venus was unable to be viewed and Cook failed to observe the Great Southern Continent. A few implicit successes in support of further south-sea explorations were, in fact, a product of this voyage. The first success being in Cook's realization and proclamation to the Royal Society that another, more deliberate, expedition was necessary to potentially find the southern continent (Deacon, 1984). The second success was in the excitement that followed from the written and visual accounts produced by those aboard the *HMS Endeavour;* the public was now interested in scientific exploration. Both of these successes helped in the promotion of Cook's second voyage, which occurred the next year and ultimately lead to the discovery of the Southern Ocean and the Antarctic Circumpolar Current.

The Endeavours of Captain James Cook: Second Voyage

Cook's second expedition began in Plymouth on June 2nd, 1772 aboard the *HMS Resolution* (Figure 2.13)*,* commanded by himself, and the *HMS Adventure,* commanded by Captain Tobias Furneaux. Accompanying the crew was a great deal of official artists, naturalists and astronomers in order to fulfill the scientific endeavours of the voyage (Cobbe, 1979). Astronomers William Wales and William Bayley each joined the *HMS Resolution* and *HMS Adventure*, respectively, with the task of measuring latitude and longitude throughout their journey (Deacon, 1984). The exhaustive methods they used in monitoring their chronometers allowed them to determine longitude within 1.5 degrees of accuracy. Consequently, Cook, his crew, and the scientists aboard were able to write incomparably detailed accounts in their journals (Cobbe, 1979 and Deacon, 1984). Wales and Bayley also conducted another study, taking nine deep ocean temperature recordings of the Southern Ocean, revealing warmer water located at a depth of approximately 100 fathoms, or 600 feet, with colder waters at the surface (Deacon, 1984). We know today that this difference in temperature can be attributed to the lower salt content of the Antarctic surface water, making it less dense than the warmer, saline water deep below it. These observations became important for future explorers and scientists as they provided evidence for the further understanding of fluid dynamics in the Southern Ocean, particularly that of the Antarctic Circumpolar Current.

In the later months of 1772, when the ships reached approximately 48°S, Cook recounted in his journal that the air became "pinching cold" rather suddenly (Deacon, 1984). By December 12th, travelling even further south to 51°S, those aboard the two ships spotted the first iceberg of their voyage. From this point on, the waters became increasingly difficult to navigate due to the icy, stormy seas (Deacon, 1984 and Aughton, 2004). One of the botanists, Anders Sparrman, aboard the *HMS Resolution*, described their environment as a "wearisome monotony of sea, ice, and horizon" (Aughton, 2004, p.41) and detailed the ship's encounter with huge, dangerous ice masses in his journal. Sparrman wrote: "The sight of icebergs and their proximity became an ordinary event, and one that produces little comment. [...] Driven by wind, the great resistance of such an enormous ice colossus must necessarily meet with a corresponding displacement of water; the waves, breaking tremendously, rose high above the iceberg with a violent roar, in a fury of foaming froth" (Aughton, 2004, p.40). As the southward commute continued, *HMS Resolution* and *HMS Adventure* were ceased at 55°S by an immense "ice field" to which there seemed no end (Deacon, 1984). Cook and his colleagues did not realize at the time that their descriptions of rapidly transitioning ocean conditions and temperature were likely the cause of their positioning within the Current. The multitudes of icebergs that they encountered were likely the cause of the barrier created by the Current, blocking out the warmer water from the north (Walton, 2013).

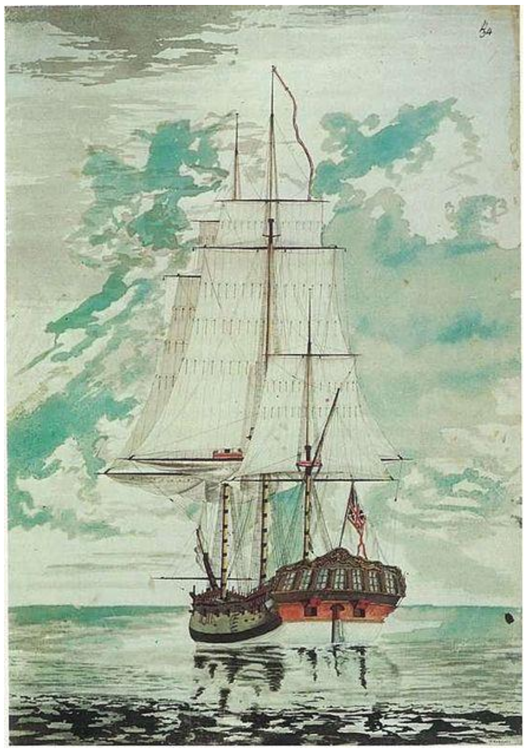


Figure 2.13. Artist's rendition of the HMS Resolution *at sea, as captured by midshipman Henry Roberts in watercolour paint (1757-1796) (Roberts, 1775).*

On January 17th, 1773, *HMS Resolution* and *HMS Adventure* crossed the Antarctic Circle while located in 39°E, approximately 200 miles from the coast of what is now western Dronning Maud Land (Aughton, 2004 and Stonehouse, 2002). From Cook's accounts, they were "...undoubtedly the first and only ship that ever crossed that line [; the Antarctic Circle]" (Aughton, 2004, p.45). By February, due to packed ice and fog, *HMS Adventure* became lost and eventually headed home, leaving *HMS Resolution* to complete the remaining of the journey alone (Cobbe, 1979). As *HMS Adventure* headed in the direction of New Zealand, the crew journaled their experiences of a strong, constant succession of westerly winds between the latitudes of 51° and 53°S. These winds were undoubtedly due to the West Wind Drift, which is known today as the system of winds contributing to the maintenance of the rapidly flowing Antarctic Circumpolar Current (Walton, 2013).

Once Cook's second voyage was completed, the accounts and journals from the two ships were published as books that attracted much public attention (Stonehouse, 2002). Overall, the second voyage produced surveys with revolutionary information on observed and measured tides, currents, winds, weather, and climate (Cobbe, 1979). Although Cook's journals did not indicate the observation of any land, he concluded that there must have been a nearby southern continent in order for such an abundance of ice to exist; he was correct (Stonehouse, 2002)! Along the way, some of the first accounts of the Current and the Southern Ocean's characteristics were made during this expedition; therefore, motivating further scientific investigations.

The Voyage of Captain James Clark Ross

In addition to Cook's voyages, Captain James Clark Ross, a British naval officer and polar explorer, led one of the most influential Antarctic expeditions of scientific discovery from 1839 to 1843 (Stonehouse, 2002). Ross, having participated significantly in five Arctic expeditions between 1819 and 1833, was appointed as captain on a two-shipped voyage with the predominant goals of investigating magnetic variation in the Southern Hemisphere and, hopefully, reaching and locating the magnetic pole of the south. Ross led the way on the *HMS Erebus*, alongside Captain F. M. R. Crozier, who lead the *HMS Terror*.

Throughout the voyage, in addition to establishing a handful of magnetic observatories along the way, Ross documented his geographical and environmental observations in his journals. His journal detailed the mountainous coast of South Victoria Land, the active volcano of a mountain henceforth known as Mount Erebus, and the great ice barrier (Deacon, 1984 and Stonehouse, 2002). With regards to oceanographic studies, *HMS Erebus* and *HMS Terror* contributed greatly to the world's understanding of the circumpolar ocean. As shown in Figure 2.14, Ross and his crew created a 5000 fathom-long line, strong enough to support up to 76 pounds, fitted with swivels to prevent unraveling (Stonehouse, 2002). After mounting the big reel of line on a small boat, kept head-to-wind by a third boat, the team recorded the amount of time taken for 100 successive fathoms of line to run off the reel. They observed that the logged times became longer as more line entered the water, which they understood was partly due to buoyancy and friction in the water, and they took measurements based on the obvious additional slowing that occurred once the weight hit the ocean floor (Brian, 2011 and Deacon, 1984). Using these rudimentary methods of data collection, Ross was able to make sufficient deep soundings to conclude that the Southern Ocean separated the Antarctic continent from the rest of the planet by encircling it with abyssal depths. However, it is important to note the incredible difficulty and inconsistency of the aforementioned experimental methods; one of the logged soundings, taken in the Weddell Sea, indicated a depth of over 4000 fathoms when the actual depth, as determined using modern methods, is slightly over half of that depth (Deacon, 1984). Even with these corrections, the south-sea depths still characterize the distinct separation from the northern waters. The team hypothesized that difficulties and discrepancies would occur due to the tug of the ocean currents; today it is understood that this was largely a result of the strong, eastern flow of the Antarctic Circumpolar Current (Walton, 2013).

Other noteworthy measurements made throughout the travels of the *HMS Erebus* and the *HMS Terror* were those of deep ocean temperature (Brian, 2011 and Deacon, 1984). Although lowering 19th century thermometers into the high-pressure depths of the Southern Ocean undoubtedly skewed the measurements, the overall results were nevertheless substantial. Ross and his team observed consistency in temperature, approximately 39.5°F (4.1°C) below 600 fathoms (about 1.1km) at six separate locations of varying latitudes (between 50° and 60°S) around the circumpolar ocean. This precision in measurements, although inaccurate, confirmed the 18th century conclusions of Captain James Cook when he noted the uniformity of the Southern Ocean's characteristics, such as temperature and currents (Walton, 2013).

Figure 2.14. Artist's rendition of the crew of HMS Erebus *measuring ocean depth using the 5000 fathom-long line created by Captain Ross (NOAA, 1840).*

Overall, the voyages conducted in the 17th through 19th centuries, by explorers such as Captains James Cook and James Clark Ross, not only facilitated the discovery of the Great Southern Continent, known today as Antarctica, but also shone a light on the potential for further scientific exploration of the newly discovered Southern Ocean and, eventually, the Antarctic Circumpolar Current.

Seismic Oceanography: A Modern Technique for Mapping Ocean Structures

Today, the Southern Ocean and the Antarctic Circumpolar Current are continually explored by scientists in numerous fields, including hydrology, geology and botany. It is now known that the Antarctic Circumpolar Current is the world's fastest global water current, transporting water at approximately 140,000,000m^3/s, and is the only current of its kind, following a closed, clockwise (moving from the west to the east) path encircling Antarctica (Walton, 2013). The current stretches variably between 40° and 60°S, evidently the common routes traveled by Captains Cook and Ross (Deacon, 1984). With strengthened understanding of the transport of water by the Current and the contributions of the West Wind Drift, it is now evident why early explorers experienced such harsh natural conditions while searching for Antarctica. The rough waters and fast currents that Captains Cook and Ross, amongst others, noted in their journals can now be logically explained. Various scientific studies were conducted aboard the *HMS Resolution*, *HMS Adventure*, *HMS Erebus, and HMS Terror,* recording variations in water temperature, salinity and current velocity (Deacon, 1984). Although rudimentary, these observations regarding salinity and temperature, which form what are called thermohaline structures (Holbrook et al., 2003), provided a leeway to the development of oceanography, and more recently, technology to study this phenomenon; particularly, seismic oceanography.

Today, seismic oceanography can be used to visualize the thermohaline structures within oceans in order to provide detailed insights into the fluid dynamics and mixing processes of the waters (Holbrook et al., 2003). At the basis of seismic oceanography is the use of seismic reflection profiling (SRP), a technique commonly used to map out and visualize ocean depths, as well as to identify different layers of rock beneath the oceanic crust (Song et al., 2012). However, in 1988, J. Gonella and G. Michon first reported the use of SRP in mapping out the thermohaline fine structures of the water itself. Unfortunately, their work remained unknown for quite some time (Song et al., 2012) and it was not until a study conducted by Steven Holbrook and his team, in 2003, that the use of SRP in the imaging of thermohaline structures became well known (Holbrook, 2008). The team was able to produce two-dimensional images of ocean structures across the front between the North Atlantic Current and the Labrador Current, two distinct currents with warm, salt water and cooler, fresh water, respectively. Recently, there are several efforts being made in this field, such as those by T.M. Blacic and Holbrook, to produce three-dimensional images of fine structures in the water column (Blacic and Holbrook, 2010).

Multichannel Seismic Imaging

To image thermohaline structures in the water column, a ship will tow an array of airguns, which provides intermittent (every 10 to 20 milliseconds) explosions of compressed air (Song et al., 2012). This compressed air is the source of acoustic waves that propagate downwards through the water column (Figure 2.15). As the acoustic waves travel through the water, they may reflect upon boundaries defined by changes in temperature, salinity, and density. These changes in temperature and salinity result in different acoustic impedances, and it is this change in acoustic impedance that results in the reflection of the source's acoustic waves. The airguns work in conjunction with a linear stream of approximately ten to twenty piezoelectric sensors, or hydrophones, which are also towed by the ship (Song et al., 2012). These hydrophones are responsible for detecting the incoming reflected acoustic waves to form a single channel, or vertical image, of reflections. Each of the channels developed by the hydrophones provide a measure, and later a

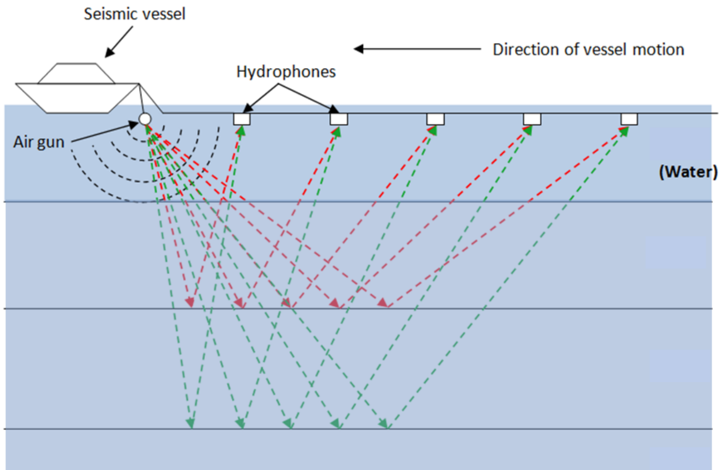


Figure 2.15. The physical set-up for multichannel seismic imaging. Submerged airguns release intermittent acoustic waves that reflect off different water masses, defined by changes in temperature and salinity. These reflections are then gathered by an array of hydrophones from which to be interpreted and imaged (Nwhit, 2012).

visualization, of the reflectivity within the ocean. A series of vertical channels of reflections collected by the hydrophones can then be amalgamated into a single image. This is what multichannel seismic imaging encompasses and allows for the creation of three-dimensional images depicting the fine structures within bodies of water such as water currents and changes in salinity and temperature (Wood et al., 2010). Due to the fact that sound speed has a greater effect on acoustic impedance than density, the images produced from this technique are more accurately interpreted as changes in sound speed, as a function of depth within the water column.

Understanding Seismic Reflection Profiling

The underlying concept of SRP involves the reflection of low frequency sound waves (approximately 10-200Hz), traveling in a heterogeneous medium, at a boundary between different water masses, unique in their salinity and temperature (Wood et al., 2010). Instead of using seismic waves to detect features characterized by solid masses such as the ocean floor, as was commonly done in the past, low frequency multichannel seismic (MCS) imaging can be used to identify fine structures within water masses (Blacic and Holbrook, 2010). The boundary between water masses, off of which acoustic waves reflect, presents itself as a change in water temperature, as small as 0.03°C, and salinity. Changes in temperature and salinity alter the acoustic impedance, that is the product of the density of a medium and the sound speed, resulting in the reflection of the source sound waves (Holbrook et al., 2003). Acoustic impedance relates to a reflection coefficient, which describes how much of the incoming acoustic wave is reflected back from a source signal. Reflected seismic waves can then be detected by a sensor and analyzed. From obtained reflections, a good approximation of the vertical temperature differences can be made as a function of depth by a simple scaling factor. Salinity, on the other hand, is estimated from an empirical relationship and then mapped on the same or different image than that of temperature (Wood et al., 2010). From this information, the density and sound speed of the water column can be calculated and interpreted, providing further information on the system of interest with increasing depth. The visualization of these boundaries between chemically and thermally different currents provides insight into the dynamics of fluids (Buffett, 2010). Using multichannel seismic (MCS) imaging, oceanographers can now visualize and study structures and phenomena within the water column such as water fronts, eddies, thermohalines fine structures, double diffusion, and internal waves (Song et al., 2012).

Tying it all Together

The Antarctic Circumpolar Current is now known as the entity that roughly defines the outskirts of the Southern Ocean, creating a separation of sorts between the northern, warmer waters and the southern, cooler waters. In addition, there exists salinity and density differences with depth and latitude. This creates a direct application for seismic oceanography, which provides the opportunity to physically visualize these properties that are otherwise difficult to accurately analyze.

Presently, scientific understanding of the Southern Ocean is much more holistic with regards to many of its physical, biological, and chemical properties. However, the region continues to be an active research site, particularly in studies of the Antarctic Circumpolar Current. Scientists worldwide are in the process of diving deeper into the circumpolar current's relationship with and influence on heat transport, carbon dioxide levels, and, most pressingly, global climate and its changes. With modern techniques such as seismic oceanography, substantial progress in more fully understanding how the global climate system works and is affected anthropogenically can, and will, be made.

Passing the Torch: The Influence of Aristotelian Nature on Mineralogy

The Study of Nature

Aristotle (384-322 BC) thought that nature could be best understood by observation and reason and that all knowledge must be acquired by experience. He was celebrated for the inductive-deductive methods he used to conclude universal truths from a number of observable facts, however, his explanations appeared to be rational rather than empirical (Gauch, 2003). Having pioneered the study of the natural world, the authority given to his theories served as an obstacle in the path of scientific (Eichholz, 1949). The path primarily involved the digression from Aristotle's natural philosophy, being intermingled with a metaphysical understanding of nature, to a more empirical, modern science.

Figure 2.16. Sculpture of the great Greek philosopher Aristotle (384-322 BC). He is responsible for the development of metaphysics, coining it "the first philosophy."

By examining the modes of interpretation of Aristotle's work and his influence on authors of successive time periods, this change can be seen to have been ushered in by the introduction of reasoning, logical assumptions and empirical testing. This change in the behaviour of utilizing existing scientific knowledge can be exemplified by comparing the contributions to mineral formation theory made by Albertus Magnus, Georgius Agricola, and Anselmus deBoodt.

Aristotle's Natural System

Aristotle investigated a variety of topics, ranging from general issues like motion and causation, to systematic explanations of natural phenomena. His inquiries into these topics followed a single, overarching framework which he describes in his treatise *Physics* (Heidarzadeh, 2008). *Physics* contained almost all there was to know about the world, however, the existence of separate forms (non-physical entities), such as his "unmoved mover of the universe," necessitated the independent study of all that is imperceptible through the metaphysical inspection of physical bodies (Heidarzadeh, 2008). The overlap between the two can be inseparable and the disciplines are said to merge into an early variant of modern science called natural philosophy.

Aristotle organized the world into four bodies (earth, air, fire and water) with four principles (cold, hot, wet, and dry); these elements combined in various ratios to create a diversity of materials (Kosciejew, 2015). While made up of these bodies, the Earth also has a certain continuity with the celestial world from which it derives its power and order (Aristotle-Webster, 1950). So, while earth and fire are the material causes of natural processes and events, the interaction and motion of the four elements is induced by celestial motions, known as the 'first cause' (Heidarzadeh, 2018).

Exhalations and Emanations

Aristotle's treatise *Meteorologica* (350 BCE) included brief speculations on earth sciences, in which he hints at origins of mineral formation processes to be influenced by the first cause. He proposed that the sun's heat causes the earth to emit either moist or dry exhalations (vapours). Their failure to escape the earth results in two substances that are formed by compression from within: dry and smoky stones and the moist and vaporous metals (Eichholz, 1949). Stones form when the dry exhalation combusts earthy matter into ash while infiltrate upwards. The degree of hardening determines whether the ash turns to stone, and the degree of burning gives stones their colour (Levy and Mangone, 2016). Alternatively, the moist and vaporous metals, which are initially ductile, condensed on the surrounding rocks solidifying with coldness. The mixture of the two exhalation is thought to account for the occurrence of most metals as ores within a stony matrix. His ideas stemmed from their observed fusibility; so, it was reasoned that while normally solid, stones must have solid earth and liquid water constituents (Norris, 2006).

The metaphysical emanation and exhalation theory was expanded by his student Theophrastus with his treatise *On Stones* (c. 300 BCE) and later in antiquity by Pliny the elder in *Naturalis Historia* (77-79 AD). It formed the basis of later ideas on mineral formation, evidently as late as 1672 with Robert Boyle's *An Essay about the Origine and Virtues of Gems* where he refers to it as 'the more received Doctrine' (Killeen, 2009).

Magnus: Mineral Virtue

During the 13th century, the rediscovery and Latin translation of ancient writings (i.e. Aristotle, Euclid, Archimedes, etc.) and influence of eastern medieval thinkers (i.e. Avicenna, Averroes, and Maimonides) expanded natural philosophy with the commentaries and independent treatises of its contemporary scholars (Hope, 1936). This period also saw the development of universities and the method of scholasticism as a system for theology and philosophy. Scholastic thought was known for its rigorous use of dialectical reasoning and inference, and its carefully draw distinctions (Hope, 1936). Under the Dominican order, teaching order founded by St Dominic in 1215, scholasticism during the High Middle Ages aimed to propagate and defend Christian doctrine (Gracia and Noone, 2008).

Albertus Magnus, a German Catholic friar and bishop, was one of these scholastics. As a member of the Dominican order, he synthesized Greek rationalism and the Christian doctrine into what was later defined as Catholic philosophy. He was the first to compose paraphrases with commentary on nearly all of Aristotle's writings, thus playing a critical role in establishing Aristotelianism and promoting Aristotle's physical system in the study of nature (Resnick, 2012). Magnus' metaphysical understanding of the world assigned Aristotle's 'first cause', the ultimate 'moving' force in the universe, to be the good of God. He believed in a hierarchically-ordered universe that reflected God's light, and that material beings and creatures existed because of this 'first cause' (Resnick, 2012). The influence of God evidently becomes implicated in his scientific works as well.

Magnus expanded upon the exhalations theory with his own observations on the natures of metals and their ores while also drawing on Avicenna's mercury-sulphur theory in his treatise *De Mineralibus* (Norris, 2006). He assumed the earth's interior contained regions of long-lasting high temperatures that facilitated slow but thorough elemental processing. The 'natural sublimation of moisture and Earth,' generated dry and moist mineral-forming exhalations, which moved upwards intrusively and eventually solidified with coldness (Magnus-Wyckoff, 1967). Having observed a mineral vein that was gold-bearing in one section and silver-bearing in another and he remarked that different compositions seemed to correspond with a difference in the host rock and its ability to withstand various strengths of heating events. Magnus believed these differences to be intrinsic and he defined the identities of rocks and metals using the concept of mineral virtue (Allen, 2012). 'Virtue' was derived from the heavens and used the earth's vapours as instruments in bringing

Figure 2.17. Portrait of German Catholic friar Albertus Magnus (1200-1280). He is distinguished as one of the 36 Doctors of the Church.

minerals into existence since they can be acted upon by Aristotle's physical principles, heat and coldness (Allen, 2012). This idea demonstrates the intricate connection between explaining the physical process of mineral formation and the invoking of a mineral's power.

In *De Mineralibus,* Magnus claims, "The aim of natural philosophy is not simply to accept the statements of others, but to investigate the causes that are at work in nature" (Magnus-Wyckoff, 1967). Despite the emphasis he places on experimentation, his fundamental understanding that minerals were brought into existence by celestial impulses skews the observations he makes and reports upon. He employs circular inference in his arguments, relying on the "first cause" in explaining mineral's virtues, whose effects he claims are observable. Using the example of opium, Magnus reasons that both the cause and purpose of the opium in sending one to sleep is because of mineral's dormitive virtue (Allen, 2012). While Magnus is committed to observation and questioning in dealing with natural science, it is evident that his need to reconcile catholic theology with classic Aristotelian philosophy hampered his ability to draw unique conclusions. Despite moving towards a more empirical method of acquiring new knowledge, the interpretation of existing knowledge lacks the same critical analysis and consideration that is seen in future years.

Agricola: Mineral Juices

Following the late Middle Ages of the post-classical era, the renaissance period is marked by the rapid and profound reforms in culture, presenting an environment considered suitable for challenging scientific doctrines and human thought (Norris, 2007). In response to the utilitarian design of medieval scholasticism, renaissance humanism emerged and sought to democratize learning. Humanists believed that individuals should be capable of engaging in civic life, and serviced this cause by withdrawing from classical grammar and rhetoric and contesting Aristotelian tradition (Kallendorf, 2002). Instead, they wrote with clarity and on subject matter that was pertinent to the public. At this time, intensive investigations of the natural world were undertaken by several European scientists in an attempt to satisfy this sudden rise in curiosity.

Georgius Agricola was a humanist scholar and formally a practicing physician; however, his main interests laid in the study of mining and geology. In 1527, his profession brought him to Joachimsthal, and later to the city of Chemnitz, both of which were important centres for mining in his time. There even exists evidence suggesting to historians that he may have owned a share in a silver mine, confirming his vested interest in the practice (Prescher, 1994). Agricola's geological writings uniquely reflected the emphasis he placed on practical study and examination, both of minerals and the applications of mineralogy and metallurgy (i.e. mining technologies and practices). His knowledge stemmed from his reading of Pliny, Galen, Avicenna and Magnus (Norris, 2007). He cautiously followed classic natural philosophers including Aristotle, Theophrastus, and Strato, with the resolution to correct the faults he found in their works (Agricola-Hoover, 1950). He did, however, arrive at his own conclusions in his contributions to the field of earth sciences. He authored the first book on physical geology, *De Ortu et Causis Subterraneorum* (1546), describing wind and water as geological forces, and explaining earthquakes and volcanic events. This prefaced his greatest work, *De Re Metallica*, which remained the authoritative text on mining practices for two centuries after its publication in 1556 (Dym, 2008). Under Agricola's guidance, the study and classification of minerals digressed from non-quantifiable properties like virtue to their observable features such as colours, tastes, strengths and localities.

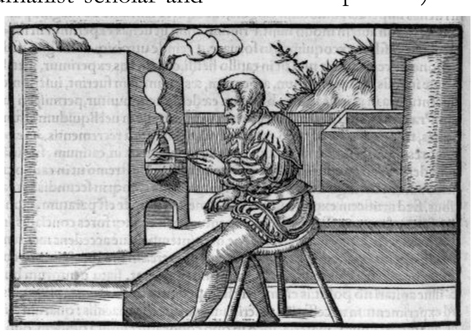


Figure 2.18. Pictured is Georgius Agricola, one of the fathers of modern geology, at his work bench heating a rock or mineral to test its physical properties.

Agricola was one of the pivotal authors to transition the understanding of mineral-forming processes from exhalation theory to the 'aqueous mineral genesis' theories that became popular in the sixteenth century. Whereas Aristotle had attributed water to be one of the elemental constituents, Agricola believed compositional moisture served as evidence of aqueous formation events (Norris, 2007). His theory reflected the three principal aspects of Agricola's observations that were common to mining operations: the presence of underground fissures, water in the mines, and fluid-like depositions (i.e. mineral encrustations and dripstones). He postulated that fissures formed by desiccation, or alternatively, by the eroding action of subterranean waters, and he related their natural placement with mineral-forming processes. In a heat driven process, these waters could absorb the mineral matter they passed through to produce 'mineral juices' and eventually solidifying with coldness (Norris, 2007). In this respect, his theory remained rooted in Aristotelian physics, operating under

Figure 2.19. An artist's depiction of Anselmus deBoodt, one of the fathers of modern geology along with Agricola.

the principles of heat and coldness as formative causes. These processes were downward flowing contrary to the traditional upward movement of proto-mineral vapours.

His writings made a clear attempt to amalgamate the learning achieved by his own practical work with the knowledge gained by traditional scientific activity. He demonstrates an empirical approach to accepting existing knowledge, which he makes evident in the following statement: "I have omitted all those things which I have not myself seen, or have not read or heard of from persons upon whom I can rely" (Agricola-Hoover, 1950). While he consults and makes use of classical, Aristotelian concepts and the subsequent studies conducted by Magnus, his own writing draw only on information he personal experience with. He abandons the influence of first causes in the formation of Earth materials, exemplifying a decisive transition from celestial influence to observable processes in mineralogy. This change demonstrates the influence of the renaissance movement for increased human experience and the development of the practical sciences of mining and metallurgy on science, encouraging more empirical methods.

deBoodt: Mineral Classification

Anselmus deBoodt was born in 1550 in Bruges, Belgium, during one of the most important eras in the world of science thought (deBoodt-Maselis, 2003). Beginning with the publication of Nicolaus Copernicus' *De revolutionibus orbium coelestium* (*On the Revolutions of the Heavenly Spheres*) in 1543 (citation), the mid-16th century is often referred to as the beginning of the scientific revolution. As such, many of the prominent figures whose contributions to the scientific body of knowledge we still reference today, lived during this period, each starting to collect and present new thinking in a variety of fields. As the personal physician to the Emperor Rudolf II, his contributions the scientific community pertain to what is known as Rudolphine knowledge and its ties to pansophy: a concept of omniscience and ultimate knowing (Purs, 2004).

deBoodt was one of these scientists. A naturalist, physician, humanist, and most influentially, a mineralogist, deBoodt is often credited as being one of the fathers of modern geology along with Agricola, one of his influences (Sinha, 2017). Coming from an aristocratic family, deBoodt's upbringing gave him access to a variety of resources that aided him in writing sophistically (Sinha, 2017). deBoodt was an avid mineral collector who travelled to a number of mining regions across Europe assessing and studying samples. His time spent here allowed him to independently classify over 600 minerals and further develop the contemporary understanding of 200 previously documented minerals. His knowledge of mineralogy was considerably thorough; he summarizes his studies in the *Gemmarum et Lapidum Historia* (The History of Gems and Stones). The book's content was inspired by many of deBoodt's interests, and included information not only pertaining to rock identification but also to the applications of gems in health studies (deBoodt-Maselis, 2003). He was particularly concerned with the renaissance pioneer Paracelsus and his medicine and pharmaceuticals made from precious stones and minerals.

As is the case with many other modern scientists, deBoodt's main tools were observation and analysis. deBoodt would not refute an idea until he could himself prove it to be inaccurate through experimentation (Duffin, 2005). For example, in *Gemmarum et Lapidum Historia,* de Boodt comments, "I remember that, when a boy, I took an old toad and set it upon a red cloth that I might secure a toadstone; for they say that it will not give up its stone unless it sits upon a red cloth. However, although I watched the toad for a whole night, it did not eject anything, and from this time I became convinced all the tales concerning this stone were merely fond imaginings" [Gemmarum et Lapidum Historia]. His inability to accept published facts as truth unless he could prove it physically hints at a more modern scientific perspective that includes philosophy, not the other way round. He did, however, believe that in order to properly understand natural phenomena, one would need to look for not only physical indicators, but also study them in hopes of uncovering secret meanings on a spiritual level (Sinha, 2017).

His views on mineral properties and their origins were heavily influenced by the likes of the early scholastic authors and philosophers previously mentioned, from Aristotle, Pliny and Galen of antiquity to more recent authorities such as Gesner and Georgius Agricola. He preferred empirical and logical thinking based on his scholastic interpretation of the Aristotelian natural philosophy (Sinha, 2017). The ideas deBoodt posits in *Gemmarum et Lapidum Historia* indicate that he does not necessarily discredit Aristotle's idea of the four elements, but rather accepts them as 'remote causes' (Clericuzio, 2000).

While he had access to the full extent of these authorities, deBoodt's focus is primarily on the taxonomic classification of new gems and stones, he eludes to their formation as well. He extends their understanding of the composition and structure of stones, drawing on modern concepts of assemblages of particles called 'atoms.' Contiguous particles made the gem is transparent; whereas simply juxtaposed particles accounted for opaque stones (Gysel, 1997). deBoodt strictly denied the occult powers of stones and dismissed their perceived power and influence of stars on earthly life and asserted that if supernatural effects were perceived, they were caused by the will of god (Sinha, 2017). Furthermore, despite the influence Paracelsian ideas about the relation of chemicals and minerals with human health had on his investigations, he was hesitant to accept unsubstantiated claims about the properties of minerals and even rejected the attribution of supernatural properties to minerals (Gysel, 1997). This marks a clear segregation between theology and natural science. In clarifying that occult properties had to be willed by higher forces and were not intrinsic, deBoodt succeeds in treating the origination and characteristics of minerals as separate from religious powers.

deBoodt's work is an example of the emerging notion of specialisation in the study of nature that "allowed one to study the phenomenon without a prior knowledge of the totality of things" (Sinha, 2017). It is argued that this emphasis is responsible for experimentation as the primary scientific method given the isolated and controlled settings the require. deBoodt integrated existing principles into his own thinking and was able to put forth original ideas pertaining to smaller domains with in the previously broad study of minerals and stones, a practice that gained traction in the seventeenth century. deBoodt was in many ways critical to progress seen in modern science communication, implementing meta-analysis and bridging the gap between eras of science. Essentially, deBoodt shows that we can acknowledge faults in existing knowledge without abandoning it; rather, we can build off of those previously established ideas by supplementing them with our own findings.

Scientific method, having first been introduced in antiquity, has defined the way by which we have organized and built upon our knowledge as spectators of the natural world. It has since transformed into a methodical process that skillfully unites observation and explanation through its use of systematic measurement, experimentation and hypothesis-testing. A particularly critical aspect of science as a process is the act of interpreting and making use of existing knowledge. The product of this behaviour is largely determined by the

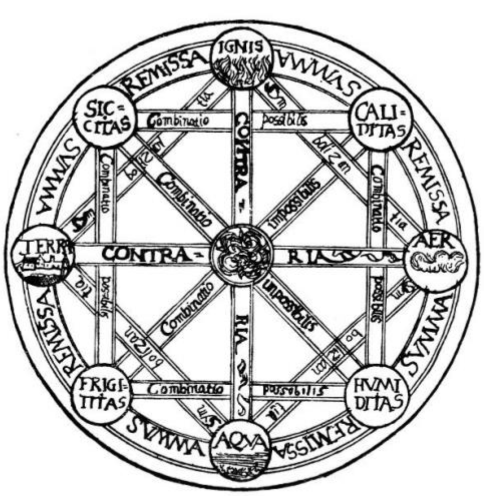


Figure 2.20. An illustration showing the connection between Aristotle's 'four elements' (Ignis- fire, Aer- air, Aqva- water, Terra- earth), which deBoodt later used to develop the 'three chemical principles'.

combined influences of the texts consulted and contemporary movements in thinking. Aristotle, as the originator of natural sciences, enforces his authority on subjects like mineralogy long after his investigations were conducted. Albertus Magnus, Georgius Agricola, and Anselmus deBoodt as Aristotle's successors demonstrate the increasing emphasis placed on empirical testing and observation with their individual understanding of his mineral formation theories. Upon closer examinations of authors in their respective time periods, the coincidence of contemporary change and advancements and changes in scientific thought is evident. With respect to these authors, the reintroduction of lost texts, the priority given to human experience and practical sciences (i.e. mining), and the shift towards specialization in knowledge, are events that have individualized the writings. In their own unique ways, these have helped these authors reshape the study of mineralogy into an empirical one in the face of its philosophical traditions.

The Modern Use of Minerals in Health Studies

Today's world is undoubtedly quite different than the world of Aristotle, Magnus, Agricola, or deBoodt. As time has moved forward, so has science, and with that forward movement has come a number of remarkable findings and discoveries in a vast range of scientific topics. Each of those discoveries has played in important role in not only the world in which they were discovered, but in the time afterwards as well. As explored earlier, today's knowledge has only been acquired through the many trials and tribulations of those who came before us. This section, therefore, serves as a culmination of this progression, by examining how minerals have a number of applications to health studies and health research. Without the thoughts of the great aforementioned scholars- who were all physicians among many other occupations- these applications may have never been found.

Minerals found in rocks carry great importance in the modern medical world. One particularly intriguing aspect of these minerals are nanomaterials. Nanomaterials are particles on the nano-scale found in minerals that have a number of unique properties. Magnetic nanomaterials, for example, display superparamagnetism- which means that their magnetic orientation can flip in response to temperature change. This property is currently being explored using nanomagnets, in the hopes that the nanomaterials can be controlled magnetically and thermally (Zhu, 2018). When it comes to biomedicine, magnetic nanomaterials can be modified with specific biomolecules to be useful in a number of regards, including imaging techniques, drug delivery, and electromagnetic radiation therapies (Zhu, 2018).

Another interesting application of minerals to the field of health care is found in the area of imaging. Quartz, for example, a mineral composed of oxygen and silicon atoms, is one of the main components found in fluorescence endoscopy instruments developed in 1962. Quartz rods in the endoscope sheath in conjunction with external lamps help identify fluorescence in biological structures such as tumours (Kingslake, 1969).

Figure 2.21. Quartzstone. This is the source of the quartz that could be used to construct quartz rods in fluorescence endoscopes.

Essentially, Aristotle and company were correct all along. Even if it wasn't because of God, minerals have the potential to serve as therapeutic to some degree, even if it isn't by just possessing them. Their properties can be used in a number of ways to image, treat, or prevent ailments. So although this might not be due to 'mineral virtue' per se, rocks do have healing powers; it just took some time to discover them.

Earthism in Planetary Science

The nature of the scientific study of any extraterrestrial object is inherently Earth-centric (or simply, Earthist). We can only understand alien things in terms of things we already understand; we need a context of familiarity against which to view the unfamiliar. What is familiar to us is Earth – it's where we've lived out our entire evolutionary history – and it is this context in which all of our scientific principles are derived. The human approach to understanding involves making connections, analogies and relations to ultimately reduce the unwieldy to the simple. Naturally, we relate external phenomena to what we know best: ourselves, and how we experience reality as humans on Earth. In the words of Thomas Henry Huxley, "the known is finite, the unknown infinite; intellectually we stand on an islet in the midst of an illimitable ocean of inexplicability. Our business in every generation is to reclaim a little more land" (Huxley, 1900, pp. 4). We add each successive piece of claimed intellectual territory to our "body of knowledge" and use it as a term in which we can understand the next item of our attention.

Perhaps the most profound object to which we pay attention is the sky. "An appreciation of the mystery and order of the sky marked the beginning of the first science, astronomy, in Mesopotamia more than 3,500 years ago" (Wilford, 1990, pp. 7). Our ancestors noticed regularities and patterns in the motions of the objects in the sky, and integrated them into our intellectual territory. This proved to our advantage in practical ways (in anticipating the onset of seasons, or navigating the seas) and in time would develop to yield the cosmic perspective of our species. Since our origins, we have been striving to make "cosmos" out of "chaos" and put the universe into terms that we understand.

However, Earthism has not always served us well. It may be that the matters external to the Earth are fundamentally different from what is familiar to us. Time and time again, the true reality of the cosmos does not conform to our expectations. Building an understanding of what we see in the sky based on what we experience on the ground can lead to conceptions that are fundamentally erroneous. The aim of this work is to describe the misconceptions that have arisen in the history of planetary science – specifically in the study of Mars and Venus. The historical development of our understanding of our nearest planetary neighbours is riddled with notions that have since been disproved and that show their prejudiced mindset in hindsight. The susceptibility of human-conducted science to Earthism should give us pause; the progress of science may hinge on our awareness of our Earthist tendencies.

Nomenclature

The word that we use to describe something is very telling of how we perceive that entity. The converse is also true – an object's given name can in turn influence our subconscious notions. An investigation into nomenclature reveals our Earthist slant on celestial objects.

That the faint dots of light in the night sky are fixed with respect to one another in their motion was apparent to humans as far back as we have historical records (Carr, 1981). However, a handful of such celestial objects did not adhere to this pattern, and were observed to follow their own path instead, sometimes against the overarching flow. These objects were named "planets," or "wanderers," from the Greek word *planes* (Carr 1981).

The mid-1600s marked the time of the application of the telescope to the sky (Wilford, 1990). Humans became better acquainted with our nearest neighbours as the practice of making dedicated observations of celestial objects became more prevalent (Figure 2.22). Hanging like a drop of blood in the sky, Mars was named after the Roman god of war (Carr, 1981). Its two satellites – small bodies, gravitationally captured asteroids – were suitably deemed Phobos ("Fear") and Deimos ("Panic") (Hoyt, 1976). The etymology of the planet Venus is similar; its unblemished, milky smooth affectation and tendency to reveal itself only in the evening or early morning hours earned it the name of the Roman god of love and sexual desire (Moore, 1961).

To their observers, our nearest planetary neighbours (and later, even the giant planets of the outer solar system) were not merely objects, as inaccessible or estranged as they are remote. Instead, they were relatable characters with their own story and temperament. In his epic 1895 publication *Mars*, Percival Lowell, a dedicated observer, wrote of the red planet: "... a world much older than Earth. To so much about his age Mars bears evidence on his face. He shows unmistakable signs of being old. Advancing planetary years have left their mark legibly there … If he once had a youth, it has long since passed away … His name is a sad misnomer; indeed the ancient [Romans] seem to have been singularly unfortunate in their choice of planetary cogonoments. With Mars so peaceful, Jupiter so young, and Venus bashfully draped in cloud, the planets' names accord but ill with their temperaments" (Lowell, 1895, pp. 27). The connotations embedded within our nomenclature comes, part-and-parcel, with associated emotions.

Similarities to Earth

For as long as Mars and Venus have been in human consciousness, they have been associated with Earth. We expected our nearest neighbours to be resemble our own planet, and with the application of the telescope to astronomy, these expectations became fulfilled.

Similarities between Earth and Mars were first recognized by observers in the mid-1600s. In 1666, Giovanni Cassini noted the presence of polar caps, and these observations were confirmed by drawings done by Christiaan Huygens in 1672 (Carr, 1981). Between 1781 and 1784, William Herschel made extensive observations of the red planet, and estimated the length of the Martian day to be roughly 24 hours, identical to that of Earth (Carr, 1981). Mars' axial tilt was also found during that time to be equal to our own: roughly 23.98° (Wilford, 1990).

Venus, of mass and radius close to that of Earth, was and continues to be considered Earth's sister planet. While an unrelenting white cloud cover kept its surface perpetually hidden from view, that there was an atmosphere at all did not come as a surprise. Former president of the British Astronomical Association Patrick Moore recounts, "Even in the time of Schroter and Herschel [late 1700s], it was known than Venus and Earth were almost perfect twins in size and mass, and it was logical to think that their atmosphere also must be similar in extent and composition" (Moore, 1961, pp. 65).

The implication of making such associations between Earth and our planetary neighbours is that we will be tempted to "use analogies drawn from experience with Earth to interpret the facts

Figure 2.22. The Earth between our nearest planetary neighbours, Venus and Mars (artist's rendition).

that we know about Venus [and Mars]" (Kellogg and Sagan, 1961, pp. 37). And indeed we have. As a consequence, we find ourselves confused in the face of contrariety: "Venus has an atmosphere, it is true, but the main constituent seems to be carbon dioxide. This is certainly curious. Venus is very like the Earth … so why should it have an atmosphere of so different a type? Our air contains relatively little carbon dioxide; why, then, should Venus have so much?" (Moore, 1961, pp. 30). Perhaps more importantly, in a world fully accustomed to free comparisons between the Earth and Venus or Mars, we also find ourselves formulating Earthist explanations for Martian or Venusian phenomena, and holding onto them with single-minded conviction.

Life

The idea that life exists elsewhere in the universe is perhaps the most Earthist thought we will ever have. Hoyt describes this universal projection eloquently: "Gods and gargoyles, minotaurs and Martians can all be considered particular manifestations of one of the seminal ideas underlying the whole of intellectual history – the idea that intelligence exists elsewhere in the universe" (Hoyt, 1976, pp. xiii). It speaks to our innate tendency to assume "a connection, a relatedness, between events on earth and in the sky" (Wilford, 1990, pp. 7). Not only is the idea viscerally attractive (and with what we know today, statistically plausible), it is logically hard to dispute. As Carl Sagan put it, "the absence of evidence is not evidence of absence" (Sagan and Druyan, 1997, pp. 223); while "the discovery of a living intelligence at any point in space and time beyond the here and now of Earth will bring it instantly and permanently into the realm of human reality" (Hoyt, 1976, pp. xiii).

It may sound like science fiction (and indeed the adventures of extraterrestrials were the subject of many popular fiction novels in the 19th century and onwards), but scientific theory does not rule out the possibility. "Scientific hypotheses concerning the origin of life generally have as their central theme the idea that living systems arise through chemical evolution, a process in which simple compounds are generally transformed under the influence of various energy sources into more and more complex molecules, ultimately resulting in a system of replicating molecules" (Carr, 1981). The arguments are, as always, based upon what we see on Earth: "Based on comparisons between the chemical composition of terrestrial living systems with cosmic abundances, as well as upon theoretical calculations, it is further assumed that the key substances in this evolution are all carbon-based compounds" (Carr, 1981). With the work of Nobel Laureate Harold C. Urey and his collaborator Stanley L. Miller in synthesizing complex amino acids from lifeless hydrocarbons in 1952, the chemical evolution of organic from the inorganic was substantiated as "an inevitable result of evolution and thus [it was thought that] life could arise on any planet in the universe possessing the requisite physical conditions" (Hoyt, 1976, pp. 154).

In the late 1800s, it was believed not only that Mars possessed the requisite physical conditions, but that there was evidence for the existence of an intelligent civilization living on the surface (Berrill, 1964). Under ideal circumstances (i.e. during a Martian opposition and given a steady atmosphere), an intricate network of criss-crossing straight lines was visible across the globe (Lowell, 1895). The initial observations were made by Italian astronomer G.V. Schiaparelli in 1877, and he sketched this network of *canali* ("channels" or "grooves") into a Martian map (Hoyt, 1976). Just a few years thereafter, a Bostonian by the name of Percival Lowell confirmed the observations, made his own sketches (Figure 2.23) and presented his own explanation.

Lowell believed that the *canali* were strips of vegetation watered by what were literally canals, and that the canals were made by an intelligent Martian civilization to deliver water to thirsty cities scattered across the barren landscape (Lowell, 1895). He bastioned the notion with a wealth of data and a full-blown scientific theory. "No one before Lowell or since has presented a case for intelligent life on Mars so logically, so lucidly, so compellingly to a skeptical science and wondering laity," (Agnes Mary Clerke, 1902, pp. 280); Lowell had authority and his views were held by serious astronomers. It may be no coincidence that this idea emerged and found engagement at a time when, on Earth, canal-building was a flourishing industry (Wilford, 1990).

Patterns & Successions

Arguably, a key feature that enables humans to conduct science is our ability to recognize patterns. Interpretations of and explanations for the observed appearance of Mars and Venus (proposed in the late 1800s and as recently as the 1950s, respectively) demonstrate our affinity for successions in nature.

In a paper published in 1955, G.A. Tikhoff described observations made by N.P. Barabashev: "He found that in those parts of Venus where the Sun's rays possibly penetrate the clouds to be reflected by the planet's surface, there is a surplus of yellow and red rays" (Tikhoff, 1955, pp. 200). Tikhoff attributed the disproportionate amount of yellow and red light as being due to the presence of vegetation on the surface, which reflected light at these wavelengths and gave the plants an orange colour (Moore, 1961). He had similar ideas for the vegetation on Mars, and wrote, "Thus we get the following gamut of colours: on Mars where the climate is rigorous the plants are of blue shades. On Earth where the climate is intermediate the plants are green, and on Venus where the climate is hot the plants have orange colours" (Tikhoff, 1955, pp. 200). This succession of plant colour by planet correlates with a rainbow, a familiar sight on Earth, progressing radially outward from the Sun.

A similar intuition was used a century and a half earlier by Percival Lowell to explain what motivated his Martians to build their extensive canal system. Lowell often employed factual and theoretical material from other scientific disciplines to decipher what he observed (Hoyt, 1976). To explain the Martian canals, he borrowed from biology and formulated a theory of planetary evolution. Just as life on Earth undergoes evolution – both on the time scale of generations via natural selection, and on the time scale of individual lifetimes – planets too, he argued, undergo an evolution of their own.

The evolution begins with the Sun Stage (during which a planet is hot enough to emit its own light), and proceeds through the Molten Stage (currently being experienced by the outer giant planets) to the Solidifying Stage (characterized by the "crinkling of crust as the cooling planet contracted within its new skin … like a dried-up apple") (Hoyt 1976, pp. 245). During this third stage, "[the planet's] face is then modelled once and for all; and its face is the expression of its character" (Lowell, 1908, pp. 14). After this "mid-life crisis," a planet progresses into the

Terraqueous Stage (as Earth occupies presently, with its seas and sedimentary deposition), through the Terrestrial Stage and finally enters the Dead Stage (Lowell, 1908).

Mars, Lowell believed, was in the Terrestrial Stage of its evolution, in which its "seas disappear, the atmosphere becomes depleted, and the planet is slowly dying from progressive desiccation" (Hoyt, 1976, pp. 158). The Martians were simply forced to respond to the inevitable transition of their home planet from Terraqueous to Terrestrial, and its resulting loss of fertile land and sea. Their solution was to build a global canal system to harvest what water remained at the poles as the planet slowly dried up (Lowell, 1908).

According to Lowell, proof that planets transition through these various stages can be found on Earth. While the Earth has retained its oceans to present, the Terrestrial Stage was setting in, as could be seen in its "expanding deserts that belt the Earth athwart the Tropics of Cancer and Capricorn, and its slowly shrinking seas" (Lowell, 1906, pp. 158). The idea that planets show their age in their "face" and physical characteristics is, absolutely, reminiscent of the human experience. Indeed, Lowell spoke of the Earth's encroaching desertism plainly in that vein: "Standing as it does for the approach of age in planetary existence, [desertification] may be likened to the first gray hairs in man" (Lowell, 1906, pp. 158).

Culture & Morality

While the observation to explain on Mars was canals, Venus had its own mysterious face features. In his 1892 publication, a French astronomer J. Trouvelot described seeing bright spots on the face of Venus and suggested that they were due to high mountain peaks protruding through the atmosphere (Trouvelot, 1892). A few decades later, preliminary estimates of the height of mountains on the Moon showed the tallest peaks to be higher than Mt. Everest (Moore, 1961), lending plausibility to Trouvelot's tall Venusian mountains. This explanation for the bright spots on Venus, although held in dubious regard by some, continued to be supported into the mid 1900s (eg. McEwen, 1947).

The counter to this argument came in 1955 in the form of collateral damage when observers D.H. Menzel and F.L. Whipple proposed an argument on a separate issue: the composition of Venus's clouds. They came down strongly in favour of water, and in arguing against carbon dioxide (the opposing side's view), they also contested the existence of mountains (Moore, 1961). Leaning on the idea that Venus is Earth's sister-planet, they pointed out that if Venus had mountains and a CO_2-dominated atmosphere, a familiar process that exists on Earth (the carbonate-silicate cycle) would occur: "The carbon dioxide would be fixed in the rocks in the form of carbonates, because of its chemical reaction with silicates in the presence of water. If protruding land masses were absent, however, the fixation of CO_2 would not continue after the formation of a thin buffer layer of carbonates; and the inference is that Venus is completely covered with water" (Menzel and Whipple, 1955, pp. 161).

Observers had long held the view that the Venusian atmosphere was moisture-laden, and even "a complete copy of Earth's" (Moore, 1961, pp. 67). Not Earth as it is today, however. Up until the second half of the 20th century, it was believed that the atmosphere of Venus resembled that of the Earth during Precambrian times (Moore, 1961). Theories about the evolution of Earth's atmosphere coupled it with volcanism; in the words of H.C. Urey, "Venus and the Earth are so similar in size and mass that volcanic activity is to be expected there too" (Urey, 1952, pp. 149). Svante Arrhenius, Nobel laureate in chemistry, agreed; he considered Venus a wet world of luscious vegetation and burgeoning primitive life. He wrote in 1918 that "the humidity is probably about 6 times the average of that on Earth. We must conclude that everything on Venus is dripping wet [and that] the vegetative processes are greatly accelerated

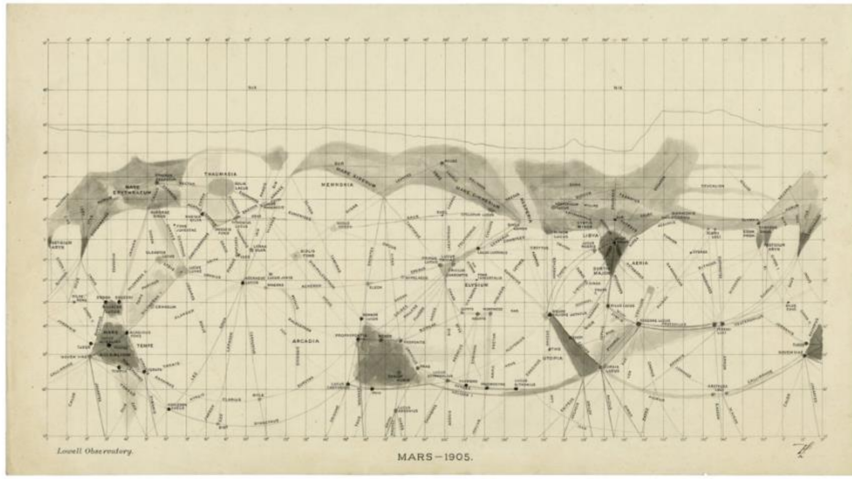


Figure 2.23. Map of Mars by Percival Lowell, 1897, published in Annals of the Lowell Observatory, *1905. This sketch depicts the intricate network of canals that he observed to exist on the surface. (Reproduced with permission from the Lowell Observatory Archives, Flagstaff, Arizona).*

by the high temperature" (Arrhenius, 1918, pp. 129).

Other observations warranted yet other explanations. An effect known as "ashen light", which commonly occurs on the Moon, was seen on Venus (Figure 2.24) for the first time in 1643 by Giovanni Riccioli (Moore, 1961). Ashen light refers to the faint illumination of the dark side of an object in phase; when the Moon is a crescent, sunlight reflecting off the Earth reflects a second time off of the Moon's dark side, giving it a soft glow. Subsequent observations of this effect on Venus were made in 1714, 1759, 1806 and numerous times thereafter by nearly every serious observer of Venus (Moore, 1961).

Figure 2.24. Authors' rendition of the ashen light effect on Venus. Adapted from an image of Venus in phase.

An explanation for ashen light was put forward around the mid 1800s by Franz von Gruithuisen, invoking the presence not merely of vegetative life on the surface of Venus, but of a civilization like that of our own, with culture and events to celebrate. His argument involved translating the average lifetime of a human into Venus-years, noting the time interval between subsequent observations of ashen light and assuming the rise to civil power of "some [Venusian] Alexander or Napoleon. If we estimate that the ordinary life of an inhabitant of Venus lasts 130 Venusian years, the reign of an Emperor of Venus might well last for 76 Venusian years. The observed appearance [of ashen light] is evidently the result of a general festival illumination in honour of the ascension of a new emperor to the throne of the planet" (Henry and Ley, 1951, pp. 36).

Meanwhile, similarly Earthist arguments were formulated to describe the culture of the intelligent, canal-building civilization on Mars. French astronomer Camille Flammarion, an endorser of Schiaparelli's drawings, lamented in 1892 that "we may hope that, because the world of Mars is older than ours, mankind there will be more advanced and wiser" (Flammarion, 1892, pp. 592). The sentiment embedded in this argument, that one's elders are wiser, is a familiar philosophy in human culture.

In a similar vein to the rainbow succession of plant colours proposed by Tikhoff, philosopher Immanuel Kant correlated orbital succession with inhabitant ethics: "The two planets Earth and Mars are the middle links of the planetary system, and it may be suspected with fair probability of their inhabitants that they stand in the centre between the extremes as regard physiology as well as morals" (Kant and Jaki, 1981, pp. 6). Percival Lowell envisioned his Martian society to be a benevolent oligarchy, having abolished "such terrestrial institutions as nations and war," with each individual acting in the interests of the whole to transport water lest the whole population go thirsty (Hoyt, 1976, pp. 288). We had something to learn from the Martians, Lowell believed. He was unhappy with human politics and societal organization, believing that the study of Mars "teaches us that well-being lies not in strife but in mutual interaction" (Lowell, 1895, pp. 288). Scientific ideas are a product of the minds that have them, and as such are influenced by the mind's feelings towards present events of its day.

Modern Astronomical Observations

The state of astronomy has changed greatly since the time of Lowell, Huygens, and other notable historic astronomers. More people are involved in the field and large institutions facilitate global collaborations. The observational scope has expanded from our nearest neighbours to include planets orbiting distant stars. Additionally, improvements in technology have allowed for greater quality observations; as such, new research has disproved some of our previous misconceptions. While we have come a long way in recognizing and correcting our prejudiced notions, the study of extraterrestrial objects remains susceptible to Earthism - simply in new ways.

Ground-Based Telescopes

The Sun's emission spectrum peaks at wavelengths between 400 and 700nm (Feynman, Leighton and Sands, 1994). Having evolved on Earth, it is these wavelengths that the human eye is geared toward (Osorio and

Vorobyev, 1996). This is inherent Earthism, as the visible range comprises only 0.0035% of the electromagnetic spectrum (Natural Resources Canada, 2015). Modern technology has allowed us to overcome this limitation and view the universe at all wavelengths.

In eliminating this limitation, another was revealed. As seen in Figure 2.25, the amount of light that the Earth's atmosphere transmits is highly wavelength dependent. Gaseous molecules which comprise the atmosphere absorb specific wavelengths of light. The large bands of low transmission in the infrared (IR) section of the electromagnetic spectrum can be attributed to many atmospheric gases, most notably: methane (CH_4), water vapour (H_2O), oxygen (O_2) and carbon dioxide (CO_2) (Earth Observation Data Group, 2018). Ozone (O_3) comprises a very small portion of the atmosphere, but is responsible for much of the absorption of light in the ultraviolet range. Information about the universe carried by photons of these wavelengths is inaccessible to ground-based observers.

Furthermore, atmospheric distortion due to moving air masses of different temperatures refract light, and cause optical aberrations such as the 'shimmering' of starlight (Vollmer and Möllmann, 2011). This is known as "bad seeing," and Percival Lowell's observations were plagued with it. Observatories on the ground have excellent optics, but ultimately are limited by the light which reaches them. No improvement in optical clarity can amend wavelengths of light which does not reach it or that are distorted on their path through the atmosphere.

The Mauna Kea Observatory, located in Hawaii, exemplifies the progress made to overcome challenges faced by terrestrial telescopes. Located on the dormant volcano of Mauna Kea, it sits at 4,205 meters above sea level (Wynn-Williams, 2018). The high elevation reduces the amount of atmosphere photons must pass through. Nine optical and infrared telescopes, three submillimeter wavelength telescopes, and one radiowave telescope make up this observatory, allowing for optimal use of frequencies which do reach Earth's surface (Wynn-Williams, 2018).

Space-Based Telescopes

Space telescopes represent our effort to move away from the influence of Earth - both metaphorically and literally. Though simple in principle, it is incredibly challenging to shift our viewpoint beyond Earth and move the observational equipment into space.

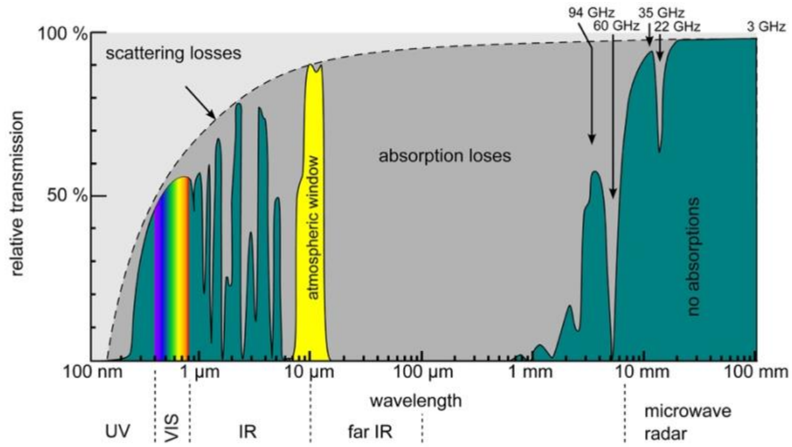


Figure 2.25. Transmission of electromagnetic radiation passing through Earth's atmosphere.

The Hubble Space Telescope (HST), proposed by Lyman Spitzer Jr. in 1946, and launched on April 24, 1990, is perhaps the most notable example (HubbleSite, n.d.). Hubble fills in the gaps of ground telescopes by detecting wavelengths of light in the infrared to submillimeter ranges. It has an impressive precision of 0.05 arcseconds, which NASA has described as comparable to "seeing a pair of fireflies in Tokyo from your home in Maryland" (Dunbar, 2016). To date, more than 10,000 scientific articles have been published based on Hubble data (HubbleSite, n.d.), including research on Earth-like planets in the TRAPPIST-1 system (de Wit et al., 2016).

Scheduled to launch in 2020, the James Webb Space Telescope (JWST) will be HST's successor (Dunbar, 2017). In an endeavour of epic proportions, the tennis-court-sized telescope will revolutionize our observational capabilities once it is unfolded beyond Earth's atmosphere (NASA, 2018). This telescope represents another shift away from Earth-centrism, as its orbit will in fact be around the Sun (NASA, 2017). It contains four image sensors to expose from optical to mid-infrared light (Space Telescope Science Institute, 2018).

An Earthist slant that remains in exoplanetary astronomy today is the fact that many observations are done with the subconscious notion or hope for the discovery of life. The planetary conditions which make life possible on Earth have led to the prioritization of similar planets. Earth analogues may provide the best likelihood of finding life elsewhere in the universe, or it simply may be that our own Earthism has swayed us towards this conclusion.

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IMAGE CREDITS

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To myself I am
only a child
playing on the
beach, while vast
oceans of truth
lie undiscovered
before me.

- Isaac Newton

CHAPTER 3

Methods Behind the Madness - Developing Techniques

Through buzzing curiosity and the fascinating explorations of the world around us, we naturally ask questions. Living on a dynamic planet, there is so much to discover through both temporal and spatial time scales: from atoms to our spot in the universe, and from the climate of early Earth to ancient organisms. In the hopes of answering these compelling questions, curious and creative individuals took it upon themselves to begin the process of developing methods of scientific techniques, procedures and measurements. These valuable contributions to the academic community have become an essential part of the scientific method and enable scientists to continue building upon scientific knowledge and communicating information in an effective way.

Many of the methods designed to answer ambitious questions started off with novel ideas which, through many trials, eventually led to becoming revolutionary techniques in exploration and discovery. Over many years, these steps and techniques became refined and modified to match the ongoing technological advancements and societal progressions. However, the original ideas and motivations continue to inspire and motivate the new adjustments.

Records of technique and measurement have been present from ancient civilizations seeking to observe our planet, its history, and its elements. By being observant, detailed, and meticulous, early scientists provided the scientific community with methods to handle artifacts, manipulate metals, measure the size of our Earth, and make sense of discovered fossils, just to name a few. More importantly, the time and effort put into the development of scientific techniques provides subsequent scientists a base to build upon, test, and better these techniques. As we enter this chapter, we delve into the stories of how scientific techniques became and developed out of a need to understand and explore.

The Evolution of Paleontological Fossil Processing Techniques

"[O]rganic remains are thus sometimes as beautifully perfect as if prepared for the purposes of instruction by the comparative anatomist" (de la Beche, 1865, pp.248).

Fossil discovery and exploration has enhanced and strengthened understanding of the prehistoric world, with the depth of knowledge of what lived millions of years ago being nothing short of impressive. While paleontological findings over the past few hundred years are a well documented field, what is not as well publicized is the actual process of fossil preparation. The evolution of these techniques, from simplistic pocket tools, to complex interdisciplinary equipment, suggests that a lot has changed. With each discovery, shared scientific understanding increases, leading to the development of better methods. In the following chapter, some of the key paleontological techniques, fossil cast creation, fossil abstraction, and chemical preparation will be discussed, as well as current modern processes including isotopic dating and DNA analysis.

Fossil Casts

Oftentimes, when fossil extraction is not possible moulds or "casts" are created to preserve and immortalize the integrity of samples. However, other reasons for creating moulds include: the preservation of specimens' spatial distribution and the option to make multiple copies. Duplicates are made to ensure preservation of the original specimen and to allow for said sample to undergo further studying and distribution.

The earliest known history of casts can be dated back to the early 19th century. In 1811, Henry de la Beche (NNDB, 2014), a privileged British man who was recently expelled from military college, travelled to Lyme Regis, England, to work alongside famous paleontologist, Mary Anning (see Chapter 5). Anning, daughter of a poor cabinet maker, was one of the first paleontologists to discover and identify plesiosaurs and ichthyosaurs and her findings initiated a change in ideals from the past (see Chapter 5). Previously, scientific views were deeply tied to religion (i.e. scriptural geology) and wealth, but these circumstances were beginning to be challenged (Grizzle, 2012).

In contrast to Anning, who lived a humble life, de la Beche, the future director of the British Geological Survey (Winchester, 2001, pp.207), lived one of controversy. His modern view of extinction and promotion, that preconceived opinions should be separated from fact, led to feuds with known geologists, such as Charles Lyell (Haile, 1997). This thought initially conceived by George Cuvier and Mary Anning (see Chapter 5) stated that fossils were created as a result of extinction and that different fossils from the same organism can be pieced together to better understand the anatomy of ancient creatures.

One of de la Beche's most memorable works, *How to Observe-Geology,* discussed his techniques for fossil mould creation. For difficult to obtain fossils, plaster-of-paris moulds were used, with de la Beche stating that moulds, "should be carefully wrapped in paper, the locality having been written on a strip of paper and enclosed with the specimen; or a particular mark may be made on the specimen, or enclosed strip of paper. which shall correspond with a similar mark in the observer's field-book" (de la Beche, 1865, pp.249). Although the idea of taking a mould may not seem significant, this event was the first time that fragile, complex fossil samples were able to be further analyzed based on structure. As well, fossil casts were able to be removed from excavation sites to be studied with more refined laboratory equipment.

With fossils only recently discovered and hardly understood, it can be said that de la Beche is one of the first to do more than simply excavate fossils from the ground. He saw the importance of preserving the orientation and proximity of structures, which is fundamental in understanding the relationship between associated samples. Comprehending fossil correlations, allows more to be known about how organisms interacted, what shared conditions they lived under, and if bones were from the same specimen, how the organism was structured (de la Beche, 1865, pp.245). de la Beche emphasis on fossil associativity, demonstrated that a deeper understanding of fossil origins and meanings were being developed.

Through the analysis of drawings and journal writings (Figure 3.1), it can be seen that the protective barrier, used when taking casts, changed with time as well. After plaster-of-paris moulds, burlap cloths drenched in gels or glues became popular (Whybrow, 1985). Flour and paste was also a popular casting method at the time, potentially due to easy availability. This technique however, later progressed to rice pastes in the 1890s. Moulding techniques, such as these, were later replaced by "plaster and gunsacking cocoons" which were similar in idea but were more specialized for specific fossils (Whybrow, 1985).

As time went on, further modifications to the process occurred, as the protective barrier between casts and fossils were also enhanced. These current methods only provided a fossil's general shape, which led to the development of techniques that displayed finer detail. (de la Beche, 1865, pp.194).

In order to fix this issue, fossil specimens began to be fully emerged into solutions which were designed for specific purposes, that included prevention of water loss, bacterial/mould growth, and increased durability. Cast barriers were then changed to be fluids (i.e. olive oil) that emphasized the curves of the system and allowed for impressions and folds to be documented (Davies, 1865). In the 1900s, more ideal casting materials were created, as knowledge of chemical compounds expanded. Adam Hermann, a preparator of over 30 years, wrote a review entitled *Modern Laboratory Methods in Vertebrate Palaeontology*, where he discussed the paleontological advances achieved at the time (Hermann, 1909). He noted that in the past, it was customary to use a solution of hardened sap called "gum arabic" (Rixon, 1976). Soft and porous specimens were immersed in this liquid, in order to harden them for later packaging. However, this solution was inadequate for tougher and less porous bones and when applied left them brittle and dry (Rixon, 1976). Due to the inadequacies of the gum, Hermann explained that recently a new substance had started being used, stating that "[t]hrough the experimentation of the various collectors of the museums in America, it can be found that shellac is in nearly all cases superior to gum" (Hermann, 1909, pp.286). He then noted that the shellac's superiority stemmed from the fact that it is waterproof and penetrates quickly into the fossil's crevices (Whybrow, 1985). Another advantage is that once dry the shellac makes the bones significantly more resistant to stress and damage (Whybrow, 1985). Since the introduction of shellac, moulding techniques have not evolved greatly, but have rather been built upon through coupling with new processes.

Figure 3.1. Painting, Professor Mudge, *by Artur Lakes of a paleontology dig site (1877-1889). A thin layering around the large fossilized bone is shown depicting what is believed to be a fossil cast.*

Fossil Extraction

Beyond making a mould, removal of fossils from the rock matrix is an important task that has evolved to become tailored to the specimens being examined. Overtime, the once crude, simplistic chisels and awls, were replaced with new electric devices. George Cuvier, who was previously mentioned, was one of the first individuals to write about his preparatory techniques. At the Académie Caroline, in Germany, Cuvier studied comparative anatomy, the art of dissection, and found his passion for fossil discovery and observation (University of California, Berkeley, 2006a). Following his graduation, he worked as a tutor while at the same time, wrote original descriptions of marine invertebrates (University of California, Berkeley, 2006a). Later, following his true passions, Cuvier began working at the Paris Museum of Natural History, instead of accepting the offer to join Napoleon's expedition to Egypt (University of California, Berkeley, 2006a). After working at the museum for years, Cuvier used his accumulated knowledge of the anatomical features of organisms, to characterise fossils that he had excavated (University of California, Berkeley, 2006a). While examining a nearly complete marsupial skeleton, in 1804, Cuvier recorded his process and described his preparatory steps: "I dug carefully using a awl, and had the satisfaction of discovering the entire anterior portion of the basin" (Whybrow, 1985b).

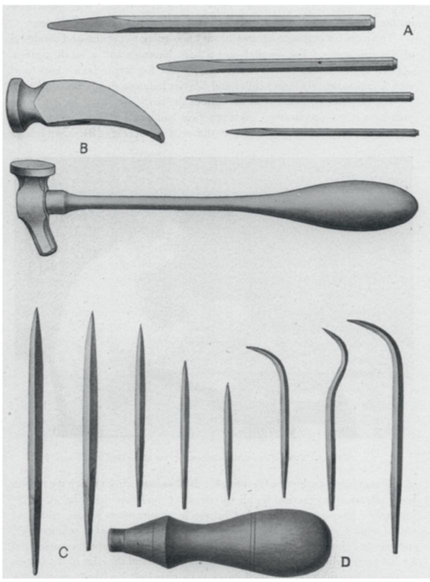


Figure 3.2. Drawing of more refined paleontological tools from the 1900s. Depicted are (A) varied chisels, (B) a hammer, and (C,D) variously sized awls.

Without refined technology, paleontological processes required extensive understanding, advance preparation, and attentive care. Into the late 1800s, fossil collectors continued using the same simple hand tools to chip away at the matrix using a repetitive tapping motion (American Museum of Natural History, n.d). Although usually efficient for fossil isolation, these processes were tedious and hard; with the potential for specimen damage (American Museum of Natural History, 2009).

As time progressed, individuals, regardless of scientific background, became more enthralled with paleontology, and new technological advancements allowed for the further refinement of excavational techniques. Preparator, a newly created title, was now used to define those tasked with preparing fossils for display (Whybrow, 1985). These individuals, unlike previous fossil collectors, no longer required a background in mining, quarrying, or stonemasonry, but rather manual dexterity, patience, and adequate knowledge on vertebrate anatomy (Whybrow, 1985).

Modern Laboratory Methods in Vertebrate Palaeontology (1909) was one of the earliest published reviews to describe the faulty preparatory techniques of the past, as well as the issues with the current practices. From Hermann's descriptions, it is evident that techniques and equipment had not changed drastically over time (Hermann, 1909). It was rather the knowledge that had evolved to the point where systematic steps were employed and adapted to different situations (Hermann, 1909). In this review, it states that, "the tools for cutting rock should vary according to the size and condition of the specimens. For small bones a light hammer and a small, narrow pointed chisel should be used. While for larger bones and hard rock, a comparatively larger chisel and heavier hammer should be employed" (Hermann, 1909, pp.290).

Similar tools and techniques are described in William Diller Matthews's 1906 letter, which explains his experience collecting fossils in South Dakota (Diller Matthew, 1906). Diller Matthew, a vertebrate paleontologist who worked primarily on mammal fossils, wrote about what to do when one encounters a specimen in the field (Diller Matthew, W., 1906). He remarked that after discovering a bone in the ground, a chisel could be used to pick and scratch around until the fossil was uncovered (Diller Matthew, 1906). Following this the rock can be further cut away to uncover the remaining features (Diller Matthew, 1906). It can be seen from both Diller Matthew's and Hermann's recounts, that while techniques of the time still resembled that of over a century ago, there had been sample driven differentiation of tools, which were conducive to ongoing discoveries (Figure 3.2).

Another major paleontological development in the early 1900s, was the introduction of electric devices (Figure 3.3). With the arrival of the dental lathe and mallet, an increase in excavation precision while working with smaller specimens was observed (Hermann, 1909, pp.292). Although innovative, Hermann expressed concern due to unfamiliarity with these devices and with technology as a whole, stating that, "[t]he only disadvantage is that the mallet gets out of order too easily in the hands of a man unacquainted with electrical appliances" (Hermann, 1909, pp.292).

This knowledge gap proved not to be a problem in one of, famous paleontologist, A.E. Rixon's final works, *Fossil Animal Remains* (1976). This book, addressing the techniques used prior to the 1970s, illustrated that scientists had become familiar with electric devices due to their increased use in both academic, professional, and societal settings (1976). In parallel, field and laboratory tools became easier to handle, lightweight, and more attuned for their specific purpose, causing for widespread use (1976). Comparing past techniques to now, it is clear that fossil extraction has come a long way since the first use of the chisel and awl, with developments mirroring the ongoing technological advancements.

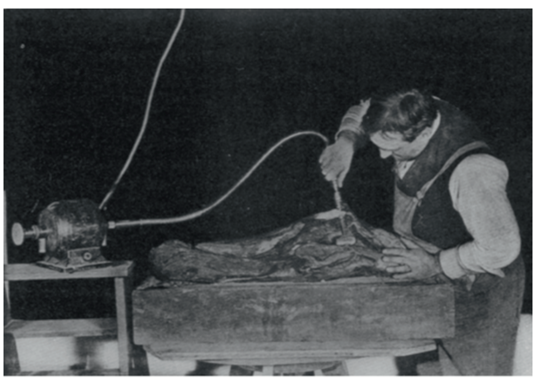


Figure 3.3. Photograph of a preparator using a dental lathe to dislodge sediment buildup

Chemical Preparation

Beyond physical methods, interdisciplinary knowledge has led to the use of chemical preparation in the development of fossils. Oftentimes, not only were specimens intricate, but occasionally the outer rocks encasing them were impenetrable. In these instances, preparators depended, and still depend on, the use of chemicals to soften the rocks and allow for easy removal of the fossil.

Chemical development started being used in the late 19th century. One of the earliest records of their usage was in Gideon Mantell's, 1844, *Medals of Creation* (Brown, 2012, pp.3). Although Mantell was a medical doctor, he and his wife shared a passion for fossil collection, allowing them to unearth large bones of terrestrial organisms. As well, while Cuvier was the first to document the process of preparation, Mantell was the first to illustrate it (Brown, 2012, pp.3). While chemical preparation was not highly described in his record, he did mention their usage briefly. The lack of detail included in his paper, suggested that there was a lack of emphasis on standardization of chemical practices at the time.

Approximately 60 years later, Hermann discussed his experience using chemicals (Hermann, 1909). In this review, he explained, "we have also employed chemicals for freeing fossils from matrix which was so hard that steel tools, such as chisels, awls, etc., were of little use" as well he noted that, "if the matrix contains lime in any form, hydrochloric acid will soften it and allow the chisel to take hold" (Hermann, 1909, pp.293). Hermann demonstrated that not only did he understand the purpose and appropriate usage of chemicals for paleontological work, but he also comprehended the chemical reactions pertaining to specific acid-rock pairings. It can be seen that, since Mantell's time, further emphasis had been placed on molecular means of fossil development, which allowed for new knowledge to be derived from specimens which previously could not have been extracted.

In Hermann's writing, he also noted precautions that must be followed when using acids (Hermann, 1909, pp.293). This demonstrates not only an increased level of knowledge of chemical processes but also the associated hazards. Since there was now an elevated understanding of the scientific importance of fossils as historical tools, rather than just for aesthetic purposes, preparators ensured that the utmost care was taken to not damage the fossils (Winchester, 2001, pp.207).

Around this time, other scientists were also experimenting with acids as a means of aiding in paleontological work, one of these individuals was F. A. Bather (Whybrow, 1985). In his paper *Preparation and Preservation of fossils*, published in 1908, he mentioned his conversation with W. F. Reid who recommended the use of "hypo-acetine" as a chemical agent (Whybrow, 1985). Although this substance is unheard of today, it can be assumed through understanding Reid's previous work with explosives, that this chemical may have contained similar ingredients (Whybrow, 1985). Meaning, that while not the most appropriate substance for fossil extraction, scientists utilized the chemicals they were familiar with, regardless if they were volatile, dangerous, or inefficient. As well, this also exhibits an increase in experimentation, as scientists were now linking ideas from different fields together.

Although great advances had been achieved in the field of chemical development, at this time only invertebrate fossils were being used. It wasn't until 1938 that Harry Toombs and A. E. Rixon, colleagues at the Natural History Museum of London, experimented with different concentrations of acetic acid to see their efficiency at removing vertebrate fossils from carbonate rocks (Rixon, 1976, pp. 84). This was different than previous chemical applications, since solutions were now being optimized for specific rocks-sample pairings. For example, Toombs and Rixon discovered, through experimentation, that concentrations between 10-15% were most effective on carbonate rocks (Rixon, 1976, pp.84). In addition, he noted the importance of strengthening the fossil post chemical treatment with hardening agents such as shellac (Rixon, 1976)

Figure 3.4. Fish fossil prepared using transfer technique invented by Rixon and Toombes.

Although Toombs and Rixon were successful at initiating the use of acid, as a paleontological chemical agent, the method was not perfect. Previously, carbonate rock matrices would be removed by simply submerging them within a solution of acetic acid (Leiggi, and May, 1994, pp. 157). However, for specimens such as fish and birds, dissolution of matrices led to a disassociated skeleton that increased difficulty while studying due to a lack of organization (Leiggi, and May, 1994, pp.157). To address this issue, in the 1950s, Toombs and Rixon developed a transfer technique (Figure 3.4), which utilised a polyester resin and formic acid (Leiggi, and May, 1994, pp.157). This process was made possible by the recent developments in the petrochemical industry, as it wasn't until 1937 that polyvinyl resins were produced from petroleum gas (Leiggi, and May, 1994, pp.157). For Toombs and Rixon's technique, half of the fossil was imbedded in resin (Rixon, 1976). The specimen would then be placed in formic acid, which was found to be stronger and more efficient than acetic acid. This soaking was continued until the entire matrix around the fossil was completely dissolved. (Rixon, 1976). Before the invention of this technique other solutions to this dissociation issue included cementing the specimens on a glass slide and coating it with a rubber cement. This answer however was unable to prevent disarticulation of the specimens and was thus discontinued. This transfer technique further developed fossil preparation as it enabled scientists to examine intricate fossils more accurately due to preservation of original proximity. Acid preparation is now considered a common practice and should be appreciated for being one of the first interdisciplinary approaches to unearthing fossils' histories.

Paleontology on a Microscopic Scale

Present day fossil preparatory techniques have built upon a long history of discovery and refinement. Not only has technology/tools evolved, but the understanding of dinosaurs, fossils, and geologic processes have as well. Due to past experimentation, modern equipment has become far more interdisciplinary and refined than their predecessors. Below is a discussion of two popular fossil identification techniques, which have built upon components of previous methods.

Absolute Dating

Currently, a large amount of information is known on the biostratigraphic timeline, making the dating of fossils equally as valuable as analysis of their structures. Unlike relative dating, which compares specimens to the surrounding rocks, absolute dating provides an empirically calculated age. One common method used to date fossils is isotopic radioactive decay. Atoms such as carbon-14 and potassium-40, which are found in most living organisms, can be the key to unlocking the age of fossils (Peppe, and Deino, 2013). Due to the unstable nucleuses of these isotopes, unique daughter products are produced over time (i.e. potassium-40 makes aragon-40). The production of daughter products follows the equation below, with t being the age of the rock, λ being the decay constant, D is the number of daughter product atoms, and P is the number of parent atoms (U.S. Geological Survey, 2001):

$$t = \frac{1}{\lambda} ln(1 + \frac{D}{P})$$

Through analyzing the ratio of parent to daughter product, the age can be obtained. To acquire said ratio, a small piece, approximately 10 to 20 grams (Gagné, 2018), of the organic fossil material is chosen and broken off. The sample is then placed into a Thermal Ionization Mass Spectrometer (TIMS). The TIMS produces current across a metal filament which ionizes atoms and create an electrical potential gradient (Potts, 1987). The ions exit the first section of the device through a slit and are sorted within a high magnetic field, separated based on their mass to charge ratio (Smith, 2000). Beams of different wavelengths are created for each of the respective mass to charge ratios, which are then analyzed by a computer, comparing the voltage of each of the beams (Mueller and Vervoot, 2018).

Although this methodology is effective in principle, it is important to note that the specimen did not exist in an isolated system. Due to fossil degradation and flow of daughter and parent material in and out of the system, the margins of error in this technique are large. Another limitation to this technology is the moderately short half-life of carbon-14. Carbon is one of the main isotopes found in organisms, however it only possesses a half-life of 5 730 years (Mann, Marlow, and Hughes, 1961). This short half-life means that fossils that are millions of years old may not have a large enough concentration of carbon to be detected by the TIMS. This is why other methods are used, as most elements in the organic body, other than carbon, are not prone to decay. However, while potassium would be an ideal isotope to use, it is not often found in large quantities. Due to the limitations of isotopic dating, other methods are often used in conjunction to provide more accurate and reliable results.

DNA Analysis

Alongside absolute dating, DNA analysis is a prime example of a technological innovation that allows for further understanding of a specimen's origin. DNA sequencing was first used in the 1970s in the form of a simplistic sanger sequencing gel, but has evolved greatly since then (Heather, J. M., Chain, B., 2016). Through having a record of characteristic genetic sequences, more can be understood about the phylogenetic history of the species (**Figure 3.5**), rather than just basing it off of physical features of the fossil (Wunsch, H., 1999). Thanks to the relatively modern introduction of the internet, scientists are now able to share information on genetic databases regarding different specimens. This is useful in the case of pterosaurs, as although they possess similar wings to birds, this is just a result of convergent evolution (University of California, Berkeley, 2006b).

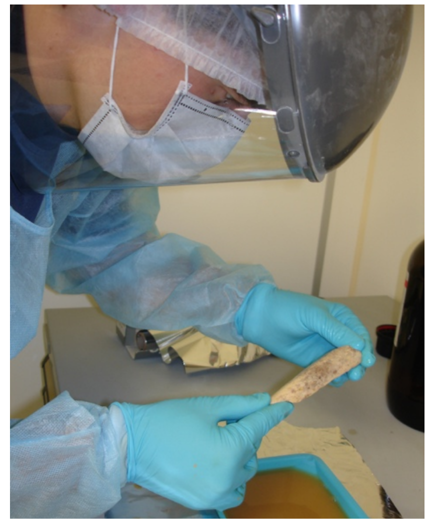


Figure 3.5. Researcher at the Max Planck Institute of Evolutionary Anthropology extracting Neanderthal DNA for further analysis.

Although revealing the ancestry this process still has its faults. There is still a large margin of error since DNA of other species can build up on the fossils over time, contaminating the sample. As well, DNA has a half-life of approximately 521 years, with samples becoming unreadable at 1.5 million years due to degradation (Kaplan, 2012). Many laboratories use different techniques for DNA analysis but one of note is flash pyrolysis. Flash pyrolysis is the process of burning a fossil without causing oxidation, with the purpose of preserving and retrieving DNA and proteins (Poinar and Stankiewick, 1999).

Once ready for analysis, the samples are cleaned and subjected to flash pyrolysis in order to vaporize the compound without reacting with oxygen (Wunsch, H., 1999). The sample then undergoes gas chromatography and mass spectrometry, a sensitive way of sorting a mixture of different molecules, to look for bits of protein left in the samples. Gas chromatography is able to separate gaseous compounds without leading to degradation. Not only can this process be used to simply provide insight into the ancestry of the specimen but also the processes it underwent since the time of its lithification. It has been found that samples older than 10 000 years may not be as reliable, due to the number of degradation environments it has been in (Poinar, Stankiewick, 1999). DNA analysis is one of the most innovative technologies, but more information that will help us unearth the history of the past is just a few technological innovations away.

Development of Biostratigraphy

Earth's history is an irreversible series of events, and for thousands of years, humans have looked to what lay beneath us to solve the mysteries of our past. At the end of the 18th century, humanity reached a turning point; James Hutton was discovering deep time, George Cuvier proved with certainty organic extinction, and geology was rapidly establishing itself as an empirical discipline (McGowran, 2005). There was a developing understanding of sediment strata and structure, which not only lay the foundation in understanding Earth's history and processes but boosted the ever-profitable coal and resource industries. It was also during this time that the study of biostratigraphy was born. The presence of fossils within sedimentary strata (layers of sedimentary rock) could reveal the succession of ancient fauna and flora, ultimately determining the chronological correlation and relative age of the strata in which these fossils were contained.

Much like the technique itself, the definition of biostratigraphy has evolved over time. According to geologist Curt Teischert, biostratigraphy was first defined by paleontologist Louis Dollo in 1904 as the overarching area where paleontology has a significant impact on geology (1958). By the 1970's, the International Stratigraphic Guide defined biostratigraphy as "the element of stratigraphy that deals with the remains or evidences of former life in strata and with the organization of strata into units based on their fossil content" (Hedberg, 1976). However, the most current definition is more interdisciplinary, as biostratigraphy is now understood through a biological lens as well as a paleontological lens, defining biostratigraphy as the use of biological traces and fossils to correlate and date geologic structures (McGowran, 2005). Although the term biostratigraphy was not coined until the 1900's, it was the work of Steno and Smith - the men called 'the fathers of modern geology", that formed the foundations for modern biostratigraphy and other correlation techniques. Thus, one must go back to the research and processes of these geologists to better understand the applications of this technique in the present day.

Nicolaus Steno (1638-1686)

Nicolaus Steno (Figure 3.6) (born Niels Stensen), was a Danish geologist who played an invaluable role in the progression of dating rock formations, and hence became known as the "founder of geology" (Cullen, 2006). Nicolaus Steno's career as a geologist was very short; he began his work as an anatomist, and after working as a geologist for less than a decade, he left science to devote his life to Catholicism (Kardel and Maquet, 2013). Interestingly, his introduction to the field of geology was met with self-struggle and conflict as his observations were often not in accordance with the religious beliefs he possessed.

Figure 3.6. Portrait of Nicolaus Steno as a bishop – his life's work after leaving the field of geology

While attending the University of Copenhagen, Steno's anatomy professor posed a question that baffled many. Seashell-like structures were found embedded in mountains, but the shells were comprised of a material far more similar to rock than to the commonly known brittle shells (Cullen, 2006). This phenomenon was puzzling at the time, because according to common religious beliefs, water and land separation occurred on the third day, while it was on the fifth day that marine life was created. While Steno pondered this question, he pursued a career in anatomy, and developed a successful career discovering new glands through dissections and releasing several original publications, such as *Anatomical Observations* (Steno, 1662), and *On Muscles and Glands* (1664).

In 1666, Steno was given the opportunity to dissect a great white shark, where he noted that the shark teeth very closely resembled *Glossopetrae*, a sharp, triangular stone commonly found on land (Kardel and Maquet, 2013). While many had accepted these stones as having Biblical origins, such as falling from the heavens, Steno began to question these ideas, devoting his time to determining how marine remnants could be found on land (Cullen, 2006).

Steno's anatomical background allowed him to provide strong evidence for *Glossopetrae* being fossilized shark teeth rather than stones (Figure 3.7) and published his findings in *Specimens of Elements of Myology* (Steno, 1667). It was this finding that lead Steno to pursue geology.

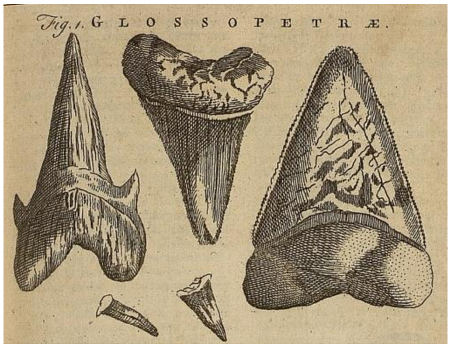


Figure 3.7. An artist's rendition of Glossopetrae: a shark tooth that was believed to be a type of stone. This image was published in 1763 in "A New Complete Dictionary of the Arts and Sciences".

Steno returned to the seashell paradox, theorizing that fossils which maintained their original structures indicated that the organism was molded in a muddy, soft layer of sediment which hardened to produce the fossil. His work began to revolve around strata, which are horizontal layers of rock (Berthault, 2002). He believed strata could act as a window into the past and provide insight into past geological environments and events. Steno's first theory stated that these horizontal layers must have been the product of a liquid such as water evenly distributing suspended sediments over the Earth, except in areas with physical barriers (Cullen, 2006). The lowest strata were comprised of the heaviest sediments settling within this liquid, hardening prior to the solidification of the top layers, which were comprised of the lightest sediments. However, this theory also went against another major principle of creationism, since this proposed process would need to occur in a much longer timespan than 6000 years (Cullen, 2006). Steno's predictions, as it turns out, were correct, as the current estimate for the Earth's existence is about 4.6 billion years (Prothero, 2018).

Between 1667 and 1669, Steno continued his research, publishing three major principles in *Provisional report on solid bodies naturally embedded in other solids*: the Law of Superposition, the Law of Original Horizontality, and the Principle of Lateral Continuity (Steno, 1669). Though their simplicity may be taken for granted today, these were in fact the foundations that paved the way for modern geology. The Law of Superposition states that in a series of undisturbed strata, the relative age increases from the topmost sedimentary layer to the bottommost sedimentary layer (1669). As well, the law states that a lower layer must be solid in order for the liquid upper layer to start solidifying. The Law of Original Horizontality states that due to water and wind (and in the modern-day definition, gravity), all sediments are deposited horizontally (1669). Thus, any strata found at an angle must have solidified horizontally and been deformed due to disturbances such as storms, tectonics, or volcanic eruptions. The Principle of Lateral Continuity states that all strata are extending continuously around the Earth (1669). After publishing his findings on shells, strata, and his three principles in 1667, Steno left science to become an ordained Catholic bishop (Cullen, 2006). While Nicolaus Steno may have kept his work on organic remnants within strata and relative aging of strata separate, these two concepts would later merge to form the primary idea behind biostratigraphy.

Ancient Thought on Ancient Remains

The significance of fossils was first appreciated by the Greeks, followed closely by the men of the Renaissance. They had no perception of how fossils could be used for stratigraphic succession – that would come later – however, they made observations and connections concerning the ecological significance associated with fossils, subsequently determining the environment in which the ancient organism lived (McGowan, 2005). Had it been a time when there was either sea or freshwater? Deep or shallow water? Near shore or far? Leonardo da Vinci (1452-1519) and his associates believed a sedimentary rock containing fossil shells reminiscent of modern shells indicated the former presence of the sea, even if the modern sea was leagues away (McGowan, 2005).

Although fascinated with fossils for thousands of years, it was not until the 17th century that paleontology and geology began to be treated with scientific rigor (Foster and Reeves, 2008). Wealthy gentlemen began to make collections of fossils and minerals; some were very serious in their dealings. However, come the late 18th century, a man named William Smith would forever change the history of geology. Smith was the first to discover that fossils could be used for characterizing, dividing, and correlating strata (McGowan, 2005). Thus, he introduced the Principle of Faunal Succession which, unbeknownst to Smith, built the foundation for theories which would change the way humanity viewed the history of life on Earth.

William Smith (1769-1839)

Figure 3.8. Clypeus ploti *(sea urchin) fossil, commonly referred to as a poundstone or Oxfordshire stone. Poundstones were only viewed as tools with which to weigh butter, rather than a preserved organism.*

Born in 1769 in Oxfordshire, England, William Smith entered a world filled with much geological fascination (Cullen, 2006). As a child, Smith found interest in poundstones, which were dome-shaped rocks often found in the Oxfordshire fields (Figure 3.8). Although used as a standard measurement in the weighing of butter, it was later discovered that these rocks were actually fossilized remains of sea urchins. Although these stones held no significance to society, they would spark in interest that would stay with Smith for the remainder of his life.

At the age of 18, Smith became an assistant to Edward Webb, a professional surveyor at Stow-on-the-Wold. Within a few months, he learned of the sediments and soils around Oxfordshire, while also gaining valuable skills in the use of surveying equipment. In 1791, Smith was sent to survey the estate of Lady Elizabeth Jones in northern Somerset, where he conducted underground observations of mines in the search for coal deposits (Cullen, 2006). Coincidentally, this area had been mapped 70 years prior to this search by British geologist and cartographer John Strachey. Strachey illustrated the stratigraphic succession of sedimentary layers, bedding altitude, faulting, and the unconformities in the Somersetshire coal field. It was also here where Smith made his very first observations of strata (Forster and Reeves, 2008).

Smith's intelligence and skills as a surveyor were held in high regard by Lady Jones, who then later enthused two members of the Coal Canal committee. Preceding this exchange, canal builder John Rennie hired Smith full time. Smith was appointed engineer at Somerset Coal Canal, a job which required extensive and accurate knowledge of the local stratigraphy. It was during this time that Smith examined extraneous fossils, which he extracted and collected (V.A.E., 1939). In the late summer of 1794, along with two other members of the canal committee, Samborne Palmer and Dr. Richard Perkins, Smith was instructed to venture on an expedition to observe the construction and drainage of other canals. It was a journey that would last months and take the men over nine hundred miles over England and Wales. This opportunity enabled Smith to further extend his knowledge of strata succession (Winchester, 2001).

In 1797, Smith recognized that strata could be ordered and correlated based on the fossils they contained. Thus, in a span of two years, he recorded this novel concept and created the world's first geological map (a circular map surrounding the area of Bath) (Foster and Reeves, 2008). In 1815, using data collected from the summer of 1794, Smith created and published his first piece of work: *Delineation of the Strata of England and Wales, with Part of Scotland* (Figure 3.9) with an accompanying 50-page textual explanation (Smith, 1815).

It was the first of its kind: an accurate, geological map detailing nationwide strata. Although his work was not initially accepted, this map became the foundation of British geography and earned Smith the title "Father of English Geology". The geological map of England and Wales displayed the stratigraphic succession of England's underlying sedimentary rock. In addition, Smith marked canals, roadways, and resources such as copper and coal. He used bands of uniform colour to represent strata with particular geographic positions and surface features, while coloured shading indicated the dip of the strata (Smith, 1815). According to an

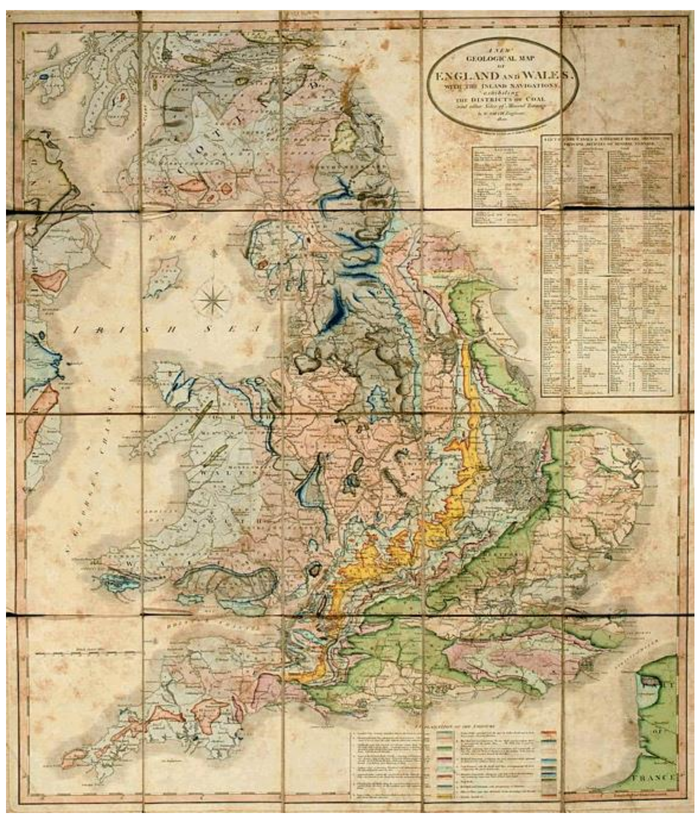


Figure 3.9. William Smith's "Delineation of the Strata of England and Wales, with Part of Scotland" map

account of John Phillips, nephew and protégé of Smith, Smith assumed that similar banding meant similar placement in the geologic succession, similar fossils, and similar lithology (McGowan, 2005). Between the years 1816 and 1819, Smith even published an unfinished series titled *Strata Identified by Organized Fossils,* which described soils and strata with illustrations of typical fossils found within them. The lithological characteristics were also described, and these included: colour of the sediment matrix, water content, clasts determination, and sorting (Smith, 1816).

Gaining Momentum

Following the Principle of Faunal Succession and the geological maps set forth by William Smith, geologists and naturalists of the 19th century found inspiration, making their own correlations concerning the various layers of sedimentary strata. Smith's protégé John Phillips altered the historical basis of mapping by utilizing fossils as the key to succession. Although similar to Smith's basis for the construction of the map of England and Wales, Phillips' premise in geologic mapping was based heavily on fossil presence, with lithological characteristics of the strata being of little importance. While Smith's geological map utilized coloured bands to represent strata with similar succession, lithology, and fossils, Phillip's map utilized bands of colour to represented strata in which similar fossils were contained. Unlike Smith, he assumed that these strata occupied the same place in the succession no matter their lithology, presuming that the relative age and position of strata are infallibly determined by their ancient remains (McGowan, 2005). In 1811, this mode of thought was also utilized by French geologists Baron de Cuvier and Alexandre Brongniart, who studied the stratigraphic succession of the Paris Basin, ultimately describing what were to be known as the Cretaceous and lower Tertiary units of strata. Cuvier and Brongniart interpreted alternating segments of marine and brackish water fossils in the basin as successional and catastrophic replacements of the fauna that once lived in the sediment. They attributed the succession of these events as changing positions of the sea and land, while also proving that fossils seen within strata which were absent today were a result of organic faunal (or floral) extinction (Berggren, 1998).

In 1833, Charles Lyell published his innovative *Principles of Geology*, where he described three divisions of stratigraphic succession, determined by the presence and absence of the fossils within each layer of strata (Figure 3.10). The first division he named the Primary (now known to be the Paleozoic division), which was determined by the presence of abundant trilobite fossils. The Secondary (Mesozoic) was distinguished by ammonite fossils, while the Tertiary (Cenozoic) was based on the presence of fossilised nummulites (Lyell, 1896). It was in this publication that Lyell also described and formalized the subdivision of the Tertiary unit. Using the succession of molluscan fauna determined by associate and friend Gérard Deshayes, Lyell was able to deduce a threefold subdivision of the Tertiary strata through quantitative assessment of the French biostratigraphic succession (Lyell, 1896). At this time, there was also similar faunal analysis of this strata completed by Hans Georg Bronn, however unlike Lyell and Deshayes, Bronn was unable to establish a formal stratigraphic division of the Tertiary (Berggren, 1998).

The Concepts of Stage and Zone

French paleontologist Alcide d'Orbigny introduced a concept known as "stage", which describes (1) a natural chronological division of Earth's history, (2) an accumulation of rock strata, and (3) a biostratigraphical unit. Much like the work of Lyell, the characteristics of a stage were based on the vertical distribution of fossils (Monty, 1968). D'Orbigny concluded that the boundary of a stage originated at the creation of new organisms, whereas the end of a stage was marked by catastrophic extinctions such as those discussed by Cuvier and Brongniart (Berggren, 1998). During his years of work, d'Orbigny used the distribution of an astounding 24000 species to name 4 Paleozoic stages, 2 Triassic stages, 10 Jurassic stages, and 4 stages in the Tertiary (Monty, 1968). In 1851, d'Orbigny coined the term "stratigraphie" which described the branch of geology concerned with the study of strata and the vertical progression of layering of these strata (Berggren, 1998).

In 1856, Albert Oppel introduced the final and fundamental unit of biostratigraphic classification: the "zone". While working with Jurassic rocks in Germany, Oppel entertained the idea of using small scale units defined by the geological range of fossil species. Oppel noted that some fossils had a vertical range which was very small, while others were quite long. He also

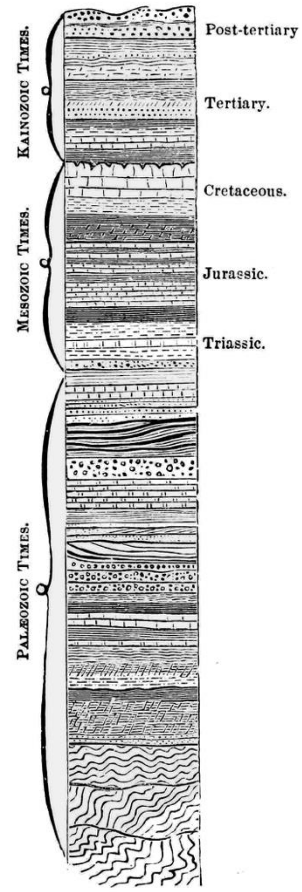


Figure 3.10. Vertical stratigraphic succession displaying the main divisions set forth by Charles Lyell and Alcide d'Orbigny.

found that collections of fossils which characterized the strata were found to overlap between stages. Thus, Oppel began to define zones by vertically categorizing the strata based on each separate species, and concluded that each zone, or subdivision of a stage, should be distinguished by the occurrence of a species not found in strata either above or below that zone (Boggs, 2001).

Much like d'Orbigny's characterization of stage, zones relied on assemblages of fossils, with boundaries determined by the creation and extinction events of fauna. Each of Oppel's zones were named after a particular fossil species - the one which was absent both above and below that zone - called an index fossil (or index species), which is one of many species present in that particular zone (Boggs, 2001). The concept of zone allowed for the further subdivision of stages into two or more smaller distinct biostratigraphical units, allowing geologists and paleontologists alike to accurately describe strata and determine their importance in the geological and biological succession.

Is Biostratigraphy Essential or Extinct?

While biostratigraphy has been an invaluable tool in understanding geological processes over time, the use of this technique may be quickly fading. The applications of biostratigraphy have been seemingly shifting from strata correlation and aging to the search for hydrocarbons and economic resources, after being used in the 1890s to draw correlations between nearby oil wells (Kaminski et al., 1993). Recently, biostratigraphy has been found useful in identifying or characterizing oil and natural gas reservoirs, through the identification of index fossils and correlation of potential reservoirs (Wescott et al., 1999).

Index Fossils as Oil Indicators

Index fossils can be incredibly helpful tools in determining relative time ranges of formations or zones, but their accuracy can vary. The most reliable index fossils are those displaying specific characteristics to accurately identify a unique zone. Index fossils should be geographically widespread, thus allowing for the continuous lateral correlation of zones - exactly as Steno's Principle of Lateral Continuity implies. Index fossils also must evolve quickly, ensuring that the fossil present in the strata and the zone is found within a short and specific amount of geologic time (indicated by depth). Finally, index fossils must be abundant within the zone, preserve readily, and be easily identifiable, or else risk being overlooked in the determination of a zone (Taylor, Taylor, and Kriggs, 2009). Hence, the most common index fossils are microfossils, such as plankton, spores, pollen, and forams (single-celled shelled protists) due to their widespread distribution and rapid evolution rates (Suryanarayana, 2015).

Index fossils can also be indicators of resources such as hydrocarbons. Forams (foraminifera) (Figure 3.11) are the most common index fossil used when locating hydrocarbon sites as they are

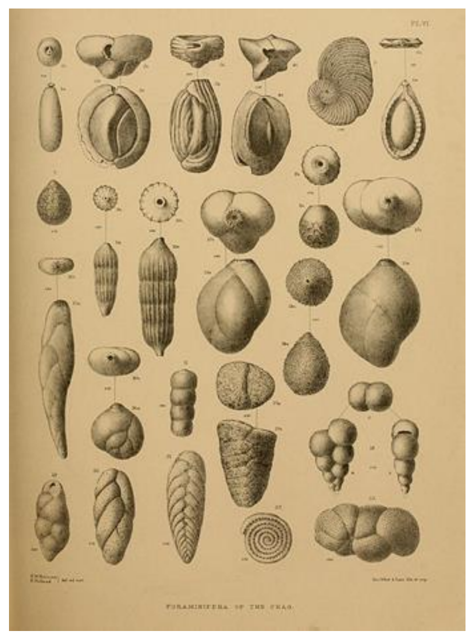


Figure 3.11. An artistic representation of various benthic and planktonic species of foraminifera.

found in very high densities in wide ranges of marine formations (Suryanarayana, 2015). It is estimated that there are thousands of species of forams that can be used as index fossils, which primarily branch into benthic (dwelling on the sea-floor) forams, with some species being planktonic (drifting in the water) (Murray, 2007).

Benthic forams can be used to indicate the environmental conditions of the sea floor, such as density and temperature, while planktonic foram species can give insight into the salinity, temperature, and latitudinal locations of the ocean water (Suryanarayana, 2015). Combined, this information can provide insight into the environment in which these organisms lived, and thus provide the potential for catagenesis (the process of converting organic by-products to hydrocarbons), resulting in oil reservoirs (Suryanarayana, 2015).

By quantifying specific microfossils within strata found at one oil reservoir, other areas with similar biological characteristics have a greater potential to contain oil, and can also provide insight into the ideal depth to drill the well (Wescott et al., 1999).

The Debate of the Relevance of Biostratigraphy

While this technique has provided promising results for almost 200 years, certain groups have been lobbying to move towards newer, more profitable techniques. A 1997 Petroleum Group conference resulted in the publication *Biostratigraphy in Production and Development Geology*, summarizing their findings of the current impact of biostratigraphy and its applications two years later (Simmons and Jones, 1999). One significant paper included in the compilation of 16 articles was published by British Petroleum (BP) executive geologists, proposing a "new model" to replace the current biostratigraphic technique, to which they referred "as a static, non-progressive science" (Payne, Ewen, and Bowman, 1999). Payne, Ewen, and Bowman argued that "the requirement for biostratigraphy must be focused and business driven, fully understanding why it is undertaken and what it can deliver and not, as has happened too often in the past, out of quasi-academic interest or because 'it has always been done'" (1999). This article attacked the current methods of biostratigraphy, claiming it was far too unreliable, inefficient from an economic standpoint, and was highly outdated for the rising global fossil fuel demand.

The main issue it posed with the current biostratigraphic techniques, which they call the "old model", is its low resolution. The index fossils on which biostratigraphy relies looks for species that were geographically widespread. However, the authors argue that having such a large area is undesirable, as accurately mapping reservoirs requires identifying local bio events (1999). The deposition time for reservoir intervals is very short, meaning even rapidly evolving species will show minute genetic changes at best, leaving too broad a window to be reliable (Payne, Ewen, and Bowman, 1999). Due to this low resolution and broad classification, a high-resolution biostratigraphy model known as biosteering was proposed.

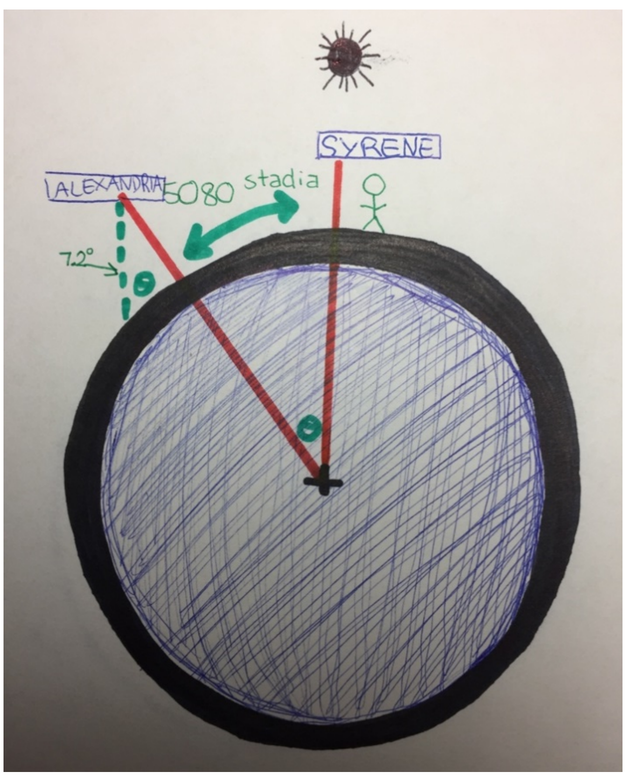
Biosteering is described by Payne, Ewen, and Bowman as a high-impact, high-resolution, economical technique which builds upon the foundations of biostratigraphy (1999). Biosteering allows for the collection of real-time data to more accurately map areas of hydrocarbon reserves on a local reservoir scale rather than focusing on entire biozones (Payne, Ewen, and Bowman, 1999). A main selling point of biosteering is its ability to optimize and predict the ideal depth at which to drill the borehole, thus minimizing costs and maximizing output (Payne, Ewen, and Bowman, 1999). Payne, Ewan, and Bowman boast an integrated approach, incorporating geology, seismic data, reservoir engineering, and applied biostratigraphy (1999). Although this publication provides several arguments for abandoning classic biostratigraphy, both the authors and article contained many apparent biases. The reasons provided for switching to biosteering were focused more on reducing costs and benefiting corporations rather than the reliability and vigour of the science and techniques themselves. While biosteering could be promising due to its higher resolution and real-time feedback, its lack of results and publications coupled with its very short timeline of development is concerning. Classic biostratigraphy has withstood the test of time up until this point, providing reliable data and leading to important discoveries. Minimizing costs should be a priority in commercial settings but not at the cost of losing proper research and scientific processes. Thus, all sides must be equally weighed as the science community debates as to whether biostratigraphy remains essential or has become extinct.

The Circumference of the Earth

In the mid-20th century, we began launching satellites into space that would help us determine the exact circumference of the Earth. However, 2000 years earlier, a man in Ancient Greece came up with nearly the exact same figure without the GPS receivers, laser range finders, or satellites that we have today (Nicastro, 2008). He even determined this without the complex surveying equipment available later in the 17th century. Known as one of the greatest scholars of all time, Eratosthenes was the first man to accurately determine the circumference of the Earth with nothing more than a sundial, a compass, and a scrap piece of paper.

Eratosthenes was a Greek mathematician and the head of the library at Alexandria. He created outstanding works in mathematics, poetry, astronomy, philosophy, and geography (Nicastro, 2008). Eratosthenes may have even been the first person to use the word geography, which translates to 'writing about the Earth' in Greek. As reported by Ptolemy (85-165 CE), Eratosthenes demonstrated his abilities in the topic of geography by being the first to calculate the tilt of the Earth's axis with remarkable accuracy. With less accuracy, Eratosthenes also calculated the distance from the Earth to the Moon and to the Sun (Roller, 2010).

Figure 3.12. Eratosthenes' measurements of the circumference of the Earth using geometry.



Around 500 BC, Greek philosophers started to shift their religious beliefs to a more scientific approach. Pythagoras conceived the idea of a spherical Earth and Aristotle corroborated this theory a few centuries later (American Physical Society, 2006). Aristotle observed that the Earth casts a round shadow on the moon during a lunar eclipse and that different constellations occur in varying latitudes. With this evidence, Eratosthenes knew that the Earth was round, and firmly believed that the planet must have a spherical nature. He attested his understanding of the round Earth by being the first to incorporate latitude and longitude in a world map (Roller, 2010). With only a simple scheme that combined simple geometry and physical observations Eratosthenes found a novel method to determining the circumference of the Earth in 240 BC.

Looking Down a Well to Measure the Earth

In the library of Alexandria, he had access to manuscripts and books from all around the world. In one of these books, he learned a curious fact about a well in Syene (currently Aswan, Egypt). At noon on the summer solstice, when the sun was highest in the sky in the northern hemisphere, the sun shone directly to the bottom of this well (Nicastro, 2008). This phenomenon occurred on June 21st every year (Roller, 2010). Without any shadows casted, the long and deep well indicated the sun to be directly overhead, appearing at the zenith. When Eratosthenes discovered this special property of the well, he immediately made plans to use distances, shadows, and geometry to find the circumference of the Earth (Figure 3.12). At Alexandria, on June 21st, he planted a stick to obtain a shadow measurement of 7.2° during noon, providing evidence that Alexandria and Syene are 7.2° apart on Earth's 360° surface (Nicastro, 2008). When applying basic trigonometry, the only missing variable, needed to determine the length on one degree of the Earth, would be the distance between Alexandria and Syrene. Eratosthenes hired someone to pace the distance between the two cities to complete his calculations. The man informed him that the cities were 5,040 stadia apart, which is equal to about 800 kilometres (Nicastro, 2008). By equating simple proportions, his final result of the Earth's circumference was 252,000 stades, working out to 39,689 kilometres. This measurement is just under 1% shy of the modern polar measurement of 40,075 kilometres.

Eratosthenes measurement of the Earth was highly regarded for hundreds of years, until other Greek scholars attempted measuring the Earth using a method similar to Eratosthenes. Posidonius measured the circumference 150 years later by using the cities of Rhodes and Alexandria (Nicastro, 2008). However, his value was incorrect by about 11,000 kilometres too small. Unfortunately, the general public still favoured Posidonius' measurement since he had the latest circumference measurement over Eratosthenes. Consequently, explorers such as Christopher Columbus believed Posidonius' value and convinced themselves that the Earth had a short enough circumference to sail around (American Physical Society, 2006). Perhaps, Columbus would have never set sail if he had instead believed Eratosthenes larger and more accurate circumference. To say what Eratosthenes' discovery was "ahead of its time" would be a disreputable understatement. His works in geography and the size of the Earth are light years ahead of what previous ancient authorities imagined our planet to be. It would not be for another 1200 years that more accurate measurements of the Earth's size would be made.

Jean Picard and the Length of a Degree

It is 1663 and Louis XIV sits on the French throne. France has just finished a string of costly wars with Spain and the King has given the task of replenishing the treasury to a man named Jean-Babtiste Colbert. A competent man, Colbert would become affluent in the King's lavish court, but his contribution to the history of the size and shape of the Earth occurs much earlier in his career (Murdin, 2009).

In 1663, Colbert realised that the charts and maps that described the King's holdings, were hopelessly inaccurate. Improving this information would be crucial to reforming the taxing and ownership laws so important to the economy. Lacking the knowledge to take on the project himself, Colbert founded the Royal Academy des Science in 1666. The Royal Academy was a society of scientists recognised by their peers as authorities in their respective fields. It was paid by the French state to work on projects of natural philosophy important to the crown. Soon after its conception, the Academy appointed an astronomer by the name of Jean Picard to the task of improving the government's maps (Murdin, 2009). Picard was a devout of early empirical thought and launched himself at the task using methods developed by his contemporary, the Dutch mathematician Willebrord Snellius.

Today, Snellius' name is immortalised in the naming of Snell's law, a physical law that can be used to determine the angles of light traveling through different mediums. Though he never claimed to be the first to use this law, it was his descriptions of it that were first published extensively (Murdin, 2009). However, during the time Picard was alive, Snellius' scientific prominence had nothing to do with refraction, instead he was known for his proposal of the triangulation method (Haasbroek, 1968).

At the heart of triangulation is the geometric sine and cosine laws. Together these can be used to find all measures of a triangle as long two angles and a side length (or two side lengths and an angle) are known. Now, imagine you are in a large field, in this hypothetical field, three towns are scattered at random points. As the king's cartographer you are commanded to accurately find the distance between these towns, and to do so quickly. One approach to this could be to set out from each town with a measuring stick and meticulously measure, stick by stick, all three distances. Unless you find that kind of monotonous torture appealing, you would agree that this method is at the very least, extremely unpleasant. This is without speaking of the continuous adjustments that would have to be made for the rising and falling of land or for the various detours that you would have to take to avoid obstacles. Being a scholar of the first rate, you decide to use geometry to simplify the issues. To do this you find the straightest, most obstacle free path from any tall building in any of the three towns. You measure this line using your sticks, build some sort of tall visible structure at the end of this line and then find two tall structures in the two remaining towns. You then use a telescope and a protractor to measure all the angles between your structure and the three buildings in each town. You account for height and the bending of light, just as you would when looking at the stars (your favourite pastime as a 1700th century scholar), and using the sine and cosine laws you calculate the distance between all points (Figure 3.13). In a nutshell, this is the method of triangulation that Snellius proposed and Picard applied to measure France. This procedure is still in use today for measuring distances as it remains time efficient and accurate.

Picard chose his baseline measurement to fall across a perfect north-south line, called a meridian, passing through the Royal Academy's headquarters in Paris. He measured the flattest, most obstacle free component he could find and set out to locate appropriate locations from

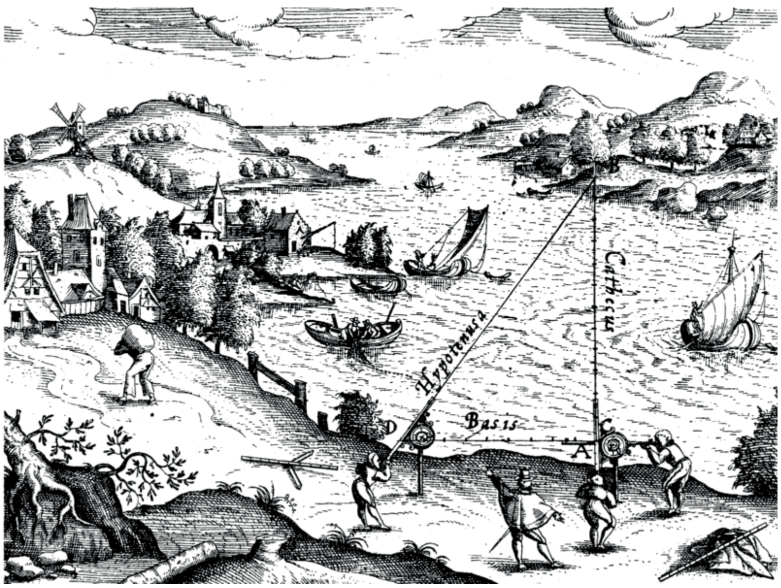


Figure 3.13. The method of triangulation shown in the 17th century sketch. The distance between the two men measuring the angle to the tree is known, and these angles would allow the surveyors to determine distances to the tree. Notice that if an angle is measured from the tree to the church steeple, and from one of the surveyors to the steeple the distance between the tree and the steeple or the surveyors and the steeple can be found without moving from a chair.

which to measure angles up and down this meridian. By 1669, Picard had measured 150 kilometres along this perfect north-south line. The maps triangulation produced pleased the government and Picard moved on to other projects, it would be up to future generations to map the rest of France (Murdin, 2009)

With these measurements and the support of Giovanni Domenico Cassini, the de facto director of the Royal Academy at the time, Picard used his data to calculate the length of one degree of the Earth much as Eratosthenes had done. Picards' measurements were the most accurate measurements of such a large portion of the surface of the Earth to ever have been conducted, and his estimate of the length of a degree of the Earth was only 0.12% different from the modern accepted average (Murdin, 2009).

The Laws of Gravity and the Shape of the Earth

There was only one issue with Picard's calculations of the size of the Earth, they assumed that the globe was a perfect sphere. During Picard's life, the notion of a perfectly round Earth was largely regarded as a convenient fact and may have remained unchallenged, had it not been for the unlikely discovery of the laws of gravity.

As the story goes, in 1684, the great astronomer Edmund Halley paid a visit to cambridge in order to inquire the opinion of Isaac Newton, a professor of mathematics at the university, on the motion of the planets. Newton surprised Halley by stating that he had calculated the trajectory of the planets to be ellipses some time before. These papers however, appeared to be lost. At Halley's insistence, Newton promised to redo the math, a promise that was kept and then expanded on like none could have imagined. Shortly after Halley received the answer he had gone looking for in 1684, Newton launched himself into a two year period of pondering and scribbling that culminated in his masterpiece, the Principia (Bryson, 2003).

The Principia was instantly recognized as a work of genius and Newton would go down in history for his work. In it, Newton gave equations for every conceivable type of motion, postulated his three famous laws of physics and from these, drew marvelous conclusions about the world. Amongst these conclusions was the notion that a spinning sphere held together by gravity, like the Earth, would be squished at the poles (Bryson, 2003). This meant that Picard's calculations of the circumference of the Earth could not be accurate, since a degree of an oval varies from pole to equator.

The French were of course not happy about this conclusion. They even went as far as suggesting that according to data collected in the years since Picard's first survey, the opposite of what Newton proposed appeared to be true - the Earth was flattened at the equator, not the poles. To prove their point the Royal Academy sent two teams of scientists to carry out measurements of the Earth. One team was sent north to Scandinavia and the other was sent south to the mountains of Ecuador. It is difficult to say which team had a harder time with the project, trekking through cold swamps or a dense jungle. However, the French were determined to prove Newton wrong and they completed their measurements after nine years. To the French's dismay, their surveys proved that Newton was right, a degree was in fact longer near the poles than near the equator (Bryson, 2003). And so, because of the speculations of Newton, the earth went from being a perfect sphere to a flattened ball. It would take one of the most violent revolutions in history to prompt scientists to revisit this model.

The Metre Revolution

100 years after the publication of Newton's Principia, the French Revolution brought many of France's old standards into criticisms. Up to this point units of measurement within the French kingdom had varied from province to province and town to town. This made trade exceedingly difficult and the common people had often called on the government to create a unit of standard measure (Alder, 2002).

By 1790, the middle class led National Assembly had enough authority to authorize the Royal Academy to begin designing a system of standardized measures. In the spirit of the ideals of rationalism and in resonance with the ideas that had fueled the revolution, the Academy sought to base their core unit of some non-arbitrary value that belonged to everyone. It was decided that the base unit would be a length called a metre, would have sub multiples of 10, and it would measure 1/10 000 000 of the distance from the pole to the equator.

This was only chosen after much deliberation. For example, there had been some pressure to set the base unit to sub counts of 12 (meaning single digit symbols for 11 and 12 would have to be created) so that values such as the price for a quarter sausage could more easily be calculated by the common folk. It was also contended that the base measure should be defined as the length of a pendulum with a period of two seconds. This was proposed because the laws of physics proposed by Newton dictated that under conditions of equal gravitational force the period of a pendulum is decided solely by its length. In the end however, it was decided that 10 was a better sub interval because humans tended to have 10 fingers to count with and the pendulum was not a good idea, because it was subject to minor gravitational changes, such as those that would be felt at higher elevations (Alder, 2002).

The decision was made to make the measurement of the Earth, along the Paris meridian that Picard had used to make his own revolutionary survey a hundred years before. This time, more accurate measuring devices called repeating circles would be used to make the measurements (Figure 3.13) and the survey would be made all the way from Dunkerque on the northern coast of France down to Barcelona in Spain. Two men were originally chosen to take on this task. Pierre-Francois-Andre Mechain and Jean-Dominique Cassini. The first was a brilliant astronomer, and the second was part of a long line of scientists (remember the Cassini that aided Picard in his own measurements of the Earth) that had each surveyed France in their own time. It was planned that Mechain would measure the northern section of the meridian while Cassini took on the more mountainous south. In this way work could be completed in less than a year (Alder, 2002).

However the project almost immediately ran into problems. By 1792, when the measurements were set to start, conflict between the crown and revolutionaries came to a point up when the king attempted to escape Paris. In the trail of politics that followed, Cassini refused to embark on the project. When the chief minister of the nation threatened to scrap the metre project and adopt the Parisian unit of measure as the standard, the Academy pleaded with Cassini to reconsider. When he persisted, they were forced to replace him with the astronomer Jean Delambre, pictured in Figure 3.14 (Murdin, 2009).

It really is a miracle that Mechain and Delambre both survived the odyssey their mission would become. It would take them six years but in the end their measurements would be used to establish the metre that is alive today. During this time, the scientists would travel through the French countryside at the height of the French Revolution and would narrowly avoid death on

Figure 3.14. Jean Babtiste Delembre was a common born scientist inducted into the Royal Academy at the eve of the meridian expedition. Both he and Mechain had been mentored by Laplace. Despite being older than Mechain, he was the junior partner in the expedition.

more than one occasion. In one particularly instance, Delembre found himself on the steps of a church lecturing an angry mob of revolutionaries on the basics of triangulation. He had been detained for questioning earlier that day because his equipment was suspicious. It also didn't help that Delambre still had with him official letters from the crown authorising him to make his measurements. It just so happened that very morning 800 men had shown up in the town's main square to demand weapons and bread to join the fighting. It was only through the intervention of the town's government that Delambre escaped the mob who had no interest in triangulation and were convinced he must be a royal spy. For his part Mechain would eventually find himself a political refugee. The spanish had been originally reluctant to aid the French in their measurement endeavors. Soon after Mechain began his survey of Barcelona the Spanish joined a coalition against Revolutionary France and Mechain found himself in enemy territory. It was under this pressure that Mechain was unable to address some discrepancies that had arisen in this data, and was eventually forced to escape to Italy (Alder, 2002).

During this time period the Royal Academy was also dissolved and reformed several times. The original proposal to standardise the French units of measure had become uncertain. It was not until 1798, when Pierre-Simon Laplace was head of the latest state-sanctioned scientific institution, that enough support was gathered to unify the data collected by Delambre and Mechain during the chaotic years of the revolution (Murdin, 2009).

England had recently taken steps to standardise its measures and the economic benefits this had brought to the country made it clear that if France hopped to compete, it would have to do the same. The matter of a standard unit was also seen as having potential political benefits. The metre had at its conception been introduced by French scientists as beneficial to all mankind, and it was their ultimate hope that it would become widespread throughout the world. One particular French politician, named Napoleon Bonaparte, saw this vision of a single standard of measure as an extension of his dream for a Europe unified under French leadership. With his support Laplace (who had taught Napoleon at some point before) was able to organise what would become the first international science conference in history. Invitations went out to scientists in the Netherlands, Denmark, Switzerland, Spain, and Italy. Blatantly exempt from these invitations were scientists from England and America, as well as anyone from the German nations (Alder, 2002).

It is clear that England was left out because of French hostility towards it during this time period. In a similar sense American scientists were excluded due to the United States' newfound policy of improving relationships with England. Meanwhile Germany was left out, because many of its scientists still preferred the second pendulum over the size of the Earth as the foundation for the base unit. In any case, the convention occurred with some deliberation and debate over the accuracy of the measurements. Delambre and Mechain themselves had many doubts about their results. They had after all, been conducted under some very straining circumstances. But they also had a deeper unspoken objection to the metre convention.

By now, scientists had come to believe that the Earth was not the squashed ball that Newton had suggested but rather some type of complex ovoid. Mechain however had not forgotten the discrepancy he had encountered in Barcelona, and after discourse with Delambre he came to realise that the surface of the Earth was not the curve of rotation (such as an ovoid, ellipsoid or sphere) required to establish a universal circumference (Alder, 2002). All Delambre and Mechain had measured, was length of the line from the pole to the equator through Paris, it was not representative of the circumference of the Earth because there was no one circumference! Despite the realisation that this would make the justification of the metre as belonging to all mankind void, it was never presented at the conference. The metre was now tied to the success and affluence of a fledgling empire, and it appears that scientific doubt would have to be silenced in this particular case.

It should be noted that the measurements that were decided at the 1789 conference were less accurate than those made by Picard earlier on in history. Despite this, it was from these imperfect values that the standard unit that is in use today was born. This suggests, ss Napoleon was soon to find out, that science is hardly a linear process. During the time of the conference, Napoleon was on his famous Egyptian expedition. The goal of this campaign was to decrease English influence in the region but Napoleon also brought with him a small regiment of scientists intent on rediscovering the classical knowledge that they hoped to find in Egypt. One such finding was that the base of the great pyramid measured 1842 metres, only 0.5% different from the value for one minute of the Paris meridian (Alder, 2002). Was this a coincidence? Were the scientists unconsciously looking for these results? Or is history really just a loop of repeating events? We may probably never know, but the questions that this foray into science history uncovered are similar to the considerations that we must make today when looking at the imperfect shapes that make up Earth and its' history.

Measurements Beyond Earth

Recently, over the past half-century, space-based geodetic technologies have revolutionized the way we look at our planet, giving us the ability to measure changes in the Earth's system with groundbreaking levels of accuracy and detail (National Research Council, 2010). Since we have already successfully obtained near exact measurements of the planet, the search for the size and shape of the Earth comes to an end. Instead, our quest advances to space exploration and beyond. The search for planetary measurements continues through cosmic revelations where the human race seeks knowledge far beyond Earth itself.

The first exoplanets were only discovered two decades ago, and since then, the number of known exoplanets has doubled every 27 months (NASA, 2016). Exoplanets are usually billions of times fainter than the star they orbit, making them extremely difficult to detect. However, in the late 20th century, the first exoplanets were found. Today, we have discovered thousands of these worlds orbiting other stars in the galaxy.

Detecting Exoplanets

The radial velocity method was the first method used to discover exoplanets. In 1995, astronomers used this technique to search for the tiny wobble in a star's speed caused by a planet's orbit (Perryman, 2011). This led to the discovery of 51 Pegasi b as one of the first exoplanets. In 1998, gravitational microlensing showed low-mass planet orbiting a star near the centre of the galaxy approximately 30,000 years away (Perryman, 2011). In general relativity, the presence of matter distorts space time, resulting the path of electromagnetic radiation to be deflected. Gravitational microlensing observes light rays from a distant parent star when an exoplanet changes the electromagnetic radiation.

In 1999, the first transit of a previously detected exoplanet was reported, being the first piece of news to confirm these methods of detecting planets was working. In 2003, transit photometry was first used. By the phenomenon of observing regular intervals of dimming at a parent star, there is evidence of an exoplanet orbiting a star within its respective orbital period. By 2004, the first of wide-field star survey discoveries were reported, where wide field cameras are used to observe precise light curve changes (Perryman, 2011). By 2008, the first exoplanet search from space observations was made.

Other methods at exoplanet astronomers' disposals include astrometry, direct imaging, and pulsar timing (Fischer et al., 2015). Today, the most common method for detecting exoplanets is the transit method. Using the transit method, planets can be detected when there is a block of light in front of a parent star (Lunine, Macintosh and Peale, 2009). The planet size can be indicated by the change in brightness when the amount of light through the atmosphere is calculated (NASA, 2010).

In February 2nd of 2018, new research presents evidence that exoplanets exist beyond the milky way (Dai and Guerras, 2018). Before this discovery, we were only aware of exoplanets beyond the solar system, but now we can search beyond our own galaxy. The study used quasar microlensing, which studies lensing objects in a statistical analyses to probe extragalactic planets, giving a glimpse to the possibility of over a trillion exoplanets existing in the Milky Way (Dai and Guerras, 2018). Twenty years after the first observational confirmation of their existence, exoplanet detection has advanced rapidly in techniques and instrumentation. From looking at sunlight in a deep well to searching a hundred thousand stars every half hour for tiny light fluctuations- techniques for measuring the size and shape of the planet will only continue to advance at an unprecedented level.

Classical Alchemy

Alchemy is a practice that is older than Christianity, from an era when polytheism was commonplace in what is now Europe and Egypt (Gilchrist, 1984). Practiced by several cultures including the ancient Egyptians and Greeks, it was considered a practice for only the wisest and most spiritually attuned (Gilchrist, 1984). The common misconception of alchemy as a form of witchcraft to transform lead into gold is founded in the exoteric and esoteric natures of the study (Gilchrist, 1984). Though the esoteric spirituality involved is a large component, the exoteric nature of substance transmutation provided a basis for our understanding of metallic properties (Gilchrist, 1984). Transformation, however, was not necessarily ill founded. For example, transforming lead into plumbago, a form from which silver can be extracted, is actually an ancient process founded in alchemy (Forbes, 1964).

Figure 3.15. Egyptian crucible from the New Kingdom era. Used for smelting materials, they are designed to withstand the heat of a furnace while allowing the metal inside to melt (Tylecote, 1992).

Perhaps the most notorious goal of the alchemist is finding the philosopher's stone, which was believed to be a transmuting agent that could transform any metal into gold, or even prolong ones life (Gilchrist, 1984). This concept was founded in the idea of metallic inclination to evolve into its perfected form, i.e. gold (Gilchrist, 1984).

Desire for Gold

Within ancient civilizations, gold was more than just a commodity (Spalinger, 2008). Much like in the modern era, to have gold was to have power. Possibly due to its brilliance, rarity stability (as it does not tarnish), or accessibility, gold has long held high value in many places across the world (Spalinger, 2008). Known as a precious metal, gold was only possessed by the elite or royalty and could be used for trade with other kingdoms, or as a way to demonstrate power (Spalinger, 2008). As such, in places such as Egypt, gold was highly desirable, and though the territory already contained much of it, gold was brought back along with slaves as spoils of war (Spalinger, 2008). These treasures contributed to the established power behind the throne of the New Kingdom of Egypt, also known as the Egyptian Empire, between 1500 and 1100 BC (Spalinger, 2008).

Metallurgy

Perhaps one of the best ways to understand the elements is through extraction and manipulation. After mining, most metals require additional processing to extract metals from the ores in which they are found, therefore, until the 19th century, metallurgy was considered a part of the mining sector (Habashi, 1998). Ancient Greek and Egyptian civilizations had limited knowledge of geology, but a large desire for the shining metals produced by what we now understand to be geological processes (Healy, 1978). With a greater interest for precious metals also gave rise to increased curiosity and composition, as well as new methods for their extraction. Extractive techniques were enhanced during the Bronze age (between 1600 and 1100 BCE), by the use of smelting (Tylecote, 1992). Crucibles (left), stone containers, were an important tool for this process, as they were involved in the heating required to make alloys such as bronze (Tylecote, 1992). Crucibles were used to hold scraps of metal as they are melting. After melting, a reducing agent such as coal is used with the purpose of separating the components of ore, such as copper, by weight (the desired material sinking to the bottom) (Tylecote, 1992). Though this method was widely used in the ancient Greco-Roman Empires, Egyptians did not adopt this practice during the Bronze and Iron ages, likely due to the political upheaval of the era and the development of the New Kingdom (Tylecote, 1992). Egyptians were, however, known for their use of gold and ability to gold-plate objects for adornment (Gilchrist, 1984). The metallurgical process was intriguing to natural philosopher's, who developed their own theories of metallic formation (Flambas).

Ancient Egyptian Chemistry

Around the development of the New Kingdom, appearances in Egypt were extremely important. As such, Egyptians found new ways to create cleansing creams, perfumes, and even makeup (Chaudrhi and Jain, 2009). Though of these were a mixture of oils, extracted ore materials, and organic material, other makeup components required a series of chemical reactions. Perhaps as the first displays of chemistry, Ancient Egyptians Synthesized their own makeup using chemical reactions and repetitive operations (Walter et al., 1999).

In addition to makeup synthesis, since the era of the New Kingdom, Egyptians began to work with sands to create, and decorate glass ornaments.

Mining

Egyptian and Greeks are known for their mining of precious metals, but initially the acquisition process did not come in the form of the large mining expeditions that we see today (Healy, 1978). Before mining was required, gold was found in two forms on the surface of the Earth: alluvial, via weather and erosion of mineral bearing rocks, or reef, involving the mechanical mixture of native metal with a solid matrix (Healy, 1978). Additionally, gold was also found in debris falling off mountains. The nature of these early sources of gold meant that no additional processing was required, and the technique for isolation involves sifting from fluvial environments (Healy, 1978).

After exhausting the materials on the Earth's surface, these civilizations were forced to go underground. Mines were possible due to the geological simplicity of the area, and during expeditions maps were often produced of mining sites (below). Famous mines including the Greek mines of Macedonia, where miners consisted of slaves that lived underground (Healy, 1978). In the Egyptian mines of Nubia, however, miners were often criminals or prisoners of war that were forced to work regardless of age and health status (Gilchrist, 1984).

By an account given by Greek geographer Agatharchides of Cnidus, Diodorus Siculus of the first century BCE described the Eqyptian mining technique in his *Bibliotheca Historica:* "The gold bearing earth which is hardest they first burn with a hot fire, and when they have crumbled it in this way they continue the working of it by hand;; and the soft rock…which can yield to moderate effort is crushed with a sledge by myriads of unfortunate wretches…the physically strongest break the quartz-rock with iron hammers, applying no skill to the task, but only force…rock as it is cast down….into mills…they grind it until it… has the consistency of the finest flour" (Nutton, 1974, pp.52).

This new method of acquisition allowed for advancement in the knowledge of ores, strata, and morphology and some theory of metal genesis to locate these deposits (Healy, 1978).

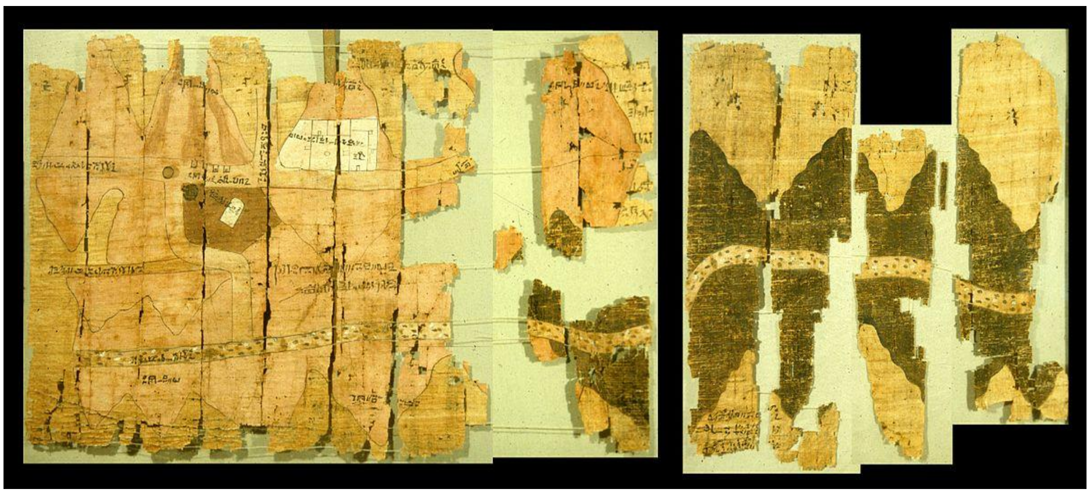


Figure 3.16. Turin papyrus fragments of Egyptian mining map from the Rameses IV expedition in the New Kingdom

Philosophy meets Chemistry

Plato was one of these intrigued individuals that developed his own theories of rock and metal formation. His theories were recorded them in a dialogue known as *Timaeus*. With respect to rocks, it was theorized that the water that rested in the earthly substance became air and its weight compresses the earth into an insoluble form (Healy, 1978). Metals on the other hand, were described as liquids that remained solid at earth's temperatures (referring to melting metal) (Healy, 1978). It was also here that he recorded the idea of four basic elements (water, earth, fire, and air) that would be largely important to the practice of alchemy for centuries to come.

In the year 367 BCE, Plato was teaching at an Academy in Athens (Johnston, 2007). Little did he know that this would be the year that his most renowned student would enter under his tutelage; Aristotle (Johnston, 2007). Though Plato taught him of the religious side to philosophy, Aristotle developed more of an empirical way of thinking, though there is no evidence to suggest that these differences affected their personal relationship (Johnston, 2007).

After Plato's death, Aristotle went on to marry, and was soon hired by Philip of Macedon to become a tutor for his son, Alexander (now recognized as Alexander the Great) (Johnston, 2007). After tutoring the young leader for four years, Aristotle left the life of the Empire for the Greek city-state and opened a school known as The Lycuem (Johnston, 2007). It was at this time that he began to write his well-known works (Johnston, 2007).

By 322 BCE, a new and powerful, arguably Greek or Macedonian, leader had arisen from Greece known as Alexander the Great (Randall, 2004). After conquering Tyre, Alexander set his sights on a greater challenge; Egypt. At the time, Egypt was ruled by the Persians, but the people did not support this power and were pushing toward becoming an independent nation (Randall, 2004). Following an unsuccessful revolt against the Persians, Egyptians welcomed Alexander as their liberator (Randall, 2004). Supposedly descended from Heracles and Achilles, Alexander's divine relations made him an ideal candidate for the next pharaoh (Randall, 2004). This strong bond between the Egyptians and the Greek/Macedonians gave rise to the flow of ideas, including those of alchemical practice between the two nations (Randall, 2004).

Greek Philosophy

After the Greek conquest began the Hellenistic Age, which is known for the flow and merging of ideas between the Greeks and the Egyptians (Edson, 2012). Whether by coincidence, or this flow of ideas, Aristotle wrote much of his most renowned work in this era. Eager to discuss natural philosophy, Aristotle derived to main theories that provide the foundations of alchemical practice.

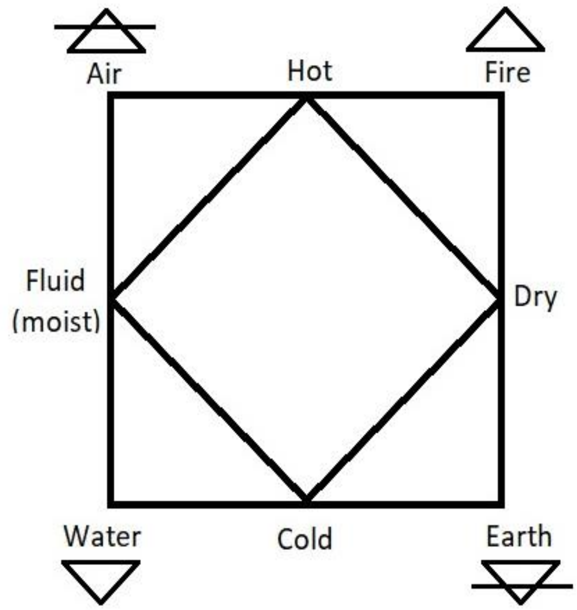


Figure 3.17. Alchemist symbolism for the four elements depicting water, earth, fire, air, and their characteristic connections with one another. Each of the elements shares at least one characteristic with another element (Gilchrist, 1984).

In Aristotle's *Meteorologica*, metals were described as growing within the womb of the Earth, and all base metals were seen as having an evolutionary progression to the more noble metals, such as gold (Ede and Cormack, 2016). Within the same piece, Aristotle also made additions to Plato's four element theory. He supported the idea of transmutation through shared qualities (hot, cold, wet, and cold) (above). Each quality had an opposite, and no two elements could share the same two qualities (Gilchrist, 1984). Aristotle also used the idea of transmutation to develop his idea of eternalism, or the theory that all things that are present have always been present in some form (Burnet, 1691).

The First Alchemy Encyclopedia

After the rise of the Roman Empire the first recording of alchemy was in 300 CE by a Greco-Egyptian individual named Zosimos (Ede and Cormack, 2016). Zosimos was responsible for composing an encyclopedia of alchemy, known as *Cheirokmeta*, a series of books that included descriptions of mysticism and laboratory practicum (Ede and Cormack, 2016). These books also consistently name proceeding alchemists that appeared to have influenced his study and provide the first mention of the "Philosopher's Stone" (Ede and Cormack, 2016).

With regards to the practice, Zosimos most commonly accredits the sister of Moses from the third century BCE (an Egyptian woman named Miriam, also known as Maria de Jewess) as one of the first female alchemists (Ede and Cormack, 2016). One of the main inventions that he attributes to her is the double boiler, which was used to heat sulphur (Ede and Cormack, 2016).

The idea of the stone was also given under other names, such as the "elixir of life" though the stone itself was described as less of a stone and more of a wax that could be converted into its liquid form "the elixir of life" (Gilchrist, 1984). The goal of the alchemist was therefore to "activate a process that will transform a base material, or prima materia, into the Philosopher's Stone (Gilchrist, 1984). This perfecting process often involved some techniques from modern chemistry, such as distillation and heating, but with spiritual foundations that corresponded to certain astrological configurations (Gilchrist, 1984).

Alchemy in the Renaissance

In Egypt, Greece and Rome, there seems to be a gap between the written records of Alchemy between the encyclopedia of Zosimos written in 300 CE that lasts until the Renaissance era. Possibly, this gap is because of religious wars during this era or because there were no major advancements in alchemy at this time in these regions, though there are mentions of progressions in Islam and China from the seventh to tenth centuries CE.

Known as the age of enlightenment, the Renaissance saw the beginnings of the scientific revolution. Within this era grew new philosophies and increased secrecy, not only for the sake of knowledge, but as protection from persecution in a place ruled by the church (Bensaude-Vincent, Schummer and Tiggelen, 2007).

In addition to the symbols for each of the four elements, there were also symbols for the base and noble metals, each with their own astronomical association (right). For example, silver was also known as Diana, the moon goddess, due to its silvery colour (Forbes, 1964). Lead is the element that was known as the metal of osiris, later the metal of saturn, that alchemy is notorious for attempting to transform into gold (Forbes, 1964).

Determined that transmutation was possible, a Polish alchemist by the name of Michael Sendivogius developed a theory of metallic formation. Using concepts from Neoplatonic alchemy, Sendivogius believed that all the metals were created by processes within the Earth, described the core of the Earth as being like a second sun where all elements are digested, and their seeds are then spouted upwards until its spews out of the Earth as a vapour that eventually becomes the water that seeds all life (Rosenbourg, 2009).

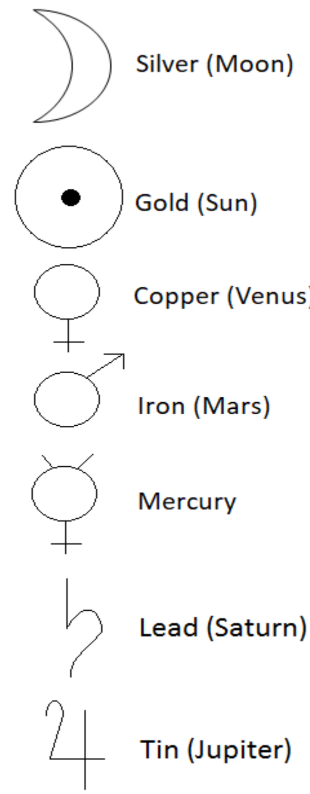


Figure 3.18. Depiction of alchemical symbols and their astronomical associations. These symbols were used as a method for protection, both of intellectual property and from persecution from the church for their practice (Bensaude-Vincent, Schummer and Tiggelen, 2007).

One of these characters was Thomas Burnet, a naturalist in the late 17th century, that had taken interest in the formation of rocks from a religious perspective. In his book *The Sacred Theory of the Earth*, he made arguments against Aristotle's theory of eternalism: "The Earth and Mankind had an original and were not from eternity. This is proved by Divine Authority, and from the nature and form of the Chaos, out of which the Earth was made" (Burnet, 1691, p.43). Burnet strongly believed that the Chaos was responsible for creating the "original" Earth, but that this "original" was not habitable. In addition, he refuted the idea of eternalism by using the idea of the four elements to further disprove Aristotle's theory. Burnet wrote: " If the Elements had lain in that order to one another, as Aristotle hath dispos'd them, and as seems to be their first disposition, the Earth altogether in a mass in the middle, or towards the Center; then the Water in a Spherical mass about that; the Air above the Water, and then a Sphere of Fire, as he fancied, in the highest Circle of the Air: If they had lain, I say, in this posture, there might have been some pretence that they had been Eternally so; because that might seem to be their Original posture, in which Nature had first placed them. But the form and posture we find them in at present is very different" (Burnet, 1691, p.45). In other words, he believed that the Earth was dynamic. His theories, however, were highly debated within the scientific community (Rosenbourg, 2009).

Known as one of the fathers of modern day physics, one would not typically associate Newton with chemistry and geology, and in all candor, his work in chemistry is not given much scholarly attention. Nonetheless, he also expressed interest in this field of science often employing alchemical logic to Earth's rock and mineral forming processes (Rosenbourg, 2009). Originally written in the 1670s and 80s, many of his geological manuscripts went unpublished until 2006, when a manuscript of particular interest related alchemical practice with geochemical applications (Rosenbourg, 2009). As it happens, after writing his book, Burnet sent Newton a copy of his manuscript for an opinion. The arguments made within this manuscript may have influenced many of Newton's own geological theories and little-known works within this area in the late 1600s (Rosenbourg, 2009).

In addition, Newton was a follower of the works of Sendivogius (Rosenbourg, 2009). Supporting Sendivogius' theory to an extent in one of his manuscripts, *Humore's Minerales*, which is debated to have been written in the 1670s, Newton discussed the idea of consistent metal generation in the Earth, suggesting that the process behaves similar to a biological process (Rosenbourg, 2009). This would consistent with an alchemist's point of view as it was a belief of the practice that metals were grown, and that it was the Philosopher's Stone that had the ability to increase the rate of this process.

Origins of the Western Perception

Although transmuting lead into gold was an important goal of alchemists, the practice stretched further than this limiting perspective. Alchemy laid the foundations for understanding Earth's materials and properties. The demotion of alchemy from a science to a pseudo-science is largely due to French Scientists of the Academie de Sciènce. In the mid-18th century, these scientists decided to distinguish between chemistry and alchemy, depicting the practice as a greedy individual's quest for gold (Brock, 2016). This limitation was likely due to the religious contexts of alchemy, as opposed to strictly scientific. One example of this is a mixture known as Diana's (Diana referring to the silvery moon) tree. Alchemists discovered that a mixture of nitric acid, mercury, and silver, when left for weeks, would mix to form a branched tree (Brock, 2016). Where alchemists saw it as a step toward the elixir of life and Philosopher's Stone, more modern chemists saw an example of mechanical crystallization (Brock, 2016).

Geochemical Analysis

One could argue that geochemistry is founded in alchemy and metallurgy, both being imperative to the development of our understanding of Earth's chemical composition and processes (Wainerdi, Uken and Bullard, 1971). Rock geochemistry involves finding the distribution of elements from ore-forming and lithification processes (Govett, 2013).

Geochemistry as Modern Alchemy

Though we now have the ability to find and extract gold, as well as understanding the processes of its formation, we are still far from being able to produce gold from other materials on a massive scale. Possibly the closest technique that we have to transmutation is radiometric analysis. Through radioactive decay and the loss of a proton, radioactive metals do have the ability to decay into their daughter element (For example potassium to Argon) (Aldrich, 1969). Though it does not produce the wealth desired, radiometric analysis can produce its own treasures. Specifically, metals decay at a relatively consistent rate (half a constant half-life), thus providing a good source for dating of materials (Aldrich, 1969).

This is useful as it is able to determine the age of igneous rocks (as sedimentary rocks are typically stable) at deposition, which provides more information about the age of the earth and time depth of its dynamic (Aldrich, 1969)

Geochemistry and mining

Rock geochemistry research allows us to determine the distribution patterns of elements within the Earth, and to observe laws that determine the abundance relationship to the distribution of these elements (Wainerdi, Uken and Bullard, 1971). One technique that can determine the amount of an element within a geological source is known as atomic emission spectrometry (Fassel, 1978). This method uses light emitted from a source, such as a flame, to measure the wavelength of the light. As each element emits a different wavelength of light a summary of the elements present in the sample will be produced (Fassel, 1978). This method is applicable to mapping promising mining locations. After collecting a rock sample from a potential mining location, atomic emission spectrometry can be used to determine the amount of an element present at that site (Fassel, 1978).

Cosmological Geochemistry

Now that we have more advanced techniques for finding the minerals within the earth, more research has gone into studying the source of these elemental materials. This branch of geochemistry is known as rare earth metal cosmochemistry (Henderson, 1994).

Modern views of our solar system suggest an event similar to the "chaos" that Burnet described. One generally accepted theory is that the world was created through a "Big Bang", when a large cloud of dust and gas collapsed on itself. The heat released from the collapse of gravitational energy was enough to vaporize the dust (Henderson, 1994). Once cooled, the gases formed grains that amalgamated together to form the planets in our solar system (Henderson, 1994).

Most geologists recognize that the presence of metals within our solar system were originally produced in stars and dispersed as a result of supernova explosions. This statement, however, does not explain the entire story as to how they arrived on Earth (Alverez et al., 2017).

Modern Gold Detection

Though metals possess cosmological origins, this in itself is not enough to explain the form in which they are present on Earth (Lovett, 2013). Gold veins, or gold in its nugget/solidified form, is deposited after a geological disturbance releases magma from the Earth (Lovett, 2013). New evidence has found that they can form instantly (Lovett, 2013).

Gold is found on all modern continent but is often deposited in such low quantities that it requires geochemical analytical equipment to

detect its presence. Specific quantities of gold in most geological samples can only be measured by quantitative electron microprobe (above) or through performing a bulk chemical analysis (Asadi, 2000).

The electron microprobe is a tool that allows for the geochemical analysis of materials on a microscopic scale (Goldstein, 1975). It is used for the collection of compositional data in a non-destructive manner that can provide quantitative analysis of elemental presence to an accuracy of roughly 2% (Goldstein, 1975). Electron microprobes can also be used to obtain images with embedded x-ray signal scans. These can be used to accurately measure the distribution of elements in an area of interest (Goldstein, 1975). Beyond elemental compositions, electron probe micro analyzers can also detect electron and photon emission. This can be measured for insight into a material's surface topology and potentially elemental composition (Goldstein, 1975).

Figure 3.19. Electron Probe Microanalyzer which uses x rays to determine the composition of elements on the surface of a sample (Goldstein, 1975).

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THE RESOLUTION OF
REVOLUTIONS IS SELECTION
BY CONFLICT WITHIN THE
SCIENTIFIC COMMUNITY OF
THE FITTEST WAY TO
PRACTICE FUTURE SCIENCE.

- THOMAS KHUN

CHAPTER 4

Coming to a Conclusion - Conflict in the Scientific Community

In an ideal world, science would be a purely objective entity, one based solely in facts and free from bias and other human foibles. The reality is quite the opposite. As the sciences of paleontology, geology, geography, and archaeology were changing and developing due to new observations and theories, complications arose within the scientific community. Scientists were presenting contradictory observations and theories, competing for prestige, and struggling with different ideologies. This resulted in people and theories being pitted against one another. At times, these conflicts became highly personal affairs, destroying personal relationships between competing scientists, spanning decades, and often devolving into public exchanges of insults.

In the process of collecting new observations within the natural sciences, conflict between scientists acted as both motivation and hindrance. On the one hand, the newly competitive field of science inspired an increasing number of scientists to participate in the field and led to many new discoveries and publications. On the other hand, confounding observations that contradicted already developed and widely accepted hypotheses led to scientific dispute and unrest. By analyzing the details of these conflicts, one can learn a great deal about the scientific process and how it is influenced by human bias, as well as the difficulties of finding widely accepted theories in all areas of study.

The chapter to come will explore key conflicts in the early earth sciences, from the competition between two paleontologists in the 'Bone Wars', to the heated debate over the first humans in North America, to the conflicting ideologies of uniformitarianism and catastrophism. The scientific process, as will be made clearer in the stories to come, is not an idealistic, objective process, but rather a tug of war between data, ideas, and the people behind them.

Peopling of the Americas

The Clovis Culture

The first person to realize that something was hidden in Clovis, New Mexico, was a local 19 year old named Ridgely Whiteman. In 1929, Whiteman found a stone projectile point and some mammoth bones, sent them to the Smithsonian Institution, and was promptly ignored (Plains Anthropologist, 1990). The magnitude of Whiteman's discovery would remain unknown until three years later in 1932, and even then came to light largely by chance. A geologist named Edgar B. Howard was studying stratified deposits at the nearby Burnet Cave, staying in Clovis as he did so. During Howard's time in Clovis, locals told him about a nearby gravel pit – Blackwater Draw – where flint projectile points and large animal bones were frequently exposed by wind (Howard, 1935). Howard, who had studied anthropology at the graduate level before becoming a geologist, was intrigued. September of that same year, he returned to Blackwater Draw, this time to conduct an archaeological excavation.

The initial excavations at Blackwater Draw were populated by a rather colourful crew, among them a cowboy who had never used a toothbrush and a sixty year old man with a habit of getting into bar fights (Boldurian and Cotter, 2013; Plains Anthropologist, 1990). The excavations themselves were notably interdisciplinary for their time: Howard's geological background led him to construct stratigraphic sequences (Howard, 1935), and other early reports out of Blackwater Draw were primarily concerned with local geomorphology (Stock and Bode, 1936). These stratigraphic findings would serve as important background when the dig was taken over by anthropologist John Cotter in 1936 (Cotter, 1937).

Cotter took over with the specific objective of documenting associations of artifacts and faunal remains as a way to provide absolute proof of the existence of Ice Age hunters (Plains Anthropologist, 1990). He found exactly what he was looking for: cut mammoth bones found in close proximity to flint points (Figure 4.1), the latter of which were characterized by "bold flaking and incipient grooving from the base" (Cotter, 1937).

In order to appreciate the significance of Howard and Cotter's findings, it must be understood that until very recently – 1927, to be precise – the idea that early humans had inhabited the Americas had been considered the stuff of "crackpot amateurs", resulting in the loss of the scientific reputations of its proponents (Ellis, 1957). The first and only accepted challenge to this status quo occurred in 1927, when Jesse Figgins began a series of excavations in Folsom, New Mexico, that discovered projectile points in association with bison kill sites (Figgins, 1927) Thus, the Folsom culture was thought to represent the first humans in the Americas.

Cotter initially assumed that the projectiles from Clovis were Folsom-type (Cotter, 1937). Critically, however, the findings at Clovis were distinct from Folsom artifacts in three key ways: First, Clovis projectiles had ~20mm grooves down the middle, known as 'fluting.' Second, Clovis projectiles were found in relation to mammoth bones, while Folsom points had thus far only been found associated with bison (Figgins, 1933). Lastly, fluted Clovis points were consistently found in strata below those containing Folsom artifacts – indicating, by the law of superposition, that they were likely older.

Figure 4.1. A variety of Clovis points – note the distinctive central groove ('fluting').

Following the publication of results from Blackwater Draw, re-examination of other sites, previously identified as Folsom (Figgins, 1931, 1933), revealed projectiles with the same distinctive fluting that had also been found separately from typologically Folsom artifacts (Robbins and Agogino, 1964). And so the idea of two separate, early North American cultures was born.

In the years that followed, dozens of sites containing Clovis points were found from the Rocky Mountains to as far as the east coast of the present-day United States, firmly establishing the existence of early humans with a consistent material culture (Robbins and Agogino, 1964). The inception of C-14 absolute dating in the 1960s let researchers date Clovis-associated faunal remains to between

12,000 and 11,000 BP – well before Folsom (Hester, 1970; Bryan, 1969). Armed with approximate ages, archaeologists began to establish a narrative around what was becoming known as the Clovis culture. It was thought that they had been big game hunters, perhaps living in small family bands (Gorman, 1969).

The predominant early theory for how the Clovis culture reached North America involves the Beringia land-bridge, a now-underwater landmass stretching from Siberia to Alaska (Haynes, 1971). It was proposed that early humans had crossed Beringia in pursuit of mammoth herds before travelling South through an ice-free corridor, bringing with them a characteristic means of stone tool production (Hester, 1970; Haynes, 1971). This hypothesis was slightly complicated by the lack of Clovis artifacts found in Alaska, and by the fact that at the proposed time of entry (14,000-11,000 BP), most of the continent was covered by the Laurentide and Cordilleran Ice Sheets (Schweger, 1982; Snow, 1976). Nevertheless, the sheer number of Clovis sites supporting the big game hunters hypothesis was sufficient to convince prominent academics of its truth. By the 1960s, it was widely accepted that the Clovis culture represented not only a distinct way of life, but "the earliest Paleo-Indian cultural pattern defined in North America" (Hester, 1970).

Figure 4.2. Key archeological sites in the Peopling of the Americas debate. Of particular interest are Clovis, Meadowcroft, Pedra Furada and Monte Verde; and the Beringia land-bridge.

Not the Whole Story…

Even as the story of the Clovis culture as the first North Americans expanded beyond Blackwater Draw and became a cornerstone of 'Early Man' studies across academia, a small but increasingly vocal minority of archaeologists and geologists were examining the evidence and finding it unsatisfactory.

As early as the 1950s, researchers were entertaining the idea that other cultures may have pre-dated Clovis, citing the fact that no skeletal remains had been found in association with Clovis artifacts, a significant absence (Hawley Ellis, 1957). Artifacts not fitting either the Clovis or Folsom profile were being found at sites such as Hell Gap (Agogino, 1961), and stratigraphic sequencing of Clovis sites was being re-examined in light of potential alteration by post-glacial tilting or fluvial processes (Robbins and Agogino, 1964). Furthermore, the thus-far unassailable Beringia hypothesis was under scrutiny: If the Clovis people had crossed from Siberia in 14,000 BP, why had no Clovis sites been dated to before 12,000 BP? How could a culture have radiated across most of the continent in a matter of hundreds of years (Snow, 1976)?

These trains of thought were still very much contrary to archaeological orthodoxy, but they persisted over the next decade, fueling what would become a heated debate. In a particularly well-documented example of this debate, Robert Humphrey and Alan Bryan exchanged a series of increasingly targeted papers and responses when Bryan (1969) took offense at Humphrey and his colleagues being "bold enough" to suggest an alternate timeline in a recent report (Humphrey, 1966). The debate spanned multiple years and archaeological journals, and culminated in a particularly severe indictment of Bryan's Clovis-centred views:

"Archaeological evidence has presented us with several alternative hypotheses regarding the populating of the New World, but it has been the regrettable tendency of archaeologists to concentrate on only one of these alternatives to the exclusion of the rest...[we] should not narrow our theoretical approach until all the evidence is in" (Humphrey, 1969, pp.3).

Humphrey and Bryan's diametrically opposed perspectives are representative of the two sides that had formed by the late 1960s: Clovis-First and Pre-Clovis. Supporters of the Clovis-First theory argued that the sheer volume of carbon dated and well-documented archaeological evidence of early Clovis people (and lack of evidence for anyone earlier) made Clovis-First irrefutable; while supporters of the Pre-Clovis theory argued that the Clovis-First faction was ignoring key pieces of evidence in favour of a simplistic and narratively convenient explanation.

During the early stages of the Peopling of the Americas Debate, these key pieces of Pre-Clovis evidence had minimal impact. They were spatially and temporally incongruous (Figure 4.2), and often circumstantial enough to be dismissed by staunch Clovis-First supporters (Irwin, 1971). The status-quo would not be seriously challenged until years later, following the excavation of highly-publicized, extremely controversial Pre-Clovis sites such as Meadowcroft, Pedra Furada, and Monte Verde.

Meadowcroft

The Meadowcroft rockshelter was discovered in 1955, when local historian Albert Miller found pottery shards in a groundhog burrow. Miller would not report his findings for nearly two decades, so professional excavations of the site did not begin until 1973 (Adovasio, Donahue and Stuckenrath, 1990). These excavations produced a large variety of floral and faunal remains, as well as pottery and projectile points thought to serve as evidence of hunter-gatherer practices. Notably, a fluted point was also found, serving as an early talking point: Did the fluted point prove that the Meadowcroft rockshelter had in fact been a Clovis site, or could it be proof of a transition between an unknown Pre-Clovis culture and their Clovis descendants?.

At first, Meadowcroft seemed a relatively innocuous discovery. Its location in southwest Pennsylvania was not particularly contrary to Clovis-First theories, and the presence of a Clovis point – albeit one pre-dated by other material – set it firmly within the realm of the familiar.

And then researchers dated the material.

Relative dating showed eleven distinct stratigraphic units, each with unique geological features and artifacts (Adovasio, Gunn, Donahue and Stuckenrath, 1978). Absolute dating would confirm researchers' suspicions: based on C-14 analysis of floral remains, Meadowcroft had been continuously inhabited for anywhere from 16-19,000 BP, by far the longest at any known North American site, and up to 8000 years before the prototypical Clovis site at Blackwater Draw (Adovasio et al., 1978).

The potential implications of these dates on the Peopling of the Americas debate were immediately evident and, in a field overwhelmingly dominated by a Clovis-First mentality, thoroughly and vehemently debated (Salmon, 1980; Cole, 1980; Mead, 1980). In spite of this debate – which included a memorable, three-year exchange between excavators and critics in American Antiquity that culminated in a reply snappily titled 'Yes Virginia, It Really is That Old' (Adovasio et al., 1980) – Meadowcroft was the first Pre-Clovis site to become generally accepted. Concerns about potential contamination of dated samples have been refuted (Tankersley and Munson, 1992; Sturdevant, 1999), and the site has been designated by state government as a historic landmark (Public Landmark Registry, 2008).

One site, however, would not be enough to disprove the behemoth that was the Clovis-First theory. Meadowcroft was a lone piece of evidence in a Pre-Clovis arsenal that, by the late 1970s, still primarily consisted of untested hypotheses and was continuously being undercut by highly disputed sites, the most notorious among them Pedra Furada.

Pedra Furada

Pedra Furada, a rock shelter in northeastern Brazil, is one of the most controversial Pre-


26 2.º caderno EDUCAÇÃO Domingo, 23 de setembro de 1984 FOLHA DE S. PAULO

No Piauí, o maior sítio arqueológico das Américas

HÉLIO BELIK

Figure 4.3. Pedra Furada attracted scrutiny for initially being described in a local newspaper rather than a scientific journal (Carandell Baruzzi, 2016).

Clovis sites (Figure 4.3). French-Brazilian archaeologist Niède Guidon began excavating the site in 1978, and found what she claimed to be stone tools, as well as multiple cave paintings of animals and humanoid figures (Guidon and Delibrias, 1986; Carandell Baruzzi, 2016). Preliminary C-14 analysis dated the site to "at least 32,000 years ago" (Guidon and Delibrias, 1986). If true, these dates would revolutionize the Peopling of the Americas debate, firmly debunking the Clovis-First theory and even putting the Beringia hypothesis in jeopardy. Perhaps unfortunately, it was not quite so simple. Guidon's findings were met with widespread skepticism from within the archaeological community. It has been suggested that the 'tools' might have been made by capuchin monkeys (Proffitt et al., 2016), and the dating of the site has been intensely questioned (Lynch, 1991; Rowe and Steelman, 2003).

Further doubt is cast upon the Pedra Furada findings by the fact that they were initially communicated in Brazilian news media (above) rather than in scientific journals (Carandell Baruzzi, 2016; Leitao, 1978). Guidon herself described her findings in a local newspaper seven years before academic publication (Guidon, 1979; Guidon and Delibrias, 1986). What could be the motivation for this choice? A potential answer lies in the fact that the publicity around the site led to the establishment of a museum, tourist centres, and even an airport, providing massive economic rejuvenation to an area hit hard by Brazilian political instability (Carandell Baruzzi, 2016).

Regardless of motivation or legitimacy, Pedra Furada is still notable in that it was a high profile challenge to the dominant Clovis-First school of thought – a challenge that, with a cover story for *Nature*, represented a shift in academia towards considering Pre-Clovis as a legitimate possibility. This trend would continue with the discovery of more Pre-Clovis sites of varying reputability, including Cactus Hill, Buttermilk Creek, and Bluefish Caves. These sites were located from Mexico to the Yukon, and lent credence to Pre-Clovis theories, but would not become accepted on a broader scale until one south Chilean site acted as a catalyst: Monte Verde.

Monte Verde

Long known to locals, Monte Verde was excavated between 1976 and 1987 by a large, interdisciplinary research team directed by Tom Dillehay (Dillehay, 2015). The site was an open air campsite on the banks of a small stream, surrounded by sandy knolls, damp forests, and bogs, the latter of which would become fatefully important to the site's preservation. Paleoenvironmental analysis revealed that soon after the ancient inhabitants' departure, water and fibrous peat had covered the site with a bog similar to those nearby. A lack of oxygen within the bog had inhibited bacterial decay, and because the constant saturation prevented drying for thousands of years, various types of organic material (Figure 4.4) that normally disappeared from archeological sites had been preserved (Figure 4.4; Dillehay, 2015).

A research team of more than sixty scientists was assembled to study the well-preserved artifacts excavated from the two areas at the site, called Monte Verde I and Monte Verde II. The results of this study were published in two large volumes by the Smithsonian Institution Press, and proved to be nothing short of remarkable (Dillehay, 1989; Dillehay, 1997). Dillehay (1989; 1997) reported finding parts of nearly 70 species of plants, found in the unusual form of chewed leaves. Hundreds of stone artifacts were found including projectile points and cutting and scraping tools showing signs of human intervention. Other remains included mastodon meat and bone, as well as planks and stakes that formed the foundation of a tent-like structure draped with mastodon hide. Nearly 30 radiocarbon dates were obtained from charcoal, wood, and ivory materials on the site, placing the occupation at approximately 12,500 years ago (Dillehay, 1997).

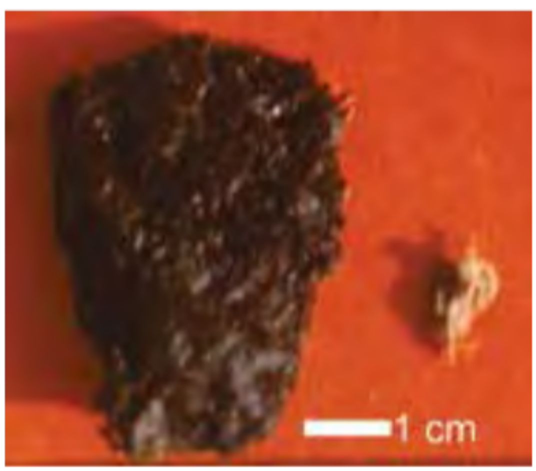

Figure 4.4. Preserved plant remains from Monte Verda. Various species of marine algae are on the left; a wild potato skin is on the right.

This, however, did not line up with the already established theory that Clovis hunters settled in the continents about 11,200 BP; and so, like other Pre-Clovis sites, Monte Verde became embroiled in decades of heated debate. Since finishing the excavations, Dillehay and other excavators have repeatedly re-analyzed findings in multiple volumes (Dillehay, 1989). This effort was considered to be analytical overkill, yet it was necessary given the great skepticism that faced any site potentially predating the Clovis culture in the Americas. Thus, overkill or not, the debate continued until 1997, when the National Geographic Society sponsored 12 Paleo-archeologists – staunch skeptics among them – to visit the site and study the excavated materials in order to confirm or refute the validity of Monte Verde.

The results of the visit were published in *Science* and *American Antiquity*, with the panel confirming that Monte Verde was 12,500 years old (Meltzer, 1997; Meltzer et al., 1997). The implications of this confirmation on the Peopling of the Americas debate were profound. Geographically, Monte Verde is a great distance from Beringia. It is also slightly more than a thousand years older than the Clovis culture. To travel this great distance in such a geographically brief timespan, it is implied that the initial arrival in the Americas must have occurred much earlier than predicted by Clovis-First theories. How much earlier depends upon the obstacles encountered along the way: The interior and coastal routes from Alaska to Monte Verde were impassable from ~20,000 to after 13,000 BP as continental glaciers formed a physical and, for several millennia after their retreat, ecological barrier to migration (Agenbroad et al., 1994). There is also the issue of how quickly early migrants would have had to adapt to an unfamiliar New World, cope with pathogens and disease, and maintain a reproductively viable population, all while living in small numbers spread thinly over large apparently unpopulated continents (Meltzer, 1995).

These complications make it clear that the issue of who was first is far from resolved; nevertheless, Monte Verde represented a marked turning point in the Peopling of the Americas debate. Two volumes of reliably dated, painstakingly catalogued evidence made one conclusion very clear: the findings at Monte Verde imply an arrival to the Americas before 20,000 BP, and thus, before Clovis.

New Perspectives

The excavations of Monte Verde and other key Pre-Clovis sites have lead to a gradual (and still ongoing) turning of the tide towards the Pre-Clovis school of thought. Clovis-First advocates still exist in academia (Fiedel, 2013), but in general, the increasing number of peer-reviewed Pre-Clovis publications in the last decade show a widespread willingness to consider the possibility that there may have been more to the story.

The changes seen in the literature are reflective of drastic changes to how researchers investigate the first humans in the Americas and, in light of broader social change, to question why the debate even matters, and consider who might be affected by its resolution.

Recent Evidence

Perhaps the most influential development in the Clovis-First vs. Pre-Clovis debate is the genetic analysis of Anzick-1, to this date the only human skeletal specimen found in association with Clovis artifacts (Owsley, Hunt, Macintyre and Logan, 2001). The remains were found in 1968 after being loaded into a dump truck by Montana construction worker Ben Hargis, but the landowner ordered the site to be covered with "several tons of material... to prevent further digging" (Owsley et al., 2001). As such, scientific study of Anzick-1 did not begin until 1999.

In spite of the delay, the results of genetic screening of Anzick-1 were hugely informative. Mitochondrial DNA evidence shows that Anzick-1 possessed a very rare haplogroup specific to Native Americans, found in modern populations along the Pacific coasts of North and South America (Rasmussen et al., 2014). DNA evidence also showed that Anzick-1 was linked to Beringia, but was more similar to contemporary South Americans than to North Americans (Rasmussen et al., 2014). These findings have been interpreted as evidence of the coastal migration theory (Kemp et al., 2007), but, crucially, Anzick-1's mtDNA contained none of the polymorphisms characteristic of modern subpopulations. Rasmussen et al. (2014) hypothesize that this could indicate an ancient, Pre-Clovis genetic divergence – perhaps an initial migration via Beringia that split off into coastal and inland groups; or perhaps there were two separate waves of migrants.

The idea that there may have been multiple 'first Americans' is not new (Haynes, 1971; Snow, 1976), but the Anzick-1 genomic data in combination with sites like Monte Verde and Meadowcroft have brought this theory to the forefront and contributed to moving the frontiers of the Peopling of the Americas debate south.

Figure 4.5. Indigenous people have long protested the disrespectful treatment of human and material remains by archaeologists.

The undisturbed underwater caves of Mexico's Yucatán Peninsula have become a hotbed for archaeological discoveries such as Naia, a partial skeleton from Hoyo Negro cave. Naia has been dated to approximately 12,500 years ago – decidedly Pre-Clovis – and is genetically linked to Beringia (de Azevedo et al., 2015; Collins et al., 2015; Chatters et al., 2014). Inspired by discoveries like those from the Yucatán and armed with knowledge of shoreline processes, teams of archaeologists and geologists are boating down the Pacific coasts of the southern continent to search for evidence of how Naia and other early humans may have arrived (Marris, 2016). The renaissance of South American 'Early Man' studies is demonstrative of decades-long changes to the field of archaeology. Clovis-First vs. Pre-Clovis researchers have transitioned from relying solely on typology to consulting earth sciences, genetics, and cultural studies – an interdisciplinary approach to an interdisciplinary question.

Considering Indigenous Perspectives

The Clovis-First vs. Pre-Clovis debate is not a purely academic exercise. The question of who the first North Americans were is by nature political, particularly as pertains to contemporary Indigenous people. Indigenous Canadian archaeologist Paulette Steeves (2017) argues that by placing the peopling of the Americas only 11-12,000 years BP, the Clovis-First theory "limits an Indigenous presence to recent time on a world history scale, and disassociates, disenfranchises and dispossesses Indigenous people from their ancestral past".

Steeves' opinion is partially due to skepticism about the feasibility of rapid pan-continental spread of a culture such as Clovis – a topic of considerable contention in the literature (Amick, 2017; Fiedel, 2004) – and partly due to the fact that historically, Western archaeology has attempted to construct the pasts of Indigenous peoples with very little regard for their traditional oral histories (Figure 4.5) (Dugassa, 2011). Engaging with the Clovis-First vs. Pre-Clovis debate from this viewpoint begs the questions: To what extent will understanding the story of the first people on the continent influence the people who live here today? What's more, how is this story influenced by the biases of researchers embroiled in a debate that, until very recently, has been dominated by a single theory taught as fact (Steeves, 2017; Swedlund and Anderson, 1999)?

More than 85 years after the discoveries of the first fluted points at Blackwater Draw, the Clovis-First vs. Pre-Clovis question has evolved into a highly contentious issue spanning decades and continents. To date, it continues to generate mainstream headlines and academic debate (Fiedel, 2017; Ryan, 2016), while serving as a reminder of the importance of scientifically rigorous and socially responsible archaeology.

Abenaki archaeologist/ecologist Frederick Wiseman wrote in 2005 that "archaeological and historical data are not merely neutral pieces of information". Few archaeological phenomena embody this concept quite as succinctly – nor as dramatically – as the Peopling of the Americas debate.

The Bone Wars

Science is the process of refining our understanding of everything; paleontology is the branch of science concerned with fossilized plants and animals. Amidst hundreds of publications and underneath the mountains of skeletal debris, lies two prominent paleontologists. This chapter delves into a period of American paleontology often labelled the "The Bone Wars" and will analyze the actions of Othniel Marsh and Edward Cope from 1860 to 1899, evaluating the lasting impact that they had upon paleontology. The two main sources carefully chosen to be referenced are *The Gilded Dinosaur: The Fossil War Between E.D. Cope and O.C. Marsh and the Rise of American Science* by Mark Jaffe in 2000 and *The Bone Hunters* by Url Lanham in 1973. The first source draws from a comprehensive collection of correspondences written by Cope and Marsh to family and colleagues. The second source explores the history of American paleontology and the contributions made by Marsh, Cope, and their contemporaries. *The Gilded Dinosaur* has been received positively by Kirkus Reviews (2000), stating: "Philadelphia Inquirer journalist Jaffe adds the color of politics . . . all the while providing rich details about his antagonists. Fortunately, science and both men survived, leaving major legacies for scholars. This account underscores how much of science is personal, and how tightly it is enmeshed in society, politics, and purse strings." Both sources were chosen to provide a comprehensive and reliable account of events, and to determine the key consequences of Marsh and Cope's feud and their lasting legacy in the field of paleontology as well as the rest of science.

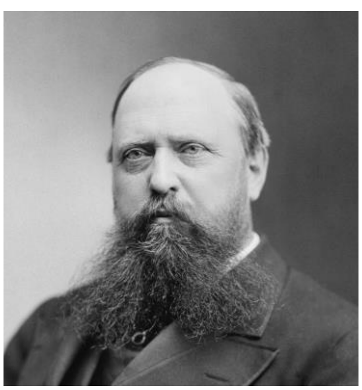

Figure 4.6. Othniel Marsh, was a slow but meticulous scientist (Brady and Handy, 1865).

Before the Marsh-Cope War

Science in the early days of America lacked a degree of respect. The public regarded it with suspicion and indifference, while the government provided little money or assistance. There lacked a central governing body through which scientists could establish themselves or enable effective collaboration between the few institutions and government-funded projects that existed (Jaffe, 2000, p. 5). When determining the sum of government funds to be received by the Smithsonian museum in 1861, Senator Simon Cameron's statement, "I am tired of all this thing called science here", echoes the attitude of the time (Jaffe, p. 4). The practice of science was conducted largely by 'self-made men'. It was the age of the generalist, where aristocrats with deep pockets and free time delved into whatever subject seemed worthy. Despite these shortcomings, a great deal of geological work was conducted in the 1800s by both American and European scientists, aiding in the understanding of the history of the Earth.

The hub of paleontology was in Europe, with scientists such as George Cuvier and J. B. Lamarck carrying out research in vertebrate and invertebrate paleontology (Lanham, 1973, p. 11). It was also a time for ground breaking theories in evolution and geology, including Charles Darwin's *Origin of Species* and Charles Lyell and his three volumes of *Principles of Geology*. Unfortunately, both faced strong criticism and opposition partly because of the implications their work had on religion, and events detailed in the Bible. Furthermore, some of their arguments were largely theoretical and lacked the ancient physical evidence to remove doubt and suspicion.

In America, one of the foremost scientists was Philadelphia naturalist Joseph Leidy. A leading authority in disciplines ranging from anatomy to geology, Leidy represented a period in science where the naturalist could write about anything (Lanham, p. 19). However, once Marsh and Cope arrived, Leidy and his fellow peers were driven out as the very nature of paleontology and its practices changed.

The Early Days of Cope and Marsh

Othniel C. Marsh was born in 1831 on a farm in Lockport, New York (Jaffe, p. 21) (Figure 4.6). At a young age, Marsh was heavily influenced by Colonel Ezekiel Jewett, a veteran and geologist, who helped foster Marsh's joy for the outdoors and for geology (Jaffe, p. 22). Jewett despised the formal pretence of academics, discouraging Marsh from leaving the farm to get a formal science education (Lanham, p. 48). However, after the death of his sister in 1851 and aided by funds from his rich uncle George Peabody, the young man threw himself into academics (Jaffe, p. 22).

He became a fossil collector, stating, "Never part with a good mineral until you have a better, and never let a fine one go in the expectation of getting [at a future time] something for it" (Lanham, p. 49). Marsh also started writing personal journals at the age of 21, "Believing that a diary, with regular additions, will be highly advantageous in improving my style of writing . . . and also a valuable assistant to my memory, I shall now commence to note down the most important events of each day, in a plain and concise manner" (Lanham, p. 60). These journals, along with his many letters, proved to be valuable resources to understand his motivations and demonstrate his pensive and meticulous nature.

He received his master's degree in Yale's Sheffield Scientific School in 1862. While at Yale, he took influences from a variety of noble professors and developed the most solid comprehension of Darwinian thought of any of his American contemporaries in geology, avoiding pitfalls that many distinguished paleontologists had fallen into (Lanham, p. 51). From there, he went to Germany to study anatomy and paleontology.

Upon returning to America, Marsh encouraged his uncle to make an incredible donation of $100,000 to Yale in 1866. The money would be used by the university to build the Peabody Museum, and ensured Marsh's appointment as Yale's newly established chair of paleontology (Jaffe, p. 24). Firmly establishing himself in academia, Marsh began excursions into the Wild West, a region that people would quickly learn contained some of the world's richest fossil beds. In his expeditions, he enlisted Yale students to work for him. Unfortunately, Marsh was very territorial, forbidding them from completing their own research. Samuel Williston was critical and disenchanted by these rules, claiming Marsh never gave his workers credit (Lanham, p. 89). This would foreshadow much of Marsh's future professional pursuits and peer relationships.

The second of the two men of the Marsh-Cope feud was Edward Drinker Cope (Figure 4.7). Born in 1840 in Fairfield, Philadelphia, Cope was destined for life in the fields as a Quaker farmer (Jaffe, p. 44). However, labouring in the field was nothing but a waste of valuable time for the young, impatient Edward Cope, who was considered a child prodigy, publishing his first scientific paper at 19 (Jaffe, p. 46). At a young age Cope wrote to his father that "Tho' I do not think I would become much interested in a business of making money for the sake of making money for its own sake, as many men are, yet the latter is a very useful asset in the furtherance of things for which one is interested in . . ." (Lanham, p. 64). Even as a young man, Cope had no interest in money itself, but still recognized its importance and power. This would go on to show that his prolific publications periods were not financially motivated.

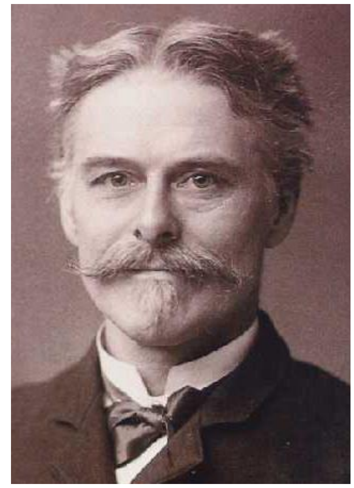

Figure 4.7. Edward Drinker Cope was the more published writer compared to Marsh (Gutekunst, 1897).

A year after his first publication, he wrote seven more, and attended Leidy's anatomy classes (Jaffe, p. 46). As a protege of Leidy and in the halls of the Academy of Natural Sciences, Cope discovered the *Laelaps* in 1866 and in 1869, began reconstructing a massive reptilian creature: the *Elasmosaurus platyrus*. Cope studied large museum collections in Europe and made acquaintances with many leading scientists. Alongside his work at the Academy and Smithsonian Institution, these experiences replaced a formal university education (Lanham, p. 69). Cope's retentive memory enabled him to once see a new reptile fossil on a colleague's desk and quickly go home and write up a description of the animal which he quickly published as a new species (Lanham, p. 241). This would be the key to his success in the future.

The Competition

Marsh and Cope first met in Berlin in 1863. At this point in time, Marsh had two degrees and two papers to his name. Cope had no degrees and 37 papers (Jaffe, p. 12). Their differences were stark; Marsh was the product of a formal education, whereas Cope was another self-made paleontologist. However, a meeting between the two American paleontologists in Europe was common grounds for friendship, in the beginning at least. Evidence of their early correspondences and activities implied that it was largely guided by their mutual interests and the exchange of fossils and knowledge. Cope even named one of his fossil finds after Marsh: *Ptyonius marshii*, which Marsh reciprocated the following year with *Mosasaurus copeanus* (Marsh, 1869, p. 48). Of course, Cope speculated if *M. copeanus* had come from one of his own fossil sites. There was also the concerning fact that an increasing number of fossils from the Jersey marl pits - which were shared among several scientists, including Cope and Leidy - were going to Marsh's residence in New Haven (Jaffe, p. 12). It was in this atmosphere of amiable yet competitive relationship that Marsh stopped by Philadelphia to pay tribute to his friend's work, where famously Marsh pointed out to Cope that he had placed the head on the wrong end of the *Elasmosaurus* skeleton (Jaffe, p. 14). Many writers including Lanham claim this to be the spark that led to the great feud between Marsh and Cope. Over the next thirty years, the two paleontologists fought to establish himself above the other, leading to slander in scientific publications, changing public and government opinion regarding the role of science in society, and fueling a race to conquer the fossils of the West.

Nothing was off the table. Lanham writes that more than twenty years later, when Cope and Marsh were engaged in open warfare, Marsh took advantage of a dark time in Cope's personal life to degrade him in the newspapers with this account from their time in Germany: "Professor Cope called upon me and with the great frankness confided to me some of the many troubles that even then beset him. My sympathy was aroused and although I had some doubts of his sanity, I gave him good advice and was willing to be his friend. During the next 5 years, I saw him often . . . although at times his eccentricities of conduct, to use no stronger term, were hard to bear" (Lanham, p. 67). Nothing could be said in confidence anymore. To cover such a phenomenon concisely, several key events of the feud that ultimately shaped the legacies of Marsh and Cope must be explored, beginning with the taxonomical conflict of Bridger Basin.

In 1872, upon returning from individual excursions into the West, Marsh, Cope, and Leidy each published their findings on a strange, many-tusked and -horned Eocene mammal found in Bridger Basin, Wyoming (Lanham, p. 90). Aware that the other two had come across identical remains, each of the paleontologists gave the fossil species a different name, claiming priority for discovering the animal. The taxonomic system during the 1800s was simple: whomever initially published the discovery of a species claimed the rights to naming the creature (Jaffe, p. 89). This ensured that each species had only one universal name. With three individuals each claiming to have published first, a conflict ensued, particularly between Marsh and Cope. It took place primarily in the pages of the *American Naturalist* periodical.

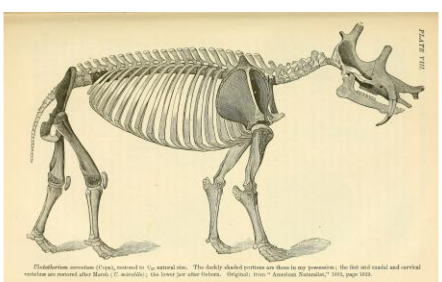

Figure 4.8. The Eocene Uintatherium cornutus *was one of many fossil specimens that Marsh and Cope fought over for priority.*

It was evident that neither men were after naming priorities simply for fame. It was more than just Marsh's *Tinoceras* versus Cope's *Loxolophodon* and *Eobasileus*. For the two scientists, it was another opportunity to prove his superiority over the other. This hostility became clear in the *Naturalist*, with Marsh making the unfounded claim that Cope had antedated his publications to take priority. They slandered the other's name, made false accusations, and devoted pages to systemically criticizing each other's work (Jaffe, p. 93). By mid-1873, the editors of the *Naturalist* had had enough, banning both scientists from filling any more pages with content related to their personal feud (Jaffe, p. 97). In the end, who had priority? Well, it turned out Leidy had published his findings more than two weeks before either Marsh or Cope (Jaffe, p. 90). Thus, the many-tusked and horned creature became *Uintatherium* (Figure 4.8).

However, while Marsh and Cope often completed their work on early mammals, they also made serious advancements with regards to dinosaur fossils, including the Mesozoic specimens of Morrison and Como Bluffs. Up until 1877, Cope and Marsh had worked largely on early mammals and similar species, ranging from the Cretaceous fauna of the Kansas plains, to the Eocene mammals of Wyoming. In mid-1877, however, their attention turned to the Jurassic specimens found near Morrison, Colorado.

The fossils unearthed by self-made geologist Arthur Lakes belonged to a massive creature, and provided the perfect opportunity to determine who the better paleontologist was. Quickly hiring Lakes and several others to continue their fossil work and guard the site, Marsh released his first paper on the Morrison beasts, "Notice of a New and Gigantic Dinosaur" (Jaffe, p. 191). If the size of the beasts had been uncertain before, it was no longer the case. Now Marsh held the title for discovering the largest land animal to have ever lived in North America, the *Apatosaurus*. This was quickly countered by Cope, who discovered the *Amphicoelias* shortly after. Thus the feud continued.

The race to find the greatest number of the largest dinosaurs continued in Como Bluffs, Wyoming. Marsh hired workers for this site, but all were temporary and put off by the severe working conditions, late wages, and resource shipment delays, and discouraged by Marsh's cold attitude (Jaffe, p. 245). Their intellect and efforts were consistently met with indifference and mandates that they could not conduct independent research. This included one Oscar Harger. Burdened by financial difficulties and a debilitating heart conditions, Harger nonetheless developed an incredible grasp for evolution and paleontology under Marsh (Jaffe, p. 274). Yet, while his greatest desire was to make contributions to the scientific community through his own publications, Marsh prevented him from doing so, even as he used the man's ideas and knowledge to draw conclusions in his own published works. Harger's mild character prevented him from taking stronger measures for independence, and after fifteen years under Marsh, Harger died in 1887, not a single publication to his name (Jaffe, p. 274).

Over the course of their feud, Marsh would lose many hired workers to Cope, who was not only willing to pay more, but who treated loyal fossil hunters with kindness. In the end, Como Bluffs turned out to be a rich dinosaur fossil site, and the richest Jurassic mammal site in North America (Jaffe, p. 241). For Marsh and Cope, however, it simply provided them with more fodder to continue the feud, which had entered the political stage by 1878.

During Marsh and Cope's feud, both men held areas of power, whether it be Marsh's Yale professorship, or Cope's position as chief paleontologist of the US Geological and Geographical Survey. The influences and associations that these titles brought were used to enhance each of the men's advantage and hinder the other. While Marsh and Cope were often on equal ground, Marsh gained an upper-hand in 1878 when he was elected interim president of the National Academy of the Science, following the death of the American scientist Joseph Henry (Jaffe, p. 206). It was also during this year that the government was undergoing a significant change. Under a new administration, attention turned to reforming the six surveys currently funded (Jaffe, p. 207). No more scrabbling for funds or accusations of trespassing between survey heads. It was time to introduce a central framework. The government called upon the Academy to advise on such a process.

Both Marsh and Cope used survey resources. Recognizing the opportunity before him, Marsh formed a committee comprised of the many allies he had made over the years through fossil donations and funding. The same year, the government accepted the committee's report on amalgamating the six surveys, and the US Geological Survey was born (Jaffe, p. 222). With Marsh's continued influence, his good friend Clarence King was appointed president (Jaffe, p. 227). Finally, a centralized system for geological work had been established, and Marsh had an inside man to continue his research while slowing Cope at every step, from funding to publication.

This eventually led to a public outing of the Marsh-Cope feud. In 1890, a newspaper article in the *New York Herald* was released, outlining a series of accusations levelled against Marsh in dramatic headlines (Jaffe, p. 319). Containing statements from individuals of the geologic community and beyond, the article accused Marsh and his colleagues of an array of charges, including misuse of USGS funds and plagiarism. Marsh would now pay the price for his treatment of Harger and other hires. It is important to note that the accused were largely comprised of instigators of the USGS reform.

The year before, faced with innumerable roadblocks to fund his work and unable to publish his research without handing over his entire fossil collection to the USGS, a frustrated Cope brought out the "Marshiana", a detailed account of all of the errors and transgressions that Marsh had made over the years. To make it public, Cope turned to journalist William Ballou. Unfortunately, Ballou had a flair for the dramatic, and was far from reputable. What accounts he had truly gathered and what were the product of fiction could not be discerned, but it didn't matter (Jaffe, p. 319). The damage had been done. While the scientific community had been aware of the Marsh-Cope feud for many years, the public had not. The inclusion of well-reputed scientists in the Herald articles created distrustful perceptions towards the newly established USGS. Even worse, congressman Hilary Herbert, an opponent to government-funded science, used the allegations to reduce USGS funds by over $37,000 while simultaneously wiping out paleontological research from the survey (Jaffe, p. 339). Thus, Cope's interaction with Ballou ultimately yielded no funds for his publications. He had sabotaged his own interests and the field of paleontology, all at the expense of publicly humiliating Marsh.

The feud finally ended when Marsh died in 1899, two years after Cope (Jaffe, p. 374). The two scientists had fought their rivalry through journal articles, across the expansive West, via political influences, and eventually in the eyes of the public. In numerical terms, the prolific Cope won in the publication race, with over 1300 papers published compared to Marsh's 270. However, Marsh proved taxonomically victorious, naming 86 species compared to Cope's 56 (Jaffe, p. 371).

Legacy

The legacy Marsh and Cope left behind is expansive. While the two paleontologists established and expanded America's fossil collection, they also left behind a taxonomical mess in their wake. The *Uintatherium* of Bridger Basin was just one of many instances in which Marsh and Cope fought over claims to a new species. This was worsened by the speed at which they published new material; their turnout rate far superseded Leidy and his contemporaries. By eagerly jumping on everything, they pushed out the careful well-versed paleontologists while setting a new standard for prolific writing. Unfortunately, the majority of their works provided scant fossil descriptions at best and were primarily written for the sake of establishing discovery dates. Such a practice frustrated fellow scientists. Zoologist and geologist James Dana once wrote ". . . It would do more for [Marsh's] reputation among zoologists to describe one species thoroughly than to be the one to name a hundred . . ." (Jaffe, p. 107).

Thus, while Marsh and Cope had attempted to elevate their own stature over the other, they ended up damaging their reputation among colleagues. The task of revising Marsh and Cope's publications to ensure taxonomic accuracy was left to the following generations of paleontologists. *Uintatherium* and Cope's *Eobasileus* became genus names, while Marsh's *Tinoceras* was discarded.

An equally extensive legacy that Marsh and Cope left behind was their vast collection of fossils, which were quickly absorbed by museums and universities, along with theories. Concepts and hypotheses that had once been solely thoughts or which faced harsh criticism from both the public and scientific community now had a treasure trove of physical specimens to draw support from. This included the concepts of evolution put forth by Darwin. Marsh's commitment to collecting bird-like fossils and horse specimens helped to demonstrate the progression of anatomy over time, while the race to find the largest dinosaur from Morrison and Como Bluffs illustrated key similarities between birds and reptiles.

One of the greatest legacies that Marsh and Cope left behind was their influence on the American outlook towards science. While suspicions and doubts remained, serious investments had been made to begin the development of a formal, government-funded system encouraging collaboration. As keeper of USGS collections, the Smithsonian was on the way to becoming a true national museum thanks to Marsh and his mandate that all the collections of the USGS legally belonged to the museum. Modern American science had finally found its legs, and not only did scientists stand taller in their growing reputability and skill, but also in the face of European criticism.

Dinosaur restorations, once limited to the single reconstruction of Leidy's *Hadrosaurus*, were becoming increasingly popular. So popular that in 1905, plaster replicas of original sauropod reconstructions began to find their way to Europe (Jaffe, p. 376). However, looking upon the bones, European scientists, especially those in Germany, believed that the Americans had assembled the sauropods incorrectly. They were reptiles after all; the position of their legs should be similar to that of a crocodile rather than a mammal with legs positioned directly beneath the body (Jaffe, p. 377). However, reconstructions of sauropods in American natural museums continued to employ the mammalian-like blueprint. Unlike in the past, the American scientists would not capitulate to their European counterparts. The Marsh-Cope war enabled American scientists after them to make independent contributions to paleontology and anatomy. Finally, in 1930, a set of *Brontosaurus* tracks were found in Texas (Jaffe, p. 378). The dimensions of the sauropod trail were only possible if the beast's legs were vertical, supporting the American conclusion. Thus, another bone war had been decided, with the Americans redefining their niche in science on the world stage.

Ultimately, Marsh and Cope's was a prime example of scientific enterprise. Both men had fought for sole control of the best fossils in the American West and coveted the attention that came with being the world's foremost paleontologist. Neither was above using political connections, from fellow scientists to politicians. Marsh and Cope's feud is one of the milestones that marks the transition of science from an avocation to a profession in America.

investigated.

Modern Paleontology

Today, the Peabody Museum of Natural History contains some of the largest collections in the world, drawing from disciplines ranging from mineralogy to evolution (Figure 4.9). And of course, paleontology. The field of modern paleontology is starkly different from that of Marsh and Cope's era.

Figure 4.9. The Peabody Museum, funded by Marsh's Uncle Peabody, is one of the oldest natural museums in the world.

Disciplines such as ecology and developmental biology continue to give scientists an enhanced ability to find ancient remnants and glean the finest of details from the fossil record. Paired with technological advances, understandings of fossil remnants have only become more enhanced. Whereas in the 1800s, during which only educated assumptions could be made with regards to physiology and behaviour using such tools as Cuvier's anatomical calculations, improvements in cross-disciplines have enabled technologies such as biomechanics. Notable examples include the Pliocene *Josephoartigasia monesi*, which Cox, Rinderknecht, and Blanco (2015) analyzed using finite element analysis (FEA) to predict the ancient rodent's bite force and associated cranial stress. Incredibly enough, FEA is a predictive technique used by engineers to analyze objects subjected to a weight. The implications of such an application of interdisciplinary knowledge continues to be investigated.

A recent and notable "bone war" in modern paleontology is regarding whether or not the *Tyrannosaurus Rex* had feathers. As in the past, scientists remain divided on certain features. As seen in the past, one new variation in a newly discovered fossil of an existing specimen can stir a frenzy of new arguments. Recent evidence for feathers in theropods has led to speculations that the largest tyrannosaurids, including the *Tyrannosaurus rex*, were extensively feathered (Bell et al., 2017). Fossil integument from *Tyrannosaurus* and other tyrannosaurids (*Albertosaurus*, *Gorgosaurus*, and *Tarbosaurus*), confirmed that these large-bodied forms possessed scaly, reptile-like skin (Bell et al., 2017). However, filamentous feathers on some large tyrannosauroids from Xu's research team in China have raised the intriguing possibility that similar feather structures were widespread throughout the group, even among the largest Late Cretaceous tyrannosaurids (2012). This hypothesis has serious implications for feather evolution, in which the developmental sequence of modern feathers is generally assumed to have developed in the phylogeny of coelurosaurian theropods (Prum and Brush, 2002). Feathers are indicators of thermal regulation, which imply that the climate must have been cooler than previously estimated. This has become a worldwide paleontological debate, which continues to advance as new fossils providing new clues are uncovered.

Science is truly a process of refinement, and this holds true even today. Modern science can be relied upon, with the knowledge that these intellectual debates are happening and ideas are being challenged, allowing us to uncover new truths.

Catastrophism and Uniformitarianism: A Debate

At the beginning of his 1998 paper exploring uniformitarian and catastrophist ideology, geologist Victor R. Baker used a Martian anecdote to highlight the significance of this debate between two geologic schools of thought. He recalled that the Mars Pathfinder landed in the Ares Vallis of Mars in July of 1997, becoming the first rover to operate beyond the Earth – Moon system (Baker, 1998). What followed in the minutes and days after the rover's landing was a stream of images transmitted back to Earth detailing the surface of Mars (Baker, 1998). Among the public spectators, geologists waited eagerly to begin their analysis and speculation on what processes may have occurred in Mars' past that resulted in the features found on Mars' surface (Baker, 1998).

Of the ideas proposed, Baker (1998) noted that a significant number would fall, if labelled, into the realm of catastrophism. Such reasoning, however, is markedly different from the debates in the 18th and 19th centuries regarding the origins of Earth's own geology (Baker, 1998). At the time, catastrophism was in the process of being rejected in favour of uniformitarianism to explain the formation of Earth's geological features. Despite this favoritism, catastrophism arose quickly and wholeheartedly when studying the geological origins of another planet, Mars, in 1997 (Baker, 1998). This contest to speculate and justify the pathway of Mars' geologic formation draws attention to the origins of the theories of catastrophism and uniformitarianism, their evolution through time, their supporting evidences, and their validity in the current age of geology.

The Origins of Debate

The terms 'catastrophism' and 'uniformitarianism' did not exist until William Whewell - a scientist, philosopher, theologian, and historian of science, coined the terms in 1832, effectively separating geologists, who speculated to the origins of the Earth and the formations of geological features, into two main schools (Huggett, 1997).

The debate between catastrophism and uniformitarianism can be traced back to Classical Greece during the time of the great philosophers such as Aristotle and Plato (Martin, 2013). Plato is recorded as having theorized momentous and violent origins of the Earth, while Aristotle (and later Strabo) proposed more gradual and temperate beginnings (Martin, 2013; Huggett, 1997). These theories, though largely philosophical in nature, regarded the formation of the Earth as well as its geological and biological traits, and would eventually be classified under catastrophist and uniformitarian camps.

Catastrophism & Uniformitarianism Over Time

Prior to the early 1800s, and before the development of uniformitarianism by Hutton and Lyell, catastrophism was the favored doctrine for the development of the world (Wood, 2009).

Catastrophism is a unique and versatile theory due to the number of forms of catastrophes and their varying capacity to influence the physical world. After the period of Greek conceptualization, any and all theories regarding the formation of the Earth and it features based on sudden and violent events can be classified under catastrophist doctrine. On the other hand, our understanding of uniformitarianism today asserts that geologic processes of the present that shape the Earth also acted in the past, and studying modern analogues can inform us about how the geologic landscape of the Earth was formed over a vast expanse of time.

Perspective on the subject matter of catastrophism and uniformitarianism allows the opportunity to define and classify past ideas based on new found definitions. Such instances of this are the cases of neptunism - a branch of catastrophism focusing on the oceanic deposition of rock, and plutonism - the idea that heat, volcanoes, and magma produce certain rocks.

Neptunism

Neptunism was put forth by Abraham Werner (1749-1817), and served as a global geological description of the origin of strata within sediment layers (Figure 4.10). Abraham Werner was a speculative geologist, who during his education in law, became fascinated with mineralogy, which ultimately lead to his change in focus and his eventual long career as a

Figure 4.10. A portrait of Abraham Gottlob Werner (1749-1817) by von Christian Leberecht Vogel (Harper, 2004).

professor and mineralogist (Harper, 2004). During his time at the Mining Academy at Freidburg in Saxony as a professor, Werner was able to develop and publicize his theory of the origin of the strata of the Earth. This presented a new way of thinking about Earth's formation based on observation and experimentation (Harper, 2004). Werner's theory, which became 'neptunism' (named after the Roman god of the sea, Neptune) was not completely original. Before the presentation of uniformitarianism, catastrophes were believed to be the cause of the world's development - a prominent theory and example of the time being Noah's biblical flood. (Wood, 2017). In addition, Werner's theory built on the ideas of previous neptunist-like theorists, particularly Johann Gottlob Lehmann (1719-1767) and Georg Christian Füchsel (1722-1773), who had previously discussed importance of the order of rock strata, and suggested that strata were formed successively over time respectively (Leddra, 2010). Werner compiled observations of strata as well as his own geologic knowledge to ultimately propose that an all-encompassing ocean was responsible for the differing rock layers on Earth (Gohau, 1990). The rocks that made up the crust of Earth would therefore have been formed from particles that settled out of the murky ocean as precipitates or sediments. The differences in rock type and layering visible in the world were explained by rises and falls in the level of the ocean, as well as the turbulence or calmness of the waters (Gohau, 1990). Werner continued to make modifications to his theory over time, adapting to new evidence for strata formation (Leddra, 2010). What made the theory of neptunism so convincing was that the theory was flexible, and therefore able to explain the entirety of Earth's strata as well as allowed for local variations (Wood, 2017). Despite the theory's popularity, it was criticized by many, and quickly abandoned by his students. The crux of neptunism became the observation by both geologists and Werner's students that geological features were not viably explained by the theory of neptunism, one such example being the deposition and presence of basalt, a common rock normally associated with lava flows. The theory of neptunism was further criticized based on the fact that it only explained the formation of the Earth's surface, not the Earth as a whole (Wood, 2017).

Plutonism

James Hutton (1726-1797) is often described as the father of modern geology (Archer, Underhill and Peters, 2017). The propositions outlined in his works towards the end of the 18th century revolutionized the way geologists thought about the processes that form the geologic landscape of the Earth. His influence and legacy impacted the future works of later geologists, notably Charles Lyell, whose contributions to this debate will be discussed later. Hutton was one of the greatest advocates for the antithesis of Werner's neptunist theory: plutonism. The plutonist faction in this late 18th century debate held the opinion that the heat of the Earth was predominantly responsible for the creation of Earth's rocks (Sigurdsson et al., 1999). Plutonists maintained the view that the solidification of magma was the creation process of rocks like basalt, which was one of the rocks at the heart of the debate, disputed as having precipitate or igneous origins (Sigurdsson et al., 1999). Hutton was at the forefront of the plutonist ideology, presenting his theory in *Theory of the Earth: Or, An Investigation of the Composition, Dissolution, and Restoration of the Land Upon the Globe* (1788) that magma was molten rock located in Earth's interior that appeared intrusively in sedimentary strata (Sigurdsson et al., 1999). Building on this theory, James Hall (1761-1832), a geologist, chemist, and a companion of Hutton, experimentally tested Hutton's theory by melting basalt samples and analyzing the composition of the silicate crystals that precipitated as a result of cooling the basalt (Sigurdsson et al., 1999). Hall's experimentation confirmed that basalt is of igneous origin, and that forces of immense heat (i.e., volcanoes) are responsible for its creation (Sigurdsson et al., 1999). This conclusion in 1805 effectively weakened the neptunist argument, and the plutonist theory of heat as the driving force prevailed (Sigurdsson et al., 1999).

Cuvier and Catastrophism

Georges Cuvier (1769-1832) has been considered one of the most important names related to theories of catastrophism, despite not being a core catastrophist in the traditional sense himself. Cuvier was unapproving of his catastrophist predecessors, namely Gregor Razumovsky, and Déodat de Dolomieu – the leading catastrophists in the late 18th and early 19th centuries respectively (Hooykaas, 1970). Cuvier believed that their search for the causes of Earth's formation and development that were different from those observable at the time made them "imagine so many extraordinary suppositions and lose themselves in so many erroneous and contradictory speculations, that the very name of their science has long been a subject of ridicule" (Cuvier, 1825, p. 14).

Throughout his professional career, Cuvier studied and contributed to a number of fields including zoology, and paleontology, and geology (Cullen, 2006). Cuvier's most famous accomplishments, the result of his wide range of exposure and knowledge, are perhaps his foundation of vertebrate paleontology and comparative anatomy. His most important contribution to catastrophism, and science as a whole, was his firm establishment of the fact of extinction of past lifeforms (Chen, 2013). As a result of his perception of past and current catastrophist theories, Cuvier restricted his own theories to instances where visible traces of events remained (Hooykaas, 1970). The main instance of Cuvier's inference of past catastrophes lies in his analysis of strata and the presence and sequence of fossils within.

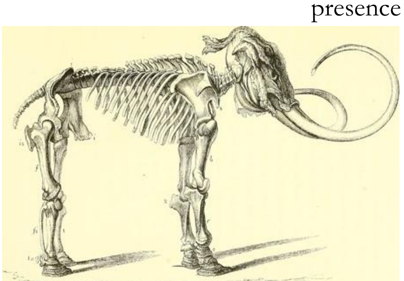

Figure 4.11 An illustration of fossilized wooly mammoth (Mammuthus primigenius) remains from the book "A history of British fossil mammals", and birds published in 1846.

At the time, the influence of creationism led to the belief that no animal had gone extinct, since this would contradict God's natural order (Wood, 2009). Cuvier observed when studying stratigraphic sequences that some fossils were characteristic of certain strata, and that the same strata appeared in the same sequential order in different geographic locations. Furthermore, Cuvier observed that lower strata displayed fauna significantly different than the current extant fauna (Chen, 2013). Cuvier was able to reconstruct fossils due to his paleontological background. Notably, Cuvier produced the arranged fossilized remains of wooly mammoths and giant ground sloths, both species being clearly absent from extant species (Figure 4.11) (Rudwick, 1997). In Cuvier's opinion, sharp transitions between stratigraphic layers based on the presence and succession of fossils provided testament to the rate at which changes occurred that defined beginnings of new geological time periods. He further speculated, based on observations and his catastrophist reasoning, that the energy of the forces that caused the sudden changes must have also been sudden and extremely powerful, "as no cause acting slowly could have produced sudden effects" (Cuvier, 1825, p. 21). This not only supported his theory of extinction, but justified that the reason for extinction was not by observation at the time, but by reconstruction based on catastrophic events.

Hutton and Uniformitarianism

James Hutton did not coin the term 'uniformitarianism' himself, but we can trace this form of geologic interpretation back to his research in the late 18th century. Like many affluent members of society in the 18th century, Hutton dabbled in many different areas of knowledge, holding positions like mineralogist, physician, philosopher, chemist, naturalist, and "gentleman farmer" (Archer, Underhill and Peters, 2017). During his time on farms, Hutton observed soil erosion and subsequent sediment deposition, a process which he noted was gradual. Archer, Underhill and Peters (2017) suggest that Hutton's observations of such gradual natural processes were key to his development of what we now recognize as uniformitarian thought. This new ideology on the nature of geologic processes that shaped (and continue to shape, according to Hutton) the Earth culminated in his paper titled *Theory of the Earth: Or, An Investigation of the Composition, Dissolution, and Restoration of the Land Upon the Globe*, published by the Royal Society of Edinburgh in 1788 (Craig, 2013). In this paper, Hutton described his theories on the cause-and-effect relationships he interpreted in geology (Bushman, 1983). He proposed that the forces of nature causing geologic formations in present day were also at work in the past and will be at work in the future (Bushman, 1983). He believed that from these cause-and-effect patterns, a set of orderly principles could be devised that could be used to judge the past, present, and future (Bushman, 1983). One of his major deviations from the catastrophist ideology was the ancient age of the Earth. He believed that the gradual nature of the processes observed today is the same as the processes of the past, but that the rates of change of probably not stagnant. He acknowledged that some changes in Earth's geologic past were likely violent and sudden, but that most of the changes happened over long intervals of time (Bushman, 1983). Hutton also acknowledged that there may not be modern analogies of processes that may have occurred in the past (Bushman, 1983). His main conclusions were that any changes, violent or gradual, adhere to patterns that fall within natural laws. Combining these postulations, Hutton believed that the gradual, uniform process he was proposing was cyclical in nature, that the Earth moved through a "succession of worlds" and the erosion to sediment of one world laid the foundations for the subsequent world (Craig, 2013). It was with this idea in mind that Hutton penned one of his lasting quotes: "The result, therefore, of our present enquiry is that we find no vestige of a beginning,-no prospect of an end" (Archer, Underhill and Peters, 2017).

In his last years, Hutton attempted to justify his theories by finding examples in the countryside that demonstrated his proposed principles. His most notable observation took place during a trip to the Scottish outcrop Siccar Point in 1788 (Figure 4.12) (Archer, Underhill and Peters, 2017). Hutton had previously deduced from other field trips that this area might yield evidence supporting his ideas on the ancient age of the Earth and the cyclical nature of Earth's processes that we recognize today as the rock cycle (Archer, Underhill and Peters, 2017). His suspicions were confirmed, as he witnessed the effect of deposition of younger strata on top of the erosional surface of older rocks (Archer, Underhill and Peters, 2017). He reported his findings at Siccar Point in his paper titled *Theory of the Earth with Proofs and Illustrations*, published in 1795 (Archer, Underhill and Peters, 2017). As an attempt to provide empirical geologic evidence, some regard this paper as the first deviation from theological explanations of geologic occurrences (Archer, Underhill and Peters, 2017). Hutton and his two companions on the trip, John Playfair and James Hall, were the first geologists to understand the significance of the outcrop to our understanding of deep geologic time (Archer, Underhill and Peters, 2017).

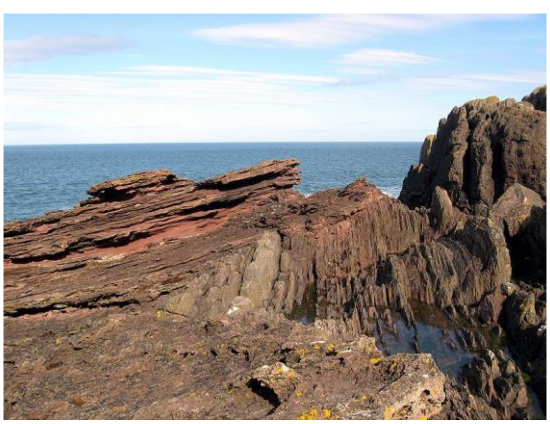

Figure 4.12. The tilted Devonian and Silurian deposits at Siccar Point located on the east coast of Scotland.

While Hutton was proposing a methodology of Earth's processes that was contradictory to the historical geology gleaned from scriptures, he was not completely abandoning the idea of a divine element. Historians like Bushman (1983) have asserted that Hutton believed there was a master design behind the workings of his observations and that there was a deity, but ultimately this divine element does not intervene in the mechanics of these processes. This is in contrast to the previous theological understanding of catastrophism at the time, that catastrophic events were brought about by divine forces. There was therefore difficulty in accepting Hutton's theories within geologic communities at the time. The uniformitarianism that we trace back to Hutton was championed in the early 19th century by geologist Charles Lyell, who was influenced by the writings and interpretations of John Playfair, a close friend of Hutton (Baker 1998).

Playfair's Interpretation

John Playfair (1748-1819) was a close friend of James Hutton, who used his background in mathematics and physics to present a different interpretation of Huttonian theory of geology after Hutton's death in 1797 (Baker, 1998). Playfair published *Illustrations of the Huttonian System of the Earth* in 1802, providing further description and elaboration of Hutton's thoughts, based on Hutton's works as well as personal conversations between the scientists (Craig, 2013). In *Theory of the Earth with Proofs and Illustrations*, Hutton described his theory (that we recognize as the beginnings of uniformitarianism) as a discovery of a natural law (Baker, 1998). He believed that he was merely shedding light on something that had already existed. On the other hand, Baker (1998) writes that Playfair interpreted Hutton's theories as a "human construct of knowledge." Playfair believed that Hutton's postulations were not set in nature, and were capable of development and improvement since they were generated from human observation and analysis (Baker 1998). This is where Hutton's belief of a grand design behind the workings of uniformity in nature began to be removed from the concept of uniformitarianism. In the same way that Newton assigned fixed principles to the study of astronomy, Charles Lyell, influenced by

Playfair's interpretation, pursued the same endeavour for geology (Baker 1998).

Lyell and Uniformitarianism

Charles Lyell (1797-1875) was a Scottish geologist who is well known to have popularized Huttonian theories in geology, specifically the idea of uniformitarianism (Eagan, 2013). It is important to note that Lyell never used this term because it had not been coined yet, instead referring to the ideology as being composed of several defining principles. His advocacy for Hutton's uniformitarianism gained momentum with the publication of his greatest work, *Principles of Geology*, a 3-volume series that he updated and republished several times during his life (Eagan, 2013).

Lyell seems to have taken a philosophical approach in his interpretation of Hutton's ideas. He pondered the epistemological implications of accepting certain doctrines in science. Lyell's evaluation of the validity of the uniformitarian and catastrophist arguments was based on his belief that all fields of science should be separated from theology and supernaturalism (Anderson, 2007). His continual advocacy for naturalistic principles (e.x., uniformitarianism) reflected his belief that human progress was tied to the abandonment of superstitious beliefs and acceptance of secondary causes that are supported by empirical evidence (Anderson, 2007). Lyell accepted Hutton's premise, but now wanted to focus on developing a methodology for inferring a system for the Earth. Hutton's and Werner's propositions were, at the moment, mainly theoretical. Hutton had begun to provide evidences for his theories, including his observations at Siccar Point in his last works. Lyell recognized the need to further ground Hutton's proposed concepts of uniformity in a methodological approach familiar to other sciences. This type of approach was likely influenced by John Playfair's writings on Hutton's theories (Baker 1998).

While writing *Principles of Geology*, Lyell asserted in his personal communications with fellow scientist Roderick Murchison that with this work, he endeavoured "to establish the principle of reasoning in the science" of geology (Rudwick, 1970). Indeed, analysis of his writing strategy in *Principles of Geology* revealed that Lyell carefully constructed arguments that acted to affirm the adequacy of using principles of uniformity to holistically describe Earth's geologic processes (Rudwick, 1970). Before addressing any of his current findings, Lyell dedicated chapters 2-4 to providing his own description of the history of geology up to the 19th century (Rudwick, 1970). In this history, Lyell addressed the pitfalls of his predecessors. He simplified their arguments to a set of characteristics that he believed were hindering scientific progress in geology (Rudwick, 1970). One of these characteristics was the tendency of his predecessors to rely on scriptural texts to act as evidence in support of proposed geologic theories (Rudwick, 1970). Connected to this was his assumption that they were unwilling to accept the proposition of the immense vastness of geologic time (Rudwick, 1970). Lyell also disdained that cosmogonic intentions (determining the origins of the Earth) dominated catastrophist arguments (Rudwick, 1970). Lyell strongly believed that discussion of Earth's geologic processes should not bother including any discussion on the origin of the Earth because, based on the cyclical nature of Huttonian geology, there is no present-day evidence to be used to infer any reasonable conclusions on Earth's origins (Rudwick, 1970). Lyell insisted that uniformitarian thought and his proposition of a steady-state Earth system based on Huttonian theories avoided these pitfalls (Rudwick, 1970).

Once Lyell published *Principles of Geology* and effectively established his position as a proponent of uniformitarian ideology, he began to subscribe to a strict doctrine that he used to defend himself against catastrophist argument. This doctrine deviated from Hutton's original postulation of uniformitarian thought, in that Lyell's uniformitarianism advocated for stagnant rates of change that produced a cyclical repetition that remains constant throughout geologic time (Albritton, 1975). He denied the growing catastrophist argument that the causes of change ultimately work towards a type of progressive development, such that there is a net result from the sum of all the changes that have occurred and will occur (Cannon, 1960). In this way, Lyell was against any type of evolutionary thought (Cannon, 1960). Considering Lyell's considerable influence on the young Charles Darwin, it is ironic to learn that Lyell struggled with accepting evolutionary theory. Cannon (1960) has suggested that this rather drastic interpretation of Hutton's uniformitarianism evolved from Lyell's unwillingness to concede certain arguments to the opposition ideology of catastrophism. Lyell's stubborn stance proved to be a weak point in his argument that was vulnerable to attack by his catastrophist opponents (Albritton, 1975).

The Use of Catastrophism to Explain Martian Geology

As more empirical evidence and studies supporting uniformitarianism were published in the late 18th and early 19th centuries, uniformitarianism eventually superseded catastrophism as the dominant theory behind Earth's geologic processes. As with any topic in science, however, the story does not end there. In recent decades, catastrophism as experienced a revival of sorts, a notable instance of this being Luiz Alvarez and his hypothesis on the catastrophic cause of the Cretaceous-Tertiary extinction event (Alvarez, 1980). Modern geologists accept a more integrated understanding of uniformitarianism and catastrophism, acknowledging the effect of catastrophic events in Earth's past in addition to the slow, gradual processes that shape the Earth's landscape. The importance of acknowledging catastrophic events is demonstrated in the case study of Martian geology. As mentioned in the introduction to this chapter, the initial exploration of Mars' surface yielded catastrophist theories. Much of the current research in Martian geology involves the analysis of water erosion features that have been hypothesized to have been created by catastrophic floods (Figure 4.13). For instance, Pacifici, Komatsu and Pondrelli (2009) used high resolution images to perform quantitative geomorphological analysis to determine that several catastrophic floods likely shaped the Ares Vallis channel on Mars. In addition to past catastrophic flooding, Mars is hypothesized to have been hit by a catastrophic asteroid impact that drastically altered the face of the planet (Leone et al., 2014). Using 3D models, researchers were able to recreate the effects of a large asteroid that likely hit the south pole of Mars approximately 4.5 billion years ago (Leone et al., 2014). Their findings accounted for the dichotomy that describes the surface of Mars: a relatively thicker crust in the southern hemisphere and a thinner crust in the northern hemisphere (Leone et al., 2014). All of these studies confirm that catastrophic events played an important role in the development of Martian geology. Ultimately it is the application of knowledge based on the development of past catastrophist and uniformitarian theories that allow more enlightened examination of both the Earth and extraterrestrial planets. Looking outwards at extraterrestrial planets will undoubtedly influence our understanding of Earth's geologic processes and force us to continue to reevaluate historical understanding.

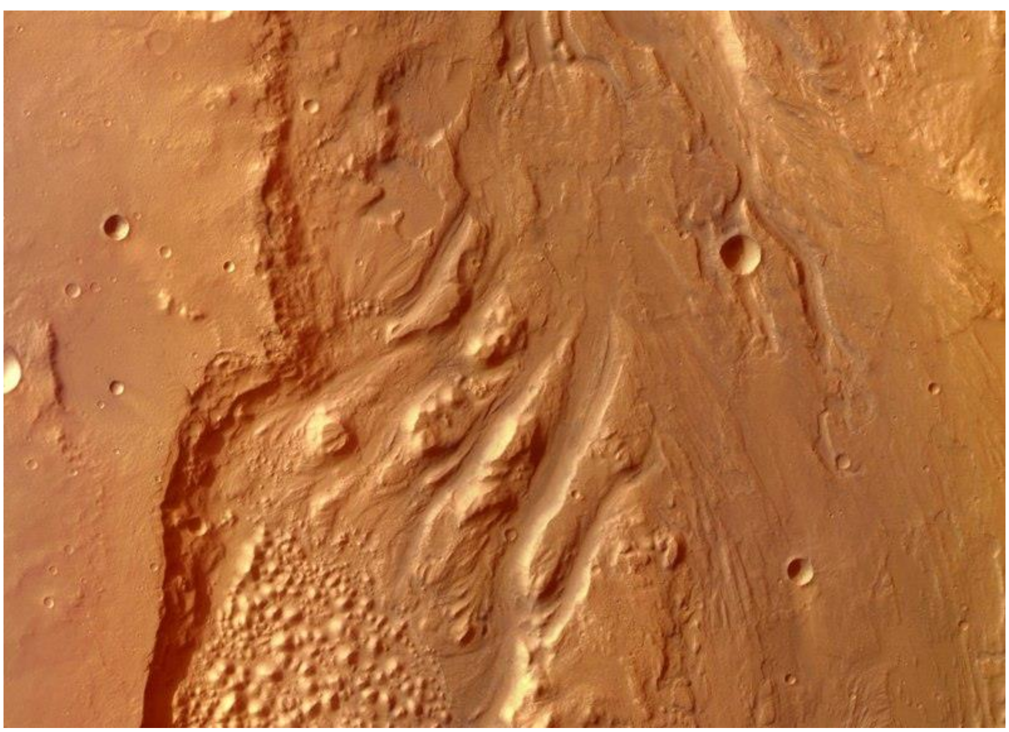

Figure 4.13. A full colour image taken by the High Resolution Stereo Camera (HRSC) aboard ESA's Mars Express spacecraft in 2004, from an altitude of 350 km with a resolution of 15 metres per pixel. It shows signs of flood erosion in Ares Vallis.

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IMAGE CREDITS

Figure 4.A Pedra Furada de Jericoacoara. Wikimedia Commons, Fjuniordf, 2011.

Figure 4.B Sítio Arqueológico Boqueirão da Pedra Furada. Wikimedia Commons, Diego Rego Monteiro, 2011.

Figure 4.1 A variety of Clovis points. Wikimedia Commons, Rummels.

Figure 4.2 Key archaeological sites. Human Origin Sites and the World Heritage Convention in the Americas, Connaughton, 2015.

Figure 4.3 Pedra Furada attracted scrutiny. Carandell Baruzzi, 2016.

Figure 4.4 Preserved plant remains. Human Origin Sites and the World Heritage Convention in the Americas. Dillehay, 2015.

Figure 4.5 Indigenous peoples have long protested. Wikimedia Commons, 2013.

Figure 4.6 Othniel Marsh. Wikimedia Commons, Matthew Brady and Levin Corbin Handy, 1865.

Figure 4.7 Edward Drinker Cope. Wikimedia Commons, Frederick Gutekunst, 1897.

Figure 4.8 The Eocene Uintatherium comutum. Wikimedia Commons, Edward D. Cope, 1887.

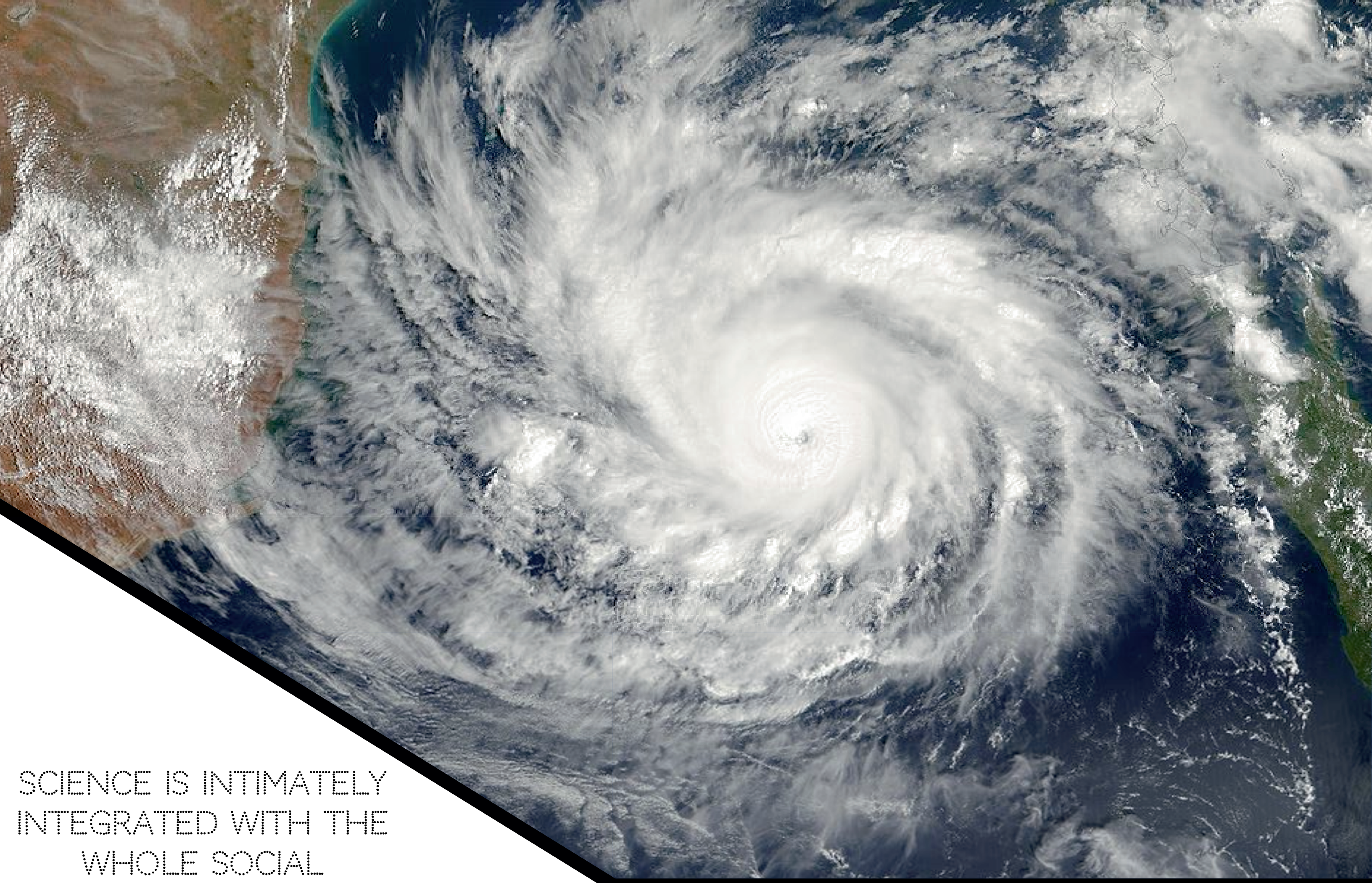
Figure 4.9 The Peabody Museum. Wikimedia Commmons, Ragesoss, 2006.

Figure 4.10 An illustration of the remains. Wikimedia Commons, Owen Richard, 1846.

Figure 4.11 The tilted Devonian and Silurian deposits. Wikimedia Commons, Dave Souza, 2008.

Figure 4.12 A portrait of Abraham Gottlob. Wikimedia Commons, Christian Leberecht Vogel, 1801.

Figure 4.13 A full colour image taken. Wikimedia Commons, European Space Agency, 2005.



Science is intimately integrated with the whole social culture and cultural tradition.

- Talcott Parsons

CHAPTER 5

Challenging Beliefs - Conflict Between Science and Society

By definition, progress means forward or onward movement towards a novel and superior destination. In the case of scientific progress, it is our pursuit of the truth that guides us onward. In the following chapter, we discuss one of the largest obstacles in the path of progress of scientific understanding – ourselves.

Whereas science requires movement, society requires stagnance and regularity upon which it can build its social order. Given enough time between advances, society will accept the current level of understanding as the truth, and adopt these truths as the foundational principles of its organization. It then becomes difficult, should new evidence arise, to convince the population otherwise. An ever-evolving narrative of what is true and what is not challenges this order. Unsurprisingly, society is rarely pleased with this. Not only will society often reject a departure from what it considers to be 'the truth', but society will resist, using any manner of excuse or unjust logic to refute the evidence presented.

Over the course of this ultimate segment, you will see many examples of this resistance. From the sexist basis on which Mary Anning's discoveries were refuted, to the religious arguments on which some of the most basic ideas behind evolution and the origins of fossils were challenged, society has relentlessly slowed scientific progress throughout history.

The Hindered Success of the Princess of Paleontology

Mary Anning, later known as the Princess of Paleontology, was born in May 1799 into a low-income family in Lyme Regis, Dorset on the England coast (Davis, 2009). Her father, Richard Anning, who made a living through carpentry, would search for fossils on the Dorset coast to sell alongside his carpentry business (Goodhue, 2004). He took Anning and her older brother Joseph on his adventures which ignited the flame for fossil collecting in young Anning (Figure 5.1) (Goodhue, 2004). The trio climbed up the limestone cliffs in search for the prettiest and most interesting fossils to sell in order to keep their family afloat (Hoodhue, 2004). Anning took a rigorous interest in the science of fossils and continued to trek to the dangerous coastlines and ridges of Dorset even after her father's death in 1810 (Goodhue, 2004). Her passion allowed her and Joseph to bring small amounts of money to their low-income and debt filled household after Richard's Death (Goodhue, 2004).

Figure 5.1. Portrait of Mary Anning with her dog Tray, and the Golden Cap outcrop in the background, Natural History Museum, London. This painting was owned by her brother Joseph Anning.

In Anning's fathers time, fossils were knick knacks with mystical stories and poetic names (Chambers, 2015). They were found and sold to higher end fossil collectors but were never really given scientific meanings as they are now (Goodhue, 2004). Around the time of Richard's death, scientists were searching for explanations for the animalistic treasures found below ground (Chambers, 2015). The concept of extinction was newly introduced and controversial at the time, however Anning's initiative and persistence for science and education brought ideologies to the surface which refuted the Genesis theory (Chambers, 2015; Goodhue, 2004).

Anning's interest in paleontology and her natural talent in the field allowed her to successfully identify the first *Ichthyosaur* in 1811, *Plesiosaur* in 1823 and *Pterosaur* in 1828. These findings were awe-inspiring to the scientific community. The higher esteemed societal men, referred to as the 'Great men of Geology', began to admit how different ancient life must have been from everything they already knew existed (Goodhue, 2014). Based on these discoveries, one might assume Anning's family's economic status started to improve and she gained the recognition she deserved. Unfortunately, Anning was born at a time where being a woman of low economic status, with no formal education denied her from receiving opportunities and recognition (Chambers, 2015).

Despite her unquestionable skills, Anning left no written records of her work or activities (Creese and Creese, 2006). This in turn led to her contributions of new fossils to be ignored and her work to be incorporated into the works of the "Great men of Geology" (Creese and Creese, 2006). Anning was not recognized for her work until she was diagnosed with breast cancer in 1845, and passed away in 1847 (Goodhue, 2004).

In the 19th volume of the International Index brought out by the Royal Society, 1000 papers were authored by 19th century women (Creese and Creese, 2006). Out of those papers 181 were geology papers and 65% were authored by women (Creese and Creese, 2006). Anning was one the most notable collectors of the early 19th century, an enigma of her time, however her name is never mentioned in articles (Creese and Creese, 2006). It would be interesting to postulate how different Anning's life would have been if she was of better economic standing with formal education and not a woman. As Jo Draper, a famous female archeologist of Dorset stated: "Mary Anning was the right person in the right place at the right time, but she was the wrong sex." (Goodhue, 2004).

Scientific Success

As briefly mentioned earlier, Anning was primarily acknowledged for her discovery of *Ichthyosaurus, Pterodactylus* and *Ammonites.* However, despite making such groundbreaking discoveries, she was faced with brutal questioning and scrutiny. Not only were her findings not credited, they were written up by men and passed off as their own (Goodhue, 2004).

At the age of 11 years old, Anning and her brother Joseph stumbled across a protruding skull amongst the towering cliffs of Lyme Regis (Figure 5.2) (Goodhue, 2004). At first the duo thought it was the head of a crocodile. However, upon further investigation along with the knowledge of the talented Anning, they realized this was everything but their initial assumption. Anning became motivated to find the remaining pieces of this strange animal. Through the risky conditions of the cliffs and erosional surfaces, Anning eventually discovered the remaining skull and 60 vertebrae composing most of the skeleton of the first recorded Ichthyosaurus - all before becoming a teenager (Goodhue, 2004).

Due to her family's poor economic conditions, Anning sold her findings to Henry Hosted Henley. However, she only received less than half of what the skeleton was sold for (Goodhue, 2004). The extent of influence Anning's discoveries had in the world was never questioned, but the idea of giving deserved credit and recognition to a female of lower class was unfathomable by the male superior members of the scientific realm. Once the fossils reached the London Museum of Natural History it gained a lot of publicity for being an unusual specimen. Even the talented Anning was puzzled by this anomaly. Going off of scientific articles written by other male scientists, Anning conducted her own research and analysis in order to learn more about this unknown creature. Sources say that Anning would make corrections to the published articles as what the authors stated was inaccurate or incorrect (Goodhue, 2004). If she had been given some recognition for her discovery, it might have been possible for her to conduct her own primary research and have a wider access to resources and opportunities. In addition, she would have been able to identify the key features of the skeleton better or faster since she had personally discovered them. These advantages could have allowed her to reach the conclusions necessary to propose the theory of evolution before Charles Darwin, becoming the Mother of Evolution.

The men who published her work and findings to be their own were given the recognition and credit Anning deserved and went on to become professors at esteemed institutions. This can only hint at the endless possibilities of where Anning could have ended up at if she had been given the right opportunities and support. If Anning had been positively rewarded with her discovery, she would have been given direct entry into the prestigious Geological Society of London. Being an esteemed member would have given her more credibility and resources allowing her to find more fascinating specimens. Members of these higher-class societies generally entered the academia field. Anning could have passed on her knowledge of fossils and inspired more female students to enter the field of paleontology. Anning could have worked with a team of future paleontologists in the field for them to gain first-hand experiences in identifying fossils and their origins. These conjectures about Anning's scientific successes without any social inhibitions are just conjectures. However, since they stem from factual incidents, it isn't too hard to imagine the assumptions being true. From these speculations, the importance of encouraging the involvement of different genders and economic status is evident.

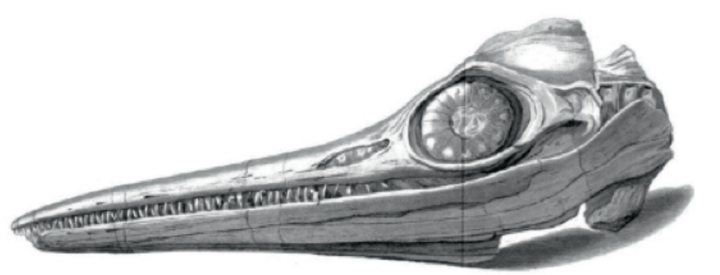


Figure 5.2. Drawing of the Ichthyosaurus (now known as Termnodontosaurus*). Platydon found by Joseph and Mary Anning*

Personal Success

Due to her poor status and being a woman Anning faced prejudice and oppression her entire life. Despite these hindrances on her path to success, Anning showed initiative and had many interpersonal successes. Although Anning pushed through, she was held back from reaching her full potential.

In terms of education, Anning surpassed the expectations set for a girl of her stature at the time. In Lyme Regis education was little to non-existent for most children, which was quite normal for the time (Goodhue, 2004). In fact, most children of low economic status were not prioritized to be taught how to read until 1818 (Picard, 2009). When Anning was eight she attended the Independent Chapel (Dorset OPC Project, 2018), which became the center of her social life and her only hope for literacy (Goodhue, 2004). This was established primarily to teach reading and writing rather than religion; very ahead of its time (Goodhue, 2004). This was just the beginning of Anning's love for education. In the 1820's Anning taught herself French in order to communicate with Georges Cuvier, who had similar ideologies as Anning in terms of extinction (WGBH Educational Foundation, 2001). Anning also taught herself anatomy by conducting her own dissections on modern fish and squid and then compared them to the fossils she found (Chambers, 2015). She had initiative and through pure hard work she became a field researcher, all on her own (Figure 5.3)

(Chambers, 2015).

Hearing about Anning's abilities to grasp complicated and new concepts fuels the

curiosity to wonder the possibilities of her future with formal education. If she was in the modern education system, Anning could have excelled more proficiently and have

certifications to endorse herself. At a time where credibility was based on being a male of high status, having a recognized degree would have helped Anning reach unbelievable heights. Anning also seemed to be fond of teaching others her skills. She taught her neighbour, Henry Thomas De la Becher what she knew about fossils (Goodhue, 2004). Eventually, he also pursued a career in geology (Goodhue, 2004). From this it is evident that Anning was an influence on other people and had the natural competency to pass on her knowledge. If she had continued to teaching school, she would have influenced countless of other people. Since geology was especially very important in her time, it would have benefitted society to have more trained minds figuring out the clues of the Earth's origin.

In order to get Anning's opinion heard, she stepped out of the normal gender rolaes that were expected out of her. She was known for being an "acid mouthed woman", who was unafraid to put people in their places (goodhue, 2004). Anning had shown disagreement with William Buckland's, Oxford's first Professor of Geology, analysis on a certain topic and voiced her opintion (Goodhue, 2004). Many onlookers of this disagreement pinned Anning as a loudmouth who did not know her place. For them it was unimaginable that a poor uneducated woman could debate with a prestigious esteemed scholar and stay on an equal level (Goodhue, 2004). Anning had the ability to hold intelligent conversation with any esteemed fossil hunter. However, as always, she was underestimated. Very few scholars even mentioned her name when they discussed specimens Anning sold to them (Chambers,

Figure 5.3. Landslip near Lyme Regis, most likely similar to the cliffs that Anning was conducting fossil excavation

2015). If she were a male of higher economic status her sharp tongue would not be an ugly characteristic, on the contrary she would have been held on a pedestal for being persistent and knowledgeable.

Anning did have many interpersonal successes that allowed her to create connections with people in the geological world, however she was not able to flourish into her full potential. She had to overcome the bias of the 'Gentlemen of Geology' who were against individuals who earned their living by selling specimens (Goodhue, 2004). Anning also had to fight the contempt from the urban society to those who lived in provincial or rural areas (Goodhue, 2004). Anning had to constantly fight a battle of classes and gender. Although scientists began to admit that Anning's point of view on life in the past was relevant, she was never given appropriate recognition at an adequate time. Yes, she did fight the system to the best of her ability at the time, and did get her name out there but she could have been so much more. For instance, if she had financial stability, she would be able to travel to places for astounding discoveries. Anning herself stated in a letter to one of her close friends that "I have never been out of the smoke of Lyme..." (Goodhue, 2004). If she had the same opportunities as Cuvier and Buckland she could have traveled all over the world to uncover more astonishing discoveries. Anning could have had the opportunity to make connections not just over paper but in person. Her discoveries would have stayed and been published as hers as she could have traveled with the specimen to labs for analysis. Anning's societal status forced her to remain in her bubble of stormy Lyme Regis. Whereas if she had no constraints, the world would have seen and known more of the phenomenal Mary Anning.

Moving from the large-scale advantages in the scientific community, supporting different members offer great personal benefits as well. Although these benefits are not directly advantageous to the public, the advancement of fellow colleagues aids the community as a whole.

Economic Success

In Britain during the 18th century, the beginning of the Industrial Revolution was sweeping the nation (White, 2009). This was the age of steam, canals and factories which changed the British economy forever (White, 2009). As the world became more industrialized people had more time to ponder about certain occurrences that pushed the advancement of science. In turn leading many to turn to geology for answers. It was not uncommon for many respected individuals to buy fossils and become avid fossil 'hunters' or collectors (Goodhue, 2004). This meant that many

Figure 5.4. Drawing of Mary Anning's house in Lyme Regis, Dorset, England Lune 1842. The house in which the famous Mary Anning lived when she first sold fossils.

people were willing to buy the pretty Knick knacks that Anning and her family were selling on Lyme Regis road side. This small income was enough to keep the Anning's afloat, but Anning was coined by many buyers who underestimated her findings and intelligence. A huge contribution for this would have to be because she was a female of low economic status.

As stated before, Anning and her family have constantly struggled to stay financially stable (Figure 5.4). Anning sold many of her specimens to fossil collectors, but they were later sold to the London Museum of Natural History for double that price (Goodhue, 2004). As Anning continuously discovered these natural treasures, she was not awarded financially or socially. During the 18th century, men and women had very distinctive gender roles, however in poor areas, such as Lyme, this boundary was blurred (Emsley, 2015). Men and women were forced to do whatever was necessary to meet ends meet (Emsley, 2015). This could be why it was so frustrating for Anning when she was not recognized for her work. Her field entailed engaging with the upper class where gender roles were strict. Anning herself said she regretted "having been born a woman, and deprived of the life and position, which as a man, [she] might have had in this world!" (Goodhue, 2004).

If Anning was born in a time where economic status and gender was not taken into consideration, she would have received prestigious awards for her work and would have been more financially stable. Men of low economic stature were able to sell their specimens, be mentioned in scientific papers, or given respect for their findings. This would have allowed Anning to climb the ranks in society a lot faster than she did in her time. By having appropriate consolidation for her contributions, Anning would have had the time and money to further delve into her research. If being a woman was not looked down upon, she would have still been able to receive encouragement and support allowing her to advance in her career despite her economic setbacks. Anning would have been given the opportunity to spread knowledge of her excavation methods through scientific papers instead of word to mouth. This would have allowed her to reach wider audiences and accelerate the advancement of paleontology. By having more people learning and progressing simultaneously, further discoveries could have been made in a shorter time. This could have resulted in more species being discovered in different parts of the world simultaneously. Another perspective is that Anning may have been able to invest in creating a more efficient way to run through the cliffs of Lyme Regis. If she were in better economic conditions, there could have been a possibility for her to receive funding to innovate novel extraction tools. This would have allowed for faster and more efficient methods instead of the tiring procedures. Along with being inefficient, there was also a high-risk factor involving the cliffs. Having more effective tools would have allowed Anning and future paleontologists to discover more fossils in a quicker and safer manner resulting in more discoveries being found. In addition, having more financial stability would have allowed Anning to have no limitations for locations to excavate fossils in the world. This increases the field range for Anning's discoveries; once again allowing for more discoveries to be made in a more efficient and effective manner.

Throughout Anning's life, socioeconomic status was always a war that had to be fought.

However, she never let the battle tear her down from fighting and pushing through the circumstances. Despite her inability to gain a proper education, she took the initiative herself to learn the necessary concepts and theories related to her field. This allowed her to minimize the gap between herself and other paleontologists who had access to money and resources.

Women in Paleontology

Supporting Women

Today, women are being given more opportunities and support to run after their aspirations in the science and technology field. Organizations such as TrowelBlazers and Paleofest have been introduced in order to ensure intelligence is not turned down due to gender discrimination. TrowelBlazers is an online blog that inspires future female geologists, paleontologists and archeologists with dedications to former successful scientists and their accomplishments (Anon, 2018). Organizations such as these allow young girls to see their dreams of being acknowledged and renowned scientists coming alive and inspire them to the same. The dedications are strictly for successful women in the aforementioned fields and mention their contributions along with brief biographies. This not only increases awareness for young women but also generates interest in the budding minds of students in any discipline.

Figure 5.5. Influential female paleontologist Lucy Edwards preparing microfossils in her lab.

Paleofest is a symposium held at the Burpee Museum in Illinois celebrating paleontology (Burpee Museum, 2018). This weekend event consists of different types of activities. These activities range from inspiring young scientists to offering a platform for esteemed paleontologists to share new and exciting research findings (Burpee Museum, 2018). Although this event is not directly aimed towards women, they hold a special Consideration for women and people of different races and economic status. By having such events held at a well-known museum, it encourages more people to be interested in the field and allow them to observe real-life applications. Within the paleontology community, Ellen Curran, a well-known and respected scientist, co-founded the Bearded Lady Project which aims to show a diversity of women, form a community and initiate awareness amongst members of this community. Her goal was to help men be more aware of their subtle sexist actions and for women to understand they aren't alone (Foley and Foley, 2017). The current incorporation of such events along with many others is a great way to encourage more women to be involved in the fields. Despite the low number of females in the paleontology field currently, there are a few that stand out because of their perseverance and initiative.

Lucy Edwards

Lucy Edwards stands out in the battle between women and the world of paleontology (Figure 5.5). Lucy is currently a Research Geologist with the U.S. Geological Survey. However, the beginning of her career was not promising. At the time of her high school graduation, the University of Virginia was a 'men-only' school. Instead of deterring from her goals and going to a women-only college or a rural school, she travelled away to the University of Oregon. Many decades before the age of computers and mobile devices, she took the initiative to take math and computer science courses in university. She went on to get her PhD from the University of California in 1977 in hopes to become a professor. However, upon her graduation she got the job as a biostratigraphy at the U.S Geological Survey mostly because of her skills in math and computers. She currently studies microfossil algae cysts in order to determine the age of rocks, and make predictions. Over the three decades of her career, she has helped discover Chesapeake Bay impact crater and been the first to publish pictures of microfossils. Despite her many successes, Lucy has faced unfortunate circumstances in her life including the initial struggle of breaking borders and chasing her dream. Her perseverance and dedication to her goals allowed her to fight back. Along with her initiative to learn new things and increase her credibility allowed her to gain some acceptance within the community. Similar to Anning, Lucy pursued her goals by not only working hard in her field but also taking every chance to increase her versatility in multiple accessory skills related to her field.

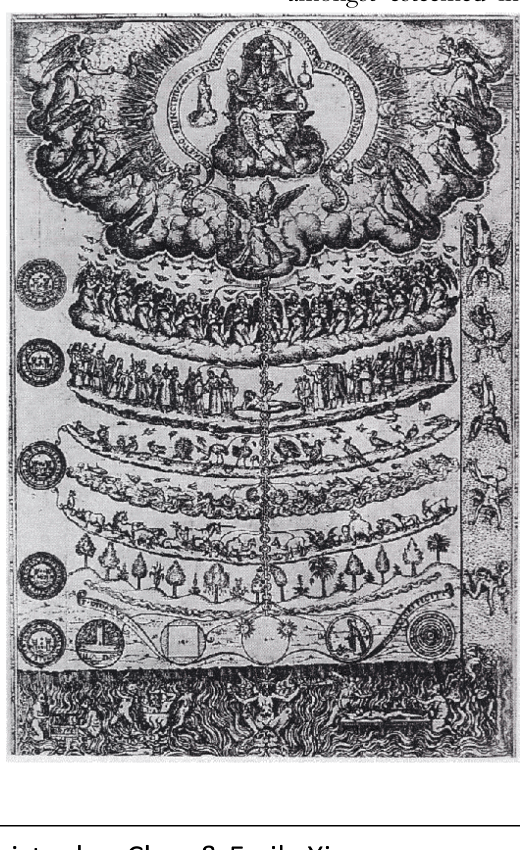
Future Steps

In order to ensure major scientific breakthroughs are not hindered due to factors such as gender, economic status, race etc., current and future scientists must be more attentive in their actions and natural bias. Science has come a long way from Anning's time however, there is still much to do in terms of inclusivity and equality. Especially in fields including paleontology where female authors only make up 16.6%. Empowering and encouraging women in different fields to reach their highest potentials would only benefit the scientific community. Many advancements could have been missed out on due to the unequal distribution amongst the genders. Similar to the Bearded Lady Project, it's vital to generate awareness for all members in the community to be more conscious. Moving forwards, it is vital for the community to make conscious efforts in supporting females pursuing their dreams. In the specific case of Anning, her contributions to the paleontology world were incredibly significant. However, it begs the question to wonder how much more of an impact she could have left if she weren't inhibited by gender or economic bias. Anning worked immensely word to take initiative in gaining skills and being the best she could be in her field. She continuously fought the battle of being a woman of low economic status with her brain and skills. Due to the efforts of people like Anning, women today are now being given more conscious support and motivation. Moving forwards from her situation, progress has been made but there is still much work to do. Women, people of low economic status and visual minorities in paleontology and other underrepresented fields must be more supported in order for there to be any considerable advances.

A Look Back at Theories of Extinction and Catastrophism

Of the four billion species thought to have existed on Earth over the past 3.5 billion years, an estimated 99% have gone extinct (Novacek, 2001). Though most of these extinctions occurred gradually over time, a significant portion are believed to have been attributed to "mass extinction" events. Mass extinctions are often characterized by a loss of over three-quarters of the number of species that exist on Earth over a relatively short geological time period (Barnosky et al., 2011). Furthermore, many believe that those in the modern day and age are living during a slow but sure extinction event even today.

Figure 5.6. Illustration of the "Great Chain of Being" taken from 'Retorica Christiana' written in 1579 by Didacus Valdes. It depicts God, angels, and humans making up the three highest links of the hierarchical chain.



Human understanding of mass extinction events and their causalities were not always clear. Theories of extinction and catastrophism in particular arose in the late 18th and early 19th centuries and were a topic of great debate amongst esteemed individuals in the field of geology at the time. How exactly did scientists reach these conclusions about the death of ancient species? Which historical factors were at play, and what past events influenced the development of modern mass extinction theories?

In the past 540 million years, mass extinction events are only believed to have occurred five times - near the end of the Ordovician, Devonian, Permian, Triassic and Cretaceous periods (Raup and Sepkoski, 1982), all exhibiting species loss of over 75% (Jablonksi, 1994). Though each extinction event was thought to have occurred to various extents and by different means, one common characteristic prevails: each event was followed by a great transition in life, in which new species were given the opportunity to flourish within the vacant niches of the old ones. For example, mammals were only able to prosper on the planet in the absence of the dinosaurs after the infamous Cretaceous-Tertiary extinction 65 million years ago (Gale, 2005).

Over time, the fossil record of these organisms would be found by mankind who, in his curiosity, would propose his ideas and theories as to what exactly happened in the past. These ideas may have been accepted, perhaps debated, or even refuted, but ultimately became the foundation of the modern geological theories of today.

Disrupting the Great Chain of Being

Pre-dating the existence of modern mass extinction theory, 18th century Europeans and Americans embraced the idea that all life on the planet had been created at approximately the same time in one grand creation event dictated by God. Consequently, the natural world that God had created, and in which His perfect order was implemented, was seen as complete and blameless in and of itself. Closely associated with this belief was the structure of the natural order, according to which all life must have been created - the *scala naturae*, or the 'Great Chain of Being' (Lovejoy, 1936). In this structure, each species forms a link in the great hierarchical chain, wherein humans, angels, and the Divine Creator Himself form the three highest links. Nature's balance was never upset, and thus the total number of species that existed at any time would always remain the same. Within this worldview, it was inconceivable that God would allow any part of His perfect creation and order to die off and become extinct. A poem titled *The Seasons* written by James Thomson in the 1720s emphasized the importance of this structure, stating: "*Each shell, each crawling insect, holds a rank... a rank which lost / Would break the chain and leave behind a gap / Which nature's self would rue.*" Extinction was thus seen as the equivalent of a break in the Great Chain of Being, wherein subsequent degeneration of the perfection of nature would surely ensue (Vidal and Dias, 2015).

The First Evidence of Extinction

The very plausibility of the theory of extinction was made possible by the discovery of two fossil organisms - the ammonite and the Irish elk. While the main figures that researched each sample did not explicitly suggest the evidence could be used to support the theory of extinction, their initial conclusions may serve as indicators for the historical context and pressures under which they fell; their initial conclusions gained notable rapport, suggesting their theories matched up with the general public's scientific beliefs at the time.

The Enlightenment was a social and intellectual movement that dominated throughout the 18th century in revolt against the previous strict ideas of creationism. It characterized the society at the time with the mindset that everything that existed in the world could be better understood using man's own mental faculties, rather than their blind faith, tradition, or any sudden revelations. Consequently, many embraced the view that the world was created by God, that the world behaves according to natural laws, and that the mechanism behind these laws could be revealed through the practice of science (Rowland, 2009). It was in this transition to a more intellectual social environment that the discovery of the first few pieces of evidence for extinction arose.

Towards the end of the seventeenth century, it was known that the English natural philosopher Robert Hooke discovered many fossils that he noted were of similar morphology to that of the nautilus, though dissimilar enough to induce doubt about their correlation as a single species (Kusukawa, 2013). With strict creationist views still heavily influential in Hooke's day, the early Fellows of the Royal Society debated fiercely over the status of these "fossil rocks", and ultimately denied his proposal that they originated from the petrified remains of ancient organisms (Saunder and Landman, 2009). Despite the opposition, Hooke still believed that there was more to the story than the Society had argued. In some parts of his writing, he even suggests that perhaps there have indeed been some species that have been lost in the past. He justified his thoughts with the apparent contradiction of finding nautilus remains in a location that, at the time of discovery, would have never been able to survive (Lyell, 1830). The fossils discovered by Hooke would go on to be identified in modern times as those that once belonged to the ancient ammonite.

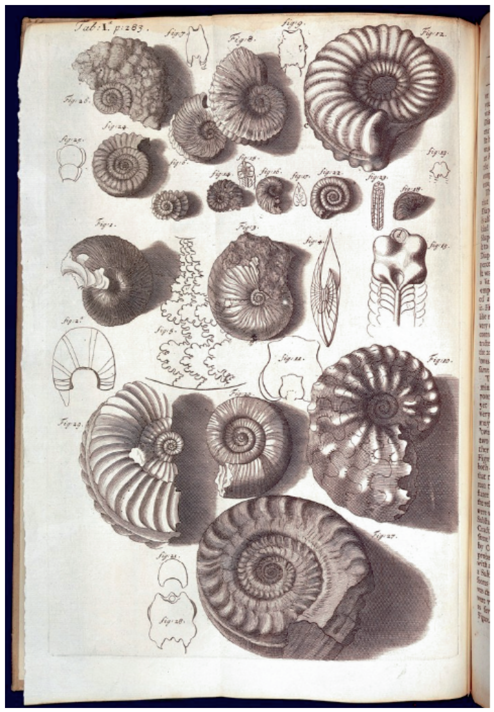


Figure 5.7. Drawings of ammonite fossils that supplemented Hooke's discourse on potential extinction (Wellcome Collection, n.d.).

In 1697, the first scientific description for a set of abnormally large fossilized antlers was written by Thomas Molyneux, hypothesizing them to have originated from a North American Moose (Gould, 1973). Though the true identity of the organism was debated throughout the 18th century - whether it had once indeed belonged to a North American moose or instead to a European reindeer - it wasn't until Georges Cuvier's response in 1812 that demonstrated to the world otherwise. Using the fossils to justify his theory of extinction, he substantiated that the remains were unlike those of any extant animal of his current time period through the observation of minute anatomical discrepancies (Gould, 1973). In time, the mammal would come to be known as the megafaunal Irish Elk, or *Megaloceros*.

These two fossil examples suggest that the societal atmosphere at the times of their respective discoveries were not welcoming to theories of extinction, with the Great Chain of Being existing as the overarching pillar in which everyone obstinately believed.

Fantastic Former Worlds

The movement for new theories of ancient organisms was coming to a kick-start after being catalyzed by the discovery of the previously mentioned fossil evidence. In the course of his examination of the world, Georges-Louis Leclerc, Comte de Buffon, published 36 volumes of his *Histoire Naturelle, générale et particulière*. He argued, in light of increasing empirical evidence, that New World quadrupeds must have been degenerate varieties of Old World species and that extinction was a real, albeit rare, occurrence. Entire sets of ancient fauna and flora must have existed at once in fantastic "former worlds", each of which had abruptly come to an end (Rowland 2009). This idea would begin to take traction and would go on to induce the works of the next generation of naturalists, including such figures as Georges Cuvier and Jean-Baptiste Lamarck.

Several factors at the time were thought to be responsible for the transition between the "Great Chain of Being" worldview and that of the "former worlds" perspective. The first was the continuous paleontological discovery of fossils which did not seem to correlate with any extant species known to man (Rowland, 2009).

Figure 5.8. Illustration of the 'Boulevard des Italiens' in Paris during the French Revolution (1789-1799). Coming out of the revolution, the mindset of the 18th century was heavily influenced by the pain and trauma of the violence, heralding the arrival of the romantic movement in Europe and America (Courtesy of the University of California, San Diego).

Secondly, great European-American explorations were being conducted, such as the Lewis and Clark expedition of 1804 -1806 into the interior of North America, that were slowly uncovering more unexplored territory on the Earth in which the living candidates of such fossils could have been lurking (Rowland 2009). Finally, it is important to note the weakening influence of the Enlightenment towards the end of the eighteenth century, and the growing popularity of the romantic movement that was borne out of the French Revolution and the revolt against the old rationalist ways (Rowland 2009). It was with this mindset that Buffon's views of such strange beasts living in "former worlds" were able to gain traction within European and American society.

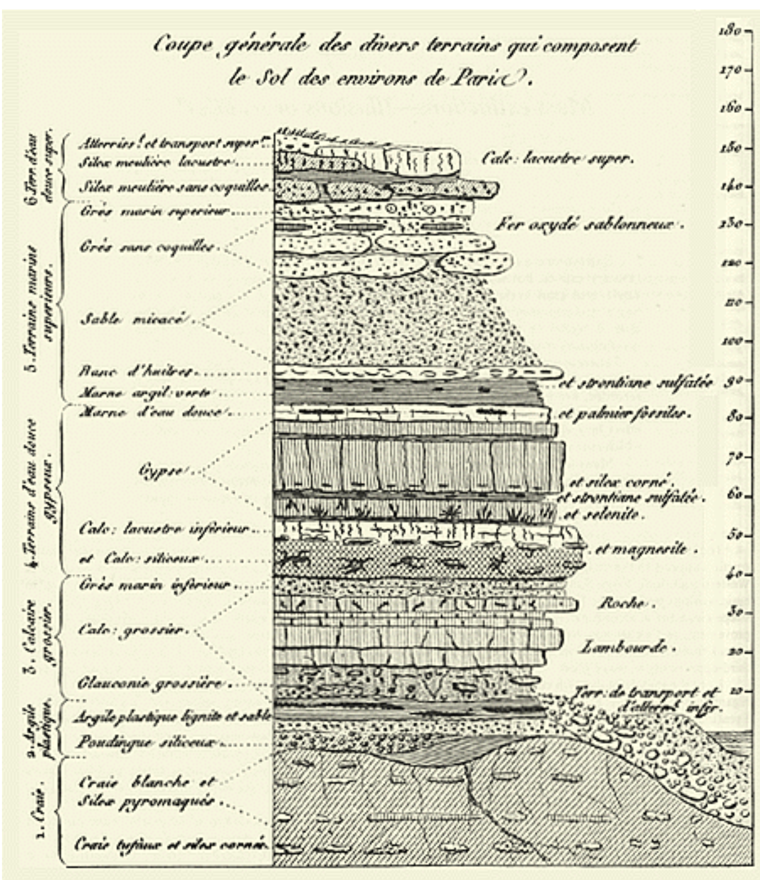


Figure 5.9. Cuvier's sedimentary log of the Paris Basin. He believed that the basin was formed by the occurrence of catastrophic events because of the abrupt stratigraphic change apparent above the Cretaceous bed labelled "I. Craie" (1812).

Mapping the Paris Basin

Perhaps one of the most influential contributors to mankind's knowledge of vertebrate paleontology and comparative anatomy, Georges Cuvier was a French naturalist that dedicated most of his life to the pursuit of the biological sciences. He was a firm believer of the prevalence of evolution and demonstrated in his *Recherches sur les Ossemens fossiles des Quadrupèdes* (1812) that the lower the rock strata in a sedimentological log, the more distinct its fossilized fauna forms were from those of the present. In a landmark study he conducted and documented with his colleague Alexandre Brogniart in his *Essai sur la géographie minéralogique* *des environs de Paris* (1811), he made some very notable observations: While studying the stratigraphy of the Paris Basin, instead of finding a continuous succession of fossils as was expected, the pair discovered several significant unconformities in the fossil record where all evidence of life would disappear for a long period of time before suddenly reappearing once more. Cuvier theorized these enormous time gaps as mass extinction events, which he recorded and popularized in his *Essay on the Theory of the Earth* in 1827. These writings marked the beginning of a new wave of history of the Earth theories on wide scale catastrophism, as well as other theories that would rise up in opposition.

Modern catastrophism described mass extinction as having occurred because of enormously destructive events that wiped out the majority of species and significantly altered the way rocks were deposited. Such events may include supernovas, global volcanism, earthquakes, or extraterrestrial impacts from comets or asteroids (Gale, 2007). When he first developed his theory of catastrophism, Georges Cuvier speculated that the lowland areas of the Paris Basin had been inundated by the neighbouring sea, thus causing the most recent extinctions in Eurasia (Taylor, 2018).

To many in Cuvier's day, however, the idea of extinction was still religiously troubling, and religious overtones soon took over some of Cuvier's hypotheses. By the early nineteenth century, views of natural theology, and the likes of geologists including William Buckland and Robert Jameson, started becoming prevalent in society. Back in the seventeenth century, Bishop James Ussher had calculated that the Great Creation of the Earth had occurred in 4004 B.C. less than 6000 years ago (Winchester, 2001). In an attempt to reconcile Cuvier's new findings with the religious constraints still present at the time, naturalists adopted the catastrophic dynamics outlined in his theory in order to compress long geologic processes into a short time (Rappaport, 1997). It essentially became a way of rationalizing new empirical observations with what was still thought to be a short history of the Earth. Naturalists like Buckland and Jameson spent significant portions of their careers linking Cuvier's geological revelations with the reality of the biblical Noachian flood as the main causal catastrophe for the unconformities that Cuvier had found (Rudwick, 1972). Their writings and worldviews quickly became extremely influential in European and American society, even though Cuvier had initially been arguing in favour of a flood of limited geographic proportions while Jameson and Buckland proposed one of a world-wide scale (Rudwick, 1972).

A Rising Opposition

Notable figures arose during this time who opposed Cuvier's ideas about how exactly extinction took place. Though it was generally agreed upon that extinction occurred, the mechanism as to how it progressed through time was still up in the air. Towards the end of his life, Jean-Baptiste Lamarck published in his *Philosophie Zoologique* counterarguments against Cuvier's initial theories about catastrophism. At the time, Lamarck was a figurehead of the gradualist point of view, which assumed that any change that occurred in nature was that of a gradual and continuous nature, and that any grand variations of the Earth developed slowly over time as opposed to abruptly and in large steps (Corsi, 1988). He hypothesized that simple life forms must have possessed some sort of driving inner force that allowed them to evolve and become increasingly complex over time as a response to the environment in which they resided. Like a muscle that's been continuously used, internal organ systems would adapt and transform according to the organism's external surroundings - a theory that was known as 'transformation theory'. Transformed traits would then be passed onto offspring (Lamarck, 1809). Lamarck had always believed extinction to be a rare and gradual process and was thus

Figure 5.10. Portrait of Georges Cuvier (left), often credited as being the 'Father of Paleontology', and who was at the forefront of scientific discovery regarding the theories of extinction and catastrophism (Courtesy of Kislak Center for Special Collections, Rare Books and Manuscript, University of Pennsylvania Libraries).

Figure 5.11. Portrait of Jean-Baptiste Lamarck (top). He was a strong advocate for the theory of gradualism and disagreed with Cuvier's claims of catastrophism (Wikimedia Commons, 2012).

skeptical regarding Cuvier's proposals of large catastrophic events killing off entire species of animals.

Also among the prominent voices in the field of geology at the time was that of Charles Lyell. Though he agreed with Lamarck's gradualist views to a certain extent, Lyell was best known for popularizing the revolutionary findings of James Hutton and the assumptions of 'uniformitarianism' in his *Principles of Geology* in the 1830's (Bartholomew, 1973). Lyell firmly believed that the Earth was historically shaped through the same, slow-moving processes that were still occurring to his day, and that these processes applied to both organic and inorganic matter. Consequently, he ultimately rejected Lamarck's claims for humans to have arisen from lower forms, and for animals to have emerged as a product of their habitat (Bartholomew, 1973), as well as Cuvier's claims of catastrophism. Furthermore, Lyell also agreed with the popular opinion that species would sometimes go extinct, but only as a result of competition. He did not elaborate much further about the mechanisms of evolution.

The 18th and 19th centuries were periods of the great enlightenment, as well as times of transition into deeper, idealistic thought. It was spurred on by new, revolutionary ideas about the origin of modern strata, as well as the human origin. It was a time of looking inwards towards oneself and attempting to connect humanity with the world that mankind saw around him. And among the motivating figureheads of the era, geologists like Cuvier, Hooke, Molyneux, Lamarck, and Lyell arrived at the forefront of evolutionary thought. Specifically, facilitated by the evidence he found in the Paris Basin, executed through the early use of the scientific method demonstrated in his approach and in his conclusions, and polished by the opposing views of other scientific voices of the era, Georges Cuvier and the naturalists have hence become essential influences on the modern understanding of extinction and catastrophism.

A Look Forward: The Holocene Extinction

The Holocene extinction refers to the theory that the sixth extinction event of the Phanerozoic is currently taking place, with the main catalyst being human activity leading to a decrease in biodiversity. Attributed to anthropogenic effects on the global climate, the scientific community seems to agree that the resulting loss of biodiversity is a large issue.

Figure 5.12. Painting of the head of the extinct Dodo, painted by Cornelis Saftlevon in 1638.

The term "biodiversity" first appeared in text in 1988 (Wilson, 1988). A 1998 survey of 400 members of the American Institute of Biological Sciences revealed that seven out of ten biologists believed that the Holocene extinction was already underway and that the loss of biodiversity would pose a threat to the survival of humans (Risher and Markow, 1998). As such, multiple estimations of population decline rates have been made. One of the earliest was from Edward Osbourne Wilson, who estimated the loss of half of Earth's species by the end of the 21st century (Wilson, 2002). At present, the rate of extinction of species is thought to be 100 to 1,000 times higher than the rate at which it existed before humans (De Vos et al., 2015), with this figure being tenfold less than that of a previous study conducted in 2008 (Chivian and Bernstein).

To come to these conclusions on the rates of extinction, data on the total number of alive and extinct species on Earth is needed. While this data is difficult to track, the modern estimation of the total number of species on Earth stands at about 8.7 million (Mora et al., 2011). Of these, about 1.9 million species are known with 866 currently listed as extinct by the International Union for the Conservation of Nature (2017), leading to questions pertaining to whether a modern-day extinction event is a valid theory. However, one thing that should be noted is that invertebrates, which constitute over 99% of species diversity, are not often scientifically tracked because of how they are relatively more difficulty to find compared to vertebrates. As such, this leads to dramatically underestimating overall levels of extinction. Taking this into account, a study in 2015 extrapolated from the observed extinction of a Hawaiian snail species that 7% of all species on Earth may have been already lost, suggesting that there is indeed reason to believe in Holocene extinction (Régnier et al., 2015).

There are two main reasons for how the preservation of biodiversity can benefit an individual and thereby the whole of humanity. The first is there is the possibility of a new scientific breakthrough based on the study of a species. For example, the chemotherapy drug Taxol was derived from the Pacific Yew tree, *Taxus brevifolia,* after one of the *Taxus* samples was found to be cytotoxic in a cellular assay (Goodman and Walsh, 2001). Another example is the discovery of the Taq polymerase. In 1976, this DNA polymerase was purified from the thermophilic bacterium *Thermus aquaticus*, allowing for the improvement of the polymerase chain reaction (PCR) technique. Since this DNA polymerase is stable at high temperatures, new DNA polymerase does not need to be added after each cycle of PCR (Saiki et al., 1988). PCR is now responsible for billions of dollars of economic activity annually. These examples show how previously unknown species can have practical value, meaning it would be beneficial to pre-emptively stop their extinction.

The other reason for preserving biodiversity is the unquantifiable benefit that other species provide for us, and the unknown cascading effect that the loss of a single species could trigger. For example, organisms may regulate the watershed, fertilize crops, pollinate flowers, or generate soil fertility. In the example of New York City, plans that were implemented showed it would be 10 times cheaper to buy parts of the watershed and manage them appropriately as opposed to building new water treatment plants (Appleton, 2002). Although it is unknown which species are key to this specific water purification process, one example of how the extinction of a species can have a cascading effect is with the dodo bird and the Carolina parakeet. Both were dispersers of seeds and likely affected forest structure in their habitat; in a 2013 study, it was found that the defaunation of the seed-eating species led to an increase in the density of saplings by 25%, which may be a problem as overcrowding promotes the spread of plant diseases (Harrison, 2013). To ensure the longevity of human existence, it would be to our benefit to also ensure the longevity of other species.

The Holocene extinction, while believed to be the sixth extinction event, is still entirely preventable. In 2017, eight authors and 15,364 scientists across 184 countries signed and supported "World Scientists' Warning to Humanity: A Second Notice" (Ripple et al., 2017). Following up the original document published 25 years prior, the paper outlines steps taken that have improved the biodiversity problem such as decreasing CFC emissions, but also suggests many more possible areas to improve. Stuart Pimm, Chair of Conservation Ecology at Duke University, said that the sixth mass extinction "is something that hasn't happened yet – we are on the edge of it." If humans continue to take steps toward the goal of preserving biodiversity, the Holocene extinction will be a thing of a past.

Figure 5.13. Mounted specimen of the extinct Caroline parakeet.

Marxism and the Prebiotic Soup Theory

The concept of the origin of life in modern terms very much depends on the theory being used to explain it. Today, we are surrounded by a vast array of interconnected concepts, such as Darwinian natural selection and Mendelian genetics, each building upon another to create a newly synthesized version of evolution that is more modern in nature (Huxley, 2010). However, what is truly interesting, is not only how we reached this point in evolutionary thought but rather the primary influences in the past that drove the development of past theories.

Of these theories, the concept of a prebiotic soups remains among the most prevalent, given two main individuals, Alexander Oparin, (Figure 5.14) and John Haldane, whose work formed its foundation. Truly, in order to best understand their theories, why they were created, and how credible they were, we must consider the societal, ideological, and political influences behind them. From Oparin and Haldane, it is evident that science cannot be analyzed in an isolated manner. In fact, the political climate at the time and ideological beliefs of scientists can be heavy influencers of the theories they create, especially with respect to the origin of life.

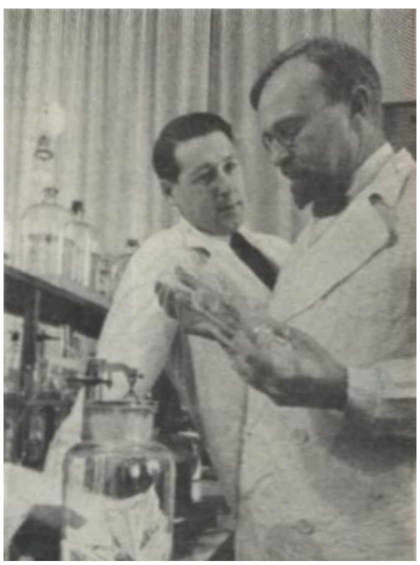


Figure 5.14. Alexander Oparin, a Russian born evolutionary biologist and revolutionary concerning abiogenesis..

Spontaneous Generation

For many years, it was believed that living organisms spontaneously arose from dead matter, as observed from maggots living on rotting meat (Haldane, 1929). This is known as spontaneous generation. It was disproved by Francesco Redi in 1668, by carefully keeping dead matter free from insects and noting that no life then arose. In 1860, Louis Pasteur conducted his famous swan-necked flask experiment, which showed that no life could grow from a nutrient broth if there was no pre-existing life within it initially. Therefore, the next logical question was: how did life start to grow on this planet, and what was its source?

Oparin's Theory

Oparin and Haldane each had a unique outlook on the concept of the origin of life, with each's theory closely mirroring that of the other's. Within his hypothesis of the origin of life, Oparin makes clear discussion of a specific and distinct substance which was the main source of prebiotic life (Farley, 1979). From this point, he builds to a working theory regarding the formation of a mixture of complex organic compounds such as proteins, lipids, carbohydrates etc, the sum of which is dubbed a coacervate (Farley, 1979). The formation of the coacervate is then dependent on concentrations of organic matter being present at different regions of an aqueous medium to initiate biotic life formation (Farley, 1979). The final stage, consists of the coacervates acquiring further molecular complexity to achieve higher order functions subject to biological laws (Farley, 1979).

Haldane's Theory

Another pioneer who generated the first fundamental and comprehensive theories about the origins of life was John Burdon Sanderson Haldane, a British-Indian biochemist . Although the details are not all widely accepted today, the theories' general principles paved the way for future researchers. Like Oparin, Haldane became a communist. In fact, there were several other scientists who contributed to theories on the origin of life who also supported Marxist ideologies, such as J.D. Bernal (Gouz, 2011). Therefore, it would be tempting to identify a trend between Marxism and the pre-biotic soup. However, the influence of Marxism was enacted slightly differently in Haldane.

In 1929, Haldane published an essay in the Rationalist Annual titled *The Origin of Life* (Haldane, 1929). The theories and postulations it contained became an integral foundation for developing the evolutionist historical tale of chemistry transitioning to life. Haldane first laid out the three main theories at the time – that life originated from meteorites, that life was supernaturally created, and that life originated from inanimate matter, despite Pasteur's conclusions pointing to the contrary. Through logic, chemistry, and evolutionary biology, Haldane wished to establish the likelihood of the third theory (Haldane, 1929).

Biochemically, Haldane's ideas happened to be very similar to Oparin's. It should be noted that his essay was developed independently of Oparin's. Although Oparin's *Origin of Life* was published in 1924, it was not translated into English until 1932, after Haldane's essay was published (Gouz 2011). Therefore, their theories have additional merit through the affirmation from each other. As a caveat, Haldane assumes that all the scientific laws of today applied to the early Earth (Haldane, 1929). In terms of the early atmosphere, Haldane believed there was little or no oxygen, high levels of carbon dioxide which are found in chalk, limestone, and organic material today, and some nitrogen. Due to the lack of ozone, Haldane postulated that the then-brighter Sun would have penetrated to the Earth's surface easily and sparked the formation from simple molecules to protein precursors and sugars. As there were no living organisms yet, the organic molecules would gather without decay in primitive oceans as prebiotic soup. Life would have started anaerobically, likely metabolizing through fermentation. This first fermenting cell would have been composed of many chemical units "suspended in water and enclosed in an oily film," a postulation which was almost identical to Oparin's predicted first cell (Haldane, 1929, p.8).

Types of Marxist Ideology

In the early 1900s, scientific thought regarding the origin of life utilized two main concepts: mechanical materialism and dialectical materialism. From a mechanical perspective, the he origin of life can be simplified into only chemical and physical processes (Oparin, 2017). Within this, an understanding of life does not allow for any use of biological laws of nature but rather a single generalized law that treats both inorganic and organic life in the same way (Blackburn, 1966). As stated by Oparin in *The Nature of Life,* use of mechanistic thought can lead to an overindulgence in simplification whereby everything that is not directly connected to fields of physics and chemistry are treated without any relation to what is observed (Blackburn, 1966). Oparin strongly disagreed with this previously used view to approach the concept of the origin of life, favouring a dialectical materialistic view, being heavily influenced by the work of Friedrich Engels, (Figure 5.15). By placing stronger emphasis on the dynamic nature of life, Engels derived a theory of nature where matter is considered to constantly evolve and will move through several stages of development; dialectical materialism (Blackburn, 1966).

Through this process, Engels remarked on the current definition of life, that revolved around

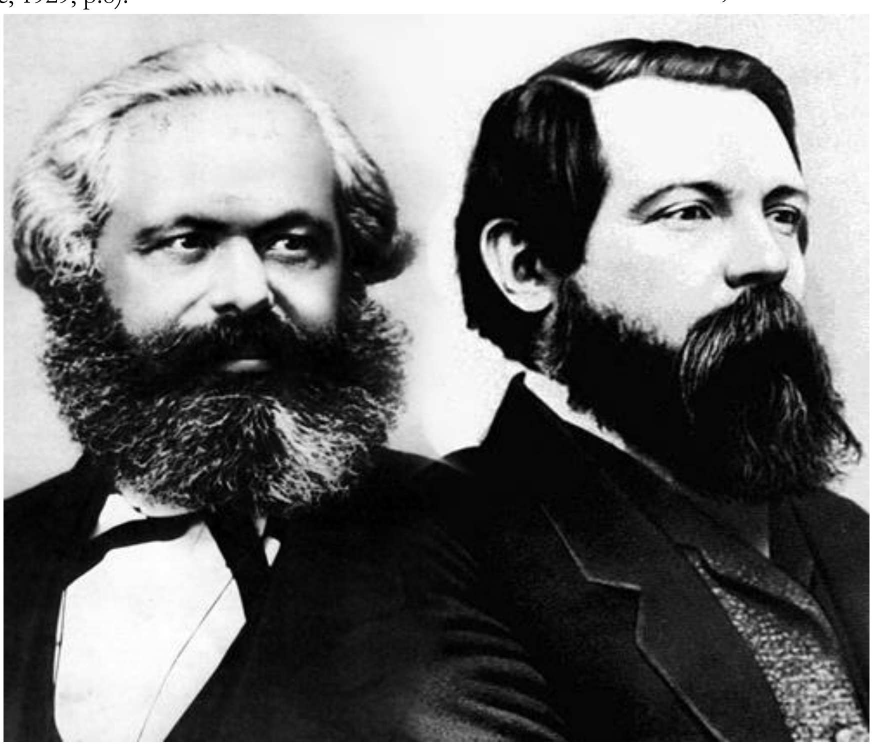


Figure 5.15. Karl Marx (left) and Friedrich Engels (right), co-writers of the Communist Manifesto *and socialist revolutionaries.*

albuminous substances, as being entirely inadequate and limited to those bodies that are the most common and the simplest (Blackburn, 1966). In order to move forward, Engels needed to define a new hypothesis to consider the topic of life's origin, and to do so turned to Darwin's writings (Medvedev, 1969). However, in this instance, Engels exclusively extracted the concepts of acquired characteristics in formulating his definition of the origin of life, and in doing so ignored concepts of natural selection and Mendelian genetics (Medvedev, 1969). Oparin used Engel's ideas to formulate his own definitions and these were a product of the scientific era that he was exposed to.

Marxist Influences on Oparin

During his conceptualization of the origin of life, Oparin also became influenced by the Marxist undertones of Engels' writings. According to Loren Graham, by 1936, Oparin's interpretations of the origin of life, and the theories involved, held foundation within Marxist perspectives of dialectical materialism, reflecting the nature of the Soviet era of science at the time (Farley, 1979). This was direct contrast to Oparin's own perspective years earlier in 1924, when he exclusively used and made reference to a reductionist mentality concerning life. He stated that life could arise spontaneously solely due to physical and chemical processes (Farley, 1979). Graham further explains that this 12 year metamorphosis in Oparin's thinking was due in part to the change in the political atmosphere of the Soviet Union at the time (Farley, 1979).

Figure 5.16. Trofim D. Lysenko, right, in his element considering the growth and germination of seeds prior to his induction into the Academy of Sciences

The 1920s in Soviet Russia was a chaotic decade during which the Russian Academy of Sciences underwent a thorough renovation by Bolshevik leaders under Stalin (Lazcano, 2016). Many new and innovative institutions were created during this time, with control being given to researchers and bureaucrats alike, each explicitly designating the use of dialectical materialism as the scientific ideology to be used (Lazcano, 2016). However, even as late as 1929, there was not as much Marxist political influence from the Communist Party within the Academy of Sciences. (Farley, 1979). The catalyst for the change in ideology came from the hands of Stalin, who between the years of 1927 to 1929, created agricultural, industrial and cultural reforms which resulted in all scientific institutions being passed to the control of the Communist Party (Farley, 1979). At this point, dialectical materialism went from being a guiding suggestion for scientific thought to a mandated approach to be adopted by all. The impacts of this movement were far reaching with continued politicization of scientific ventures; Oparin himself referred to his study of the origin of life as a manifestation of the "underlying struggle of social classes." (Farley, 1979).

Role of Lysenko

The influence of the Communist Party within scientific institutions had a much more indirect impact on Oparin, apparent in his choice of mentor and his resultant effect on how Oparin shaped his theories. During the 1930s, Trofim D. Lysenko, (Figure 5.16), gained popularity within the Soviet scientific community based on his research in cold treatment of seeds to stimulate seed germination (Hossfeld and Olsson, 2002). From his work, Lysenko theorized a mechanism to extend the agricultural usefulness of land in the Soviet Union. Though this process, Lysenko derived his own version of genetics which was in direct contrast with Mendelian theories (Hossfeld and Olsson, 2002). Due to his work in agricultural science and with Stalin's support, Lysenko became president of the Lenin Academy for Agricultural Sciences in 1938 and the USSR Academy of Science's director of the Department of Genetics by 1940. By his meteoric rise and influence, Soviet scientists, including Oparin, suppressed use of classical Mendelian genetics, further becoming a founding tenant of the Soviet ideology of dialectical materialism (Hossfeld and Olsson, 2002).

Oparin, however, was not just a follower of Lysenko but an avid supporter of his theories, tailoring his own views to suit Lysenko's ideology. In fact, during the Lysenkoite movement, Oparin, as the sole biologist to join, was responsible for the enforcement of Lysenko's creed regarding evolutionary theory and genetics (Jukes, 1997). This venture lasted from 1948 to 1955. During this time, Oparin further subjugated his own views and suppressed any consideration of the origin of genetic systems as part of how he arrived at his theory for abiogenesis (Jukes, 1997). This change was in stark contrast to the Oparin of the early 1920s, when he made motions to include Darwinian evolutionary concepts to his consideration of abiotic chemical systems and their transition to organic life (Lazcano, 2016). However, by the time Lysenko consolidated his power, Oparin had already abandoned any notion of Darwinian conceptualization and favoured sole use of astronomical data to substantiate theories regarding Earth as a highly reducing environment suitable for organic chemical synthesis, all as part of a dialectical materialistic view (Lazcano, 2016).

Impact of Oparin's Theories

This transition in Oparin's thinking had more far-reaching impacts in the theory of the origin of life. Notable American scientist John Keosian in the late 20th century described his own theories regarding the origin of life as the primary result of successive steps that increase in complexity as one approaches the final living state (Farley, 1979). The uniqueness of this idea stems from Keosian's consistent reference to processes that remained as aspects of dialectical materialism. Keosian had no known Marxist affiliations, and yet continued to make use of terms like "materialism" in his discussion of life's transition from inorganic to organic chemical forms (Farley, 1979). The very fact that these discussions took place gives credence to the circumstances of Oparin's own sources of inspiration regarding the origin of life.

Haldane and Materialism

On the other side of the continent, Haldane, (Figure 5.17), was also influenced heavily by Engel's writings and dialectical materialism as a philosophy. Very early on in his work, Haldane blatantly criticized those of religious backgrounds who completely refuted materialism in the study of life. He in fact referred to Eugene Dubois' discovery in 1892 of the fossils of *Pithecanthropus erectus,* which was a transition organism between ape and human as they evolved. Haldane used this analogy to assert that the answer to the origin of life does not have to be exclusively material, or reductionist, or to do with the spirit and soul; it can be a transition of sorts. However, Haldane opposed the idea that living things are simply inanimate forms plus their souls, believing the viewpoint to be too reductionist or traditionally materialistic. Instead, he believed things were constantly evolving with organisms consisting of multiple parts managing to come together in just the correct arrangement. Haldane attributed life's origin to emergent properties, where each part could only function in the presence of the others.

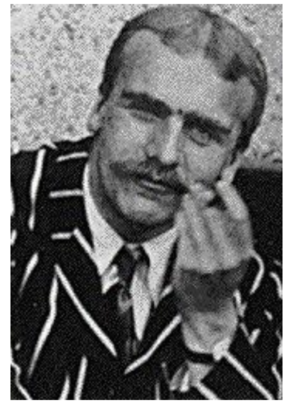


Figure 5.17. J.B.S Haldane depicted considering concept of materialism toward origin of life theory.

Haldane's theories were generally well-received by his peers. Haldane was an incredibly bold scientist, according to many of his peers, often making connections and predictions that others would be hesitant to try (Dronamraju, 1985). Although several of his predictions in the 1920s and 30s were incorrect in the field of biology and chemistry, professors such as Rene Wurmser still hailed his role in formation of biochemistry, genetics, and evolution significant. Haldane went on to mentor and influence several notable scientists, including Aldous Huxley and Boris Chain (Dronamraju, 1985). However, Haldane himself was not yet concrete in his ideas (Gouz, 2011). He always had contradictory thoughts regarding the validity of materialism and idealism, namely the inconsistencies between his scientific, political, and philosophical worlds (Shapiro, 1993).

A reasonable question to ask is why Haldane and Oparin had independently generated similar theories on the origin of life at similar times, both putting together a primordial soup hypothesis identifying the same starting materials in similar locations reaching the evolution to living organisms through similar means. Marxism is one common link. The political atmosphere was internationally leaning quickly leftward. The rise of the working classes, opposition to fascism, and the Spanish civil war was making Marxism increasingly popular at the time (Gouz, 2011). Many researchers today noted the large proportion of communists that were scientists (Shapiro, 1993; Sheehan, 1985; Sarkar, 1992). Diana Paul in 1983 theorized that Marxism was the first significant ideology to identify a science behind history and philosophy. Therefore, many biologists were attracted by the validity of the science (Paul, 1983).

Haldane himself was attracted by dialectic materialism, like Oparin, but for different reasons. He believed it filled in gaps in his philosophy that mechanical materialism could not. Philosophically, he believed life could not simply be chemicals – there was something more but it was unclear what. He once claimed that "if my opinions are the result of chemical processes going on in my brain, they are determined by laws of chemistry, not those of logic" (Haldane, 1933, p.89). However, if nothing was eternal and everything was constantly evolving through contradiction, interconnectedness, and conflicts, life was simply when materials evolved to a higher order of organization, and will continue to transition.

Dialectic materialism allowed scientists not to have to choose between vitalism and mechanistic materialism. If this is what Haldane and Oparin both believed, then at similar times, they both would have approached the origin of life question with both a biochemical and historical approach. In essence, they both believed that synthesis of organic molecules would have had to precede the origin of life, that there historically must have been transitions before life could have been created and that the changes were catalyzed by a significant event. In fact, Haldane went as far to identify D'Herelle's work on bacteriophages an inspiration to identify the intermediate between a collection of organic molecules to the current working definitions of life, in that life must have stayed in a virus stage for a long time before the transition to becoming the first cell (Haldane, 1929). Although there are historians who believe either that Haldane could not have been influenced by communism until the 1930s (Paul, 1983) or that science influenced Haldane's political views and not vice versa, it is evident that in his *Origin of Life,* there were undertones of dialectical materialism throughout (Sarkar, 1992). His examples of the hominin fossil and bacteriophages demonstrate an emphasis on intermediates in a constantly moving cycle. His assertion about the composition of the first cell was immediate followed by an explanation that each chemical part needs the presence of almost all the others in order to function, thus proving Haldane's agreeance with the interconnected facet of dialectical materialism (Haldane, 1929). Therefore, Haldane may have not been a communist politically in 1929, but his work was at the very least a transition step to his future adherence to Marxism.

Although education today is taught through subject-specific courses, knowledge of the world cannot be learned independent of each other. Oparin and Haldane likely could not have created the prebiotic soup hypothesis at the time that they did without the Marxist influences of the time period. Oparin's work was directly guided by Lysenko, inspired by Engels, and enabled by Stalin. Haldane chose to join to the growing communist community, and was in turn influenced by Engels' beliefs. Although neither were official communists when they published their origin of life theories, they were heavily inspired by the dialectical materialistic tones of Marxist ideology. As such, the environment in each of these cases is of utmost importance in determining how a theory is created and must be considered whenever we try to determine where likely sources of influence come from.

RNA World: A Modern Origin of Life Theory

Consideration of the political influences surrounding Oparin and Haldane's theories regarding abiogenesis allows for further understanding of the present state of origin of life hypotheses. Namely, by understanding how exactly each individual progressed to arrive at their respective conclusions, the current state of prebiotic theory will rapidly come into clearer picture. From this point, the foremost importance and research in the modern state of origin of life theory concerns the RNA World hypothesis and resultant implications for the source of biotic life.

The hypothesis itself consists of several constant tenants that shape a wide breadth of how biotic life could have been derived from inorganic molecules. The origin of organic molecules within this theory is pinned on the use of biocatalysis as performed by catalytic RNAs, ribozymes, to promote the necessary reactions required for biogenesis (Bartel and Unrau, 1999). One source of opposition to this theory is likelihood of RNA catalysts being able to remain stable while functioning in this capacity. The logic behind the existence of RNA catalysts, as opposed to more stable and complicated protein enzymes, is the ease that they could then serve as their own genes, allowing for much more efficient duplication

(Bartel and Unrau, 1999). From this point, the theory details that RNA overtime developed the ability to code for more complex polypeptide sequences, which serve as complicated cofactor molecules (Bartel and Unrau, 1999). The progression in the use of RNA as the primary biocatalyst changes at this junction, whereby the formation of cofactor molecules allowed for a transition with two stages whereby DNA replaced RNA as the genetic material and synthesized protein enzymes substituted biocatalysis (Bartel and Unrau, 1999).

Until recent years, there have been no effective mechanisms to demonstrate base RNA molecule synthesis into ribozymes, (Figure 5.18) (Paleos, 2015). The source of concern regarding this vein is the stability of any present RNA molecules within a chemically active solution present in the early stages of the Earth's formation. The nature of the RNA molecule would likely lend itself to being liable to hydrolytic cleavage, due to its polar structure and the reactive environment it was found in (Paleos, 2015). Because of these confounding circumstances, most current ventures are focused on providing evidence to demonstrate the likelihood of such a hypothesis.

Figure 5.18. Depiction of general ribozyme (left) structure. Presence of multiple functional domain regions allows for increased biocatalytic capabilities during proposed organic molecule synthesis.

Firstly, interest remains in the plausibility of RNA molecule synthesis within a prebiotic setting, the process of which was considered to be unlikely. However by 2009, Powner et al. were able to demonstrate the formation of pyrimidine nucleotides from prebiotic substrates using a mixture of hydrogen cyanide and hydrogen sulfide, activated by ultraviolet light . This finding does provide evidence supporting the formation of RNA molecules and by extension ribozymes (Pressman et. al, 2015). However, the slight caveat to this finding is the requirement for consistent chemical synthesis mechanisms such as pH and temperature changes (Pressman et. al, 2015).

Based on these requirements, the RNA world hypothesis has undergone modifications in the scope of possible environments that RNA molecules could have been synthesized in. From consideration of its labile nature, further work has proposed that the RNA world would more likely have evolved in colder ice dominated areas (Bernhardt, 2012). This supposition is based on work detailing that maximal ribozyme activity occurs at temperatures ranging from 265.15 K to 266.15 K. However, the results of such works have been met with some contention given that RNA sequences have the tendency to allow for extended complementary base pairing at these temperatures, possibly decreasing biocatalytic capability (Bernhardt, 2012).

In addition to this previous finding, advent of the method known as in vitro selection has been able to provide further evidence for the biocatalytic capability of ribozymes (Martin et. al, 2015). The process itself involves use of catalytic RNA molecule isolation from a molecular library by coupling to the ribozyme molecule itself (Martin et. al, 2015). This selection process then concludes with reverse transcription to a DNA molecule followed by polymerase chain reaction amplification and final transcription into an RNA pool prepared for functional sequences (Martin et. al, 2015). From this point, the developed ribozymes have the capability of catalyzing a vast multitude of reactions such as RNA ligation and peptide coupling, associated with mediation of metabolic processes (Martin et. al, 2015).

Based on the current understanding of these processes, the RNA World hypothesis remains a prevalent theory regarding the origin of life. However current arguments do exist requiring further evidence to demonstrate the likelihood of such a hypothesis being plausible. Yet, current research methodology innovations have been able to push the boundary forward with increased brevity. This allows for increased confidence in the ability for the RNA World hypothesis to be an accurate depiction of a method by which biotic substances can be derived from an inorganic world.

A Tipping Point in Paleontology

Throughout history, there have been many questions that took hundreds or even thousands of years to answer, and more still that have not yet been answered. Arguably, one of the most interesting of these was the determination of the origins and usages of fossilized remains. We hope in the following pages to take you on a journey through time, and illustrate to you the dynamic process that was the evolution of thought in the field of paleontology. Starting with Aristotle and other ancient thinkers, whose hypotheses were in fact not far off from the claims of modern science, and progressing through periods of time that challenged and even contradicted the beliefs of these ancient thinkers. The 18th century, for example, was a time when humanity appeared to entirely abandon science for faith, and ignored the work of those that came before them. However, in order to properly explain this phenomenon, we must begin with the familiar faces of Aristotle and the thinkers of his time.

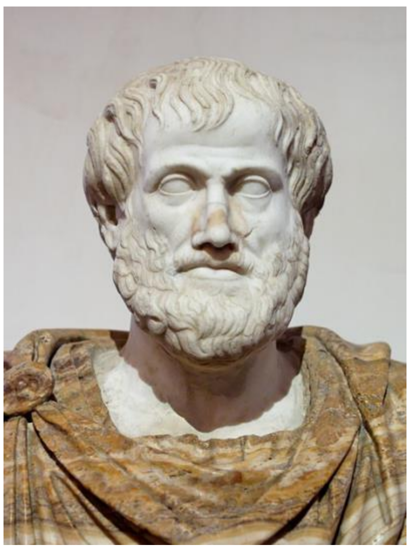


Figure 5.19. A famous bust of Aristotle, one of the first to record observations related to paleontological thought.

Aristotle and Ancient Thinkers (up to 100 AD)

The science of paleontology has existed for millenia. It was the thinkers of the ancient world that first recorded observations of what we now call and consider to be fossils, and speculated as to their origins. It is highly debated in literature whether it was Xenophanes of Colophon or Anaximander, both of whom were ancient Greek philosophers, who was the first person to discover and make claims about the origins of life (Burnet, 1920). Some argue that this ancient process of paleontology roughly began in 600 BC, when Xenophanes of Colophon observed the presence of fossilized sea shells simultaneously on flat land, and in hills and mountains surrounded by the Aegean Sea (Orlov, 1962). In addition to the sea shells, he also noticed the presence of imprints from laurel leaves in the deep rocks of the island of Paros as well as imprints of fish species in quarries in Syracuse (Barnes, 2005). Finally, he also identified rocks containing imprints from sea creatures on Malta island, indicating that the rocks had marine origins (Orlov, 1962). Accordingly, he proposed a theory about the history of earth, claiming that this evidence was the result of periodic floods that had destroyed the land and the people living there in the past (Orlov, 1962).

Likewise, Anaximander claimed that the world's first animals arose from moisture, having been encased in a 'prickly bark' (Barnes, 2005), he continued. As the life forms aged, they emerged from this bark, once the environment became more arid, and lived for a short period of time (Burnet, 1920). This proposition was very similar to that of Xenophanes', who claimed that the fossilized species he discovered were created when the earth was covered in mud, and then the outlines were created when the environment dried up (Burnet, 1920). As such, controversy arises as to whether the discovery of fossil species should be credited to Anaximander or Xenophanes.

However, some bodies of literature claim that in fact Xenophanes of Colophon and Anaximander had contradicting views; when Xenophanes claimed that the earth was gaining water and increasing in moisture, Anaximander claimed that the water that once encapsulated the earth was slowly being vaporized, and the earth would soon dry out (Barnes, 2005). Despite these inconsistencies in the recounts of these ancient philosophers, it is clear that Ancient Greece serves as the starting ground for the field of thought relating to fossils, paleontology, and the evidence they provide for the history of the earth.

Further pieces of evidence that substantiate this claim, are reports from 500 BC which describe Xanthus of Sardis, a Lydian historian, discovering fossil shells that appeared to come from the sea, in Armenia, Phrygia and Lydia (Orlov, 1962). He claimed that these areas were once covered by ocean, but were subject to alternating periods of wet and dry land. At the same time, Herodotus, a Greek historian, came across sea shells in Egyptian mountains, again suggesting that there was a time when this area was covered by the sea. In contrast to all these claims, in 300 BC, Theophrastus suggested that there was a plastic force that was responsible for the formation of fossils (Orlov, 1962). Nevertheless, it was the work of these Ionian Philosophers that influenced and inspired Aristotle, who went on to create bodies of literature on similar topics such as the origins of life, the earth and the cosmos, which were highly influential in the evolution of the theory of thought in geology, palaeontology and more.

Aristotelian thought, which would later be highly influential to a number of 16th century naturalists, suggested that fossils possessed an organic quality, and some of them even bore resemblance to living organisms (Rudwick, 1972). Aristotle proposed the idea of 'vaporous exhalations' which suggested that there was some kind of petrifying fluid that was constantly working to produce a diverse range of stoney objects (Rudwick, 1972). Moreover, Aristotle postulated an explanation to account for the varying and obscure locations in which these fossils could be found. He proposed a theory suggesting that the earth was subject to processes of erosion and silting. He explained that the globe could undergo periods of mass movements of the continents and oceans, whilst still maintaining the integrity of the earth. He went on to suggest that the earth is an ever-changing and indefinite place, where rivers drain and flood (Rudwick, 1972). These explanations could account for the discovery of fossils high on hill tops and within layers of rocks. It was the discovery of fossil evidence in varying terrestrial environments that enabled ancient thinkers such as Aristotle to formulate hypotheses as to their origins and how they could be implicated in understanding the origins of the earth. These discoveries paved the way for future geologists. It will later be explained that the propositions of these ancient Greek philosophers were disregarded or forgotten for a long period in history, but nevertheless, they were an essential building block for current understandings in the realm of paleontology.

The Dark Ages (101 - 1500 AD)

For the next 1400 years, there was very little activity in the world of paleontology. There are many possible explanations for this trend, but one must remember the priorities of mankind at the time. Many were interested primarily in their own well-being, and with the rise of royal empires and wars that dominated much of this time period, understanding the significance of fossils was not necessarily a priority to the people at this time.

However, there were a few notable exceptions during this period of inactivity. The first of these was the product of the Islamic Golden Age. Between the 8th and 16th centuries, a substantial amount of scientific activity actually did take place, in parts of Europe and Asia (West, 2008). This period is often referred to as the Islamic Golden Age, and the work referred to as Arab Science, because most of the work was done in Arabic. However, this is not to say all the important figures of the time were Arabian. In fact, many of the most prominent figures were Persian (West, 2008). In 1027, a Persian Muslim by the name of Abdallah ibn Sina, known in the western world as Avicenna, published *The Book of Healing* (Avicenna, 2009), where he references his ideas about the origin of fossils. He built on the ideas of Aristotle and others before him, and suggested that fossils were formed from the interaction of organisms and natural material with a 'petrifying fluid' (Avicenna, 2009).

Figure 5.20. A portrait of Ibn Sina, known to the western world as Avicenna. His work remains some of the only recorded insight into the field of paleontology in the Dark Ages.

The second exception to this lack of study occurred in the eleventh century, in a separate corner of the world. The Chinese Song Dynasty brought with it a new age of thought for the eastern world. It was at this time that Chinese civilization began to make significant advances in various scientific fields and use what is recognized today as an elementary scientific method (Dieter, 2009). Shen K'uo, a high government official of this time period, was one of the most influential scholars of the time. He was one of the first to record observations of a meteorite both after and during its descent, and to propose that the moon itself was not luminescent, but instead simply reflected light that was shone upon it. In 1025, he began some of the first interpretive work with fossils since that of the ancient thinkers. He used observations of petrified bamboo in a dry, desert region to come to the conclusion that the region in question once must have been a marine environment, since bamboo cannot grow in dry, arid environments (Dieter, 2009).

The final exception to this period of inactivity was the material published by Georgius Agricola in 1556. Although this publication occurred posthumously, just after the end of the Dark Ages, Agricola's work was largely done just towards the end of the time period. Accurately described as 'the father of mineralogy,' Agricola authored two works of interest to paleontologists. The first was his best-known work, *De Re Metallica*, in which he described the classes of minerals he had discovered in the ground, as well as some of the first instruction or guidance on the physical practices of mining (Agricola, 1556). In another work, *De Natura Fossilium*, Agricola again describes a class of minerals of organic nature as 'fossils' (Agricola, 1546). In De Re Metallica, he likely had also created the first written methods for the extraction of fossils from the ground. It was also in this work that we are able to see some of the first influences of faith leading into the Theological Age. He stated that although some geologic areas may seem most profitable for mining, one should not mine there if there are high winds or other 'unmistakable signs of pestilence' (Agricola, 1556). It seems here that Agricola is trying to prevent greed, one of the seven deadly sins in Christian teaching, among those who read his work.

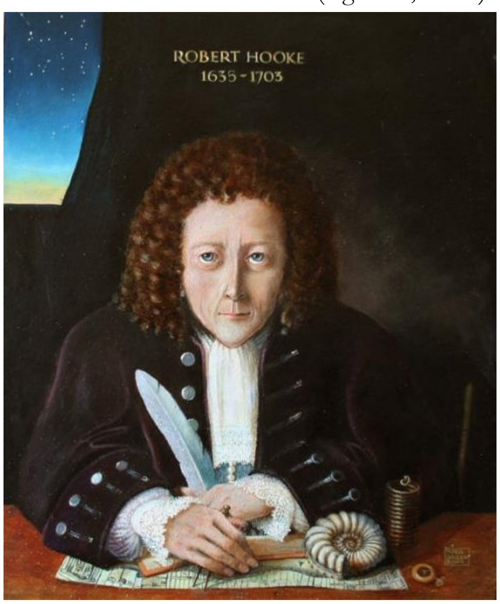


Figure 5.21. A contemporary reconstruction of a portrait of Robert Hooke. Though his work had great influence, no portraits of Hooke appeared to survive the seventeenth century. This reconstruction was created from descriptions given by his colleagues.

The Theological Age - The Tipping Point (1500 - 1800)

Here, we arrive at the tipping point in the progress of thought behind paleontology. This was truly the period where our question (that is, the determination of the origin and usage of fossils) was answered.

We must first set the stage by examining the social structures that existed at the beginning of this era. This truly was the age of religion, and the steadfast belief that the world had come from a divine source. To give an example, a widely accepted theory of the time was that proposed by James Ussher, who was an archbishop, revered as a man of science by his society, and had used scripture alone to estimate that the earth had been created in 4004 B.C. (Plummer et al., 2007). It is almost laughable to think of using scripture alone as scientific evidence today, but then, we are discussing a society very different than today's. We are placed here in a society completely different from our own, where the first, most logical, and often only explanation for many phenomena was thought to be divine intervention. We can see this religious bias again in the infamous *Lithographiae Wirceburgensis*, a work by Johann Beringer in 1726. He discovered a series of fossils with the word "God" written in Hebrew, Latin, and Arabic on them (Beringer, 1726). Beringer took this as evidence for divine intervention, however, it was later revealed that these rocks were part of a hoax performed by Beringer's jealous colleagues, who had carved them and placed the rocks in a location they knew Beringer commonly visited (Gould, 1998). The stones he uncovered, later dubbed the 'lying stones,' even had chisel marks on them aside from the writing, but instead of supposing these may have been created by human hands and placed where he had found them, he became only more certain of his thought that these were chiseled by God (Beringer, 1726). Upon discovering the truth, shortly after the book's publication, he immediately tried to buy and destroy all copies that were printed (Gould, 1998). Although even he was able to admit in the end that fossils were not the work of God, his thought process gives great insight into the way that people of the time period thought. At this time, it was not only possible, but a widely accepted and published notion that fossils were the work of God.

Long before this, however, the beginning of a revolution of thought in this field occurred. A man by the name of Robert Hooke (who later in life would become the curator of the Royal Society) laid out not only ideas, but a step-by-step process that explained the origin of fossils and how they came to be where they were found (Hooke, 1968). He had proposed a process similar to that by which peat changes to coal. As we know today, his postulation was not correct, but it was a much closer hypothesis than those proposed by paleontologists in the rest of 17th century Europe. However, his ideas were rejected by society and the religious bias which it held strong. Some argued that his explanation did not answer how fossils of marine creatures came to be found in the mountains, and others rejected it on the basis that he claimed these stones were once living creatures. They didn't believe that these stones resembled creatures that didn't currently exist on the surface of the earth (i.e. extinct species) and many argued strongly that this disproved Hooke's ideas because an extinction event was impossible in a world made by God. In fact, a play called *Vertuoso* was released in May 1676 that made a number of jokes about him and his ideas as to the origins of fossil species. In his diary, he writes "with Godfrey and Tompion at Play… Damned Doggs… People almost pointed" (Hooke, 1968, p. 235).

It was not until the beginning of the 18th century that these ideas began to gain some attention for what they were. As intrigue and curiosity grew, many began to try to find common ground between these scientific ideas and the religious beliefs by which they lived. Accordingly, the most common justification for Hooke's ideas was to draw a link between them and Noah's flood (Winchester, 2001).

One of the most influential works inspired by Hooke's ideas was the work of William Smith, author of the Map of the Strata of England and Wales, otherwise known as 'the map that changed the world' (Phillips, 1844). As a young child in the early 1700s, Smith became intrigued by small stones which he called 'pundibs,' which we now know to be Lobothyris fossils. Fifty years prior, had he been the same age with the same curiosity, he may never have had the thoughts that led him to completing the famous map. However, it was the public acceptance of Hooke's initial ideas that led Smith to another, equally important theory (Phillips, 1844).

He had, much later in life in the midst of his work on the map, noticed that distinctly different fossils were present in different strata (Phillips, 1844). This observation manifests itself in one of Smith's great contributions to the field of stratigraphy (the study of correlating rock units); the Principle of Faunal Succession, which separates rock strata based on the fossils they contain (Phillips, 1844). It could be argued that this observation was the beginning of the modern field of biostratigraphy, and inspired more recent work in the field.

Smith himself acknowledges in his own memoirs that the only reason many others were interested in fossils at all was as decoration, due to their intricate nature, and not in any scientific capacity (Phillips, 1844). Recounted by his nephew in the same memoirs, Smith also used fossils in a scientific capacity to inform coal mining practices. He informed miners of the Oxford Clays, who based their mine locations off similar rock types as other coal mines, that they would be wasting their time hunting for coal there. He knew from the lack of fossils in the area that these were not rocks deposited in areas that were likely to have sustained substantial plant life to form the coal which the miners desired (Phillips, 1844). Without these ideas from Smith, the scientific use for fossils and their connection to geology arguably would not have come to light.

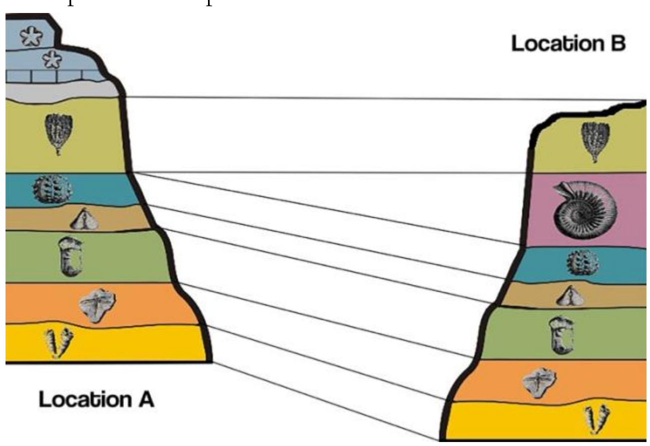


Figure 5.22. An illustration of Smith's Principle of Faunal Succession. *Strata defined by similar remains in different locations can be defined correlated by them.*

A final inspiration from the work of Hooke and Smith was the work of Georges Cuvier, the acclaimed 'Father of Paleontology.' Cuvier is credited with the first published work outlining comparative anatomy between animals (Cuvier, 1817). He organized the animal kingdom by the skeletal structure of each species, in a famous work called *Le Règne animal distribué d'après son organisation*, or *The Animal Kingdom, Distributed According to Its Organization*. Cuvier's work identified skeletal remains and he related various species, both extinct and modern, by their bone structure. However, despite these ideas supporting Darwinian evolution, he was strongly opposed to Darwin's theory, showing the lingering influence of religion at the time (Cuvier, 1817).

Hooke's ideas were clearly a breakthrough of the 18th century, and began to spur the advancement of the science of paleontology. However, that is not to say that this time period did not significantly hamper this advancement. For almost two hundred years, the works of previous thinkers were ignored, and almost forgotten, in the mission of religion to attribute fossils to a divine power. Had Hooke's ideas never been published and sparked the curiosity of society, it is entirely possible that this mission may have succeeded in the disappearance of the basic ideas behind paleontology.

Paleoclimatology

Ever since geologists have developed a more concrete understanding of what fossils are and from where they originate, the field of paleontology has progressed from trying to identify the precise origins and purpose of fossils, to using fossils as a means to extract other information about the history of the earth. By exploiting modern technology and techniques, fossils can provide a doorway into the past, allowing scientists to better understand the dynamic processes involved in historical geologic and environmental conditions. In doing so, scientists possess the ability to postulate predictions regarding future climate change or geologic activity.

A more recent case in which the identification and study of fossils was essential in contributing to our understanding of the history of the earth is in the field of paleoclimatology. Paleoclimatology refers to the use of paleontological data to study historical climate conditions on earth (National Oceanic and Atmospheric Administration, n.d.c). Climate change, however, is not a historically new phenomenon - the earth is constantly subject to periods of warmer and cooler temperatures (Markwick, 1998). The modern problem, however, is that the current climate change crisis has been anthropogenically induced and is occurring at an alarming rate (Markwick, 1998). In the scientific community, it is undisputed that one of the leading contributors to global warming is the production of greenhouse gases and increases in atmospheric carbon dioxide (National Oceanic and Atmospheric Administration, n.d.a). Accordingly, scientists are concerned with how much temperature change was accompanied by increases in atmospheric carbon dioxide in the past, how much of the current climate change is a result of human activity, and what the future implications of this look like (National Oceanic and Atmospheric Administration, n.d.a). The progression of new stable-isotope techniques and the acquisition of new information from the deep-sea fossil record has provided useful evidence for studying the potential for future climate change (Markwick, 1998).

According to Schmidt, there are two primary methods whereby scientists try to reconstruct past climate conditions: climate proxies and climate models (2018). Here, we will specifically focus on the use of climate proxies as a means to understand past climates.

Geologic sequences themselves cannot always explicitly and consistently depict the dynamic processes of historical conditions that may lead to climate change, such as changing sea levels or tectonic activity. As such, paleontologists and geologists use fossilized materials as climate proxies in order to gather data and make inferences (Schmidt, 2018).. These proxies are elements from the physical environment that have been preserved over time to provide information about both the biotic and abiotic conditions at the time of fossilization (Schmidt, 2018). Such proxies include ice cores, tree rings, corals, ocean sediments, and fossilized pollen (National Oceanic and Atmospheric Administration, n.d. b). Moreover, data contained in fossil records also provides evidence pertaining to shifts in geologic distribution, population/abundance, and migration patterns of organisms, which can be used as an indication as to how they reacted to changes in the climate (Schmidt, 2018).

An example of this are the rings in the interior of a tree, which represent different climatic and environmental conditions (National Oceanic

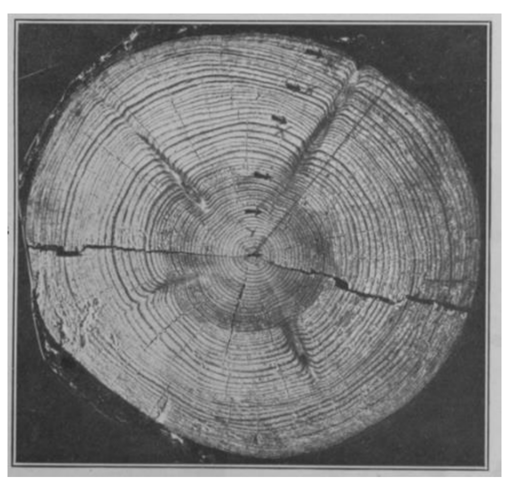


Figure 5.23. A photograph of the interior rings of the trunk of a Scotch pine tree from Norway, depicting climactic cycles.

and Atmospheric Administration, n.d. b).

The bands that are lighter in colour represent a time during the life of the tree where the temperature was warmer, during the spring and early part of the summer, whereas the rings that are darker in colour grew during the later summer months and into the fall (Stoller-Conrad, 2017). As such, one year in the life time of a tree is represented by a light and a dark interior band. In addition to this, the rings also grow wider during warm, wet conditions, and are thinner when the environment is cold and dry. Scientists have been able to come to these conclusions by analyzing the bands within the trees while monitoring the weather at local weather stations, and drawing correlations (Stoller-Conrad, 2017). If we are able to develop an understanding of patterns in historical climate changes, this may give an indication as to how the cycle will continue in the future.

Another way on which scientists are able to extract information about ancient climate conditions is through the dating of fossilized organisms. If they are able to accurately date a fossil species to a specific time and region, they can use this information in conjunction with data acquired from other climate proxies, to develop an understanding of the environment at the time. For example, if a certain marine species is discovered to be close in time and space to another climate proxy, this data can provide circumstantial evidence for overlapping time frames for certain geological events or required environmental conditions that would have allowed for the simultaneous production of these fossils. As such, researchers commonly utilize a technique called radiocarbon dating (Popular Archaeology, 2012). This is based on principles of nuclear decay and respective ratios of different atom isotopes. An isotope refers to each of the variants of a specific chemical element, all of which possess the same chemical and physical properties, but have different atomic masses (Plummer et al., 2007). An example of an isotope is radiocarbon, which is the radioactive version of carbon and is produced in the earth's upper atmosphere at a constant rate (Popular Archaeology, 2012). Radiocarbon gets absorbed into the tissues of living organisms and other organic matter, in a ratio that is consistent with that in the atmosphere (Plummer, et al., 2007). When the organism dies, its body is no longer able to produce new tissue, so the radiocarbon begins to decay, at a constant rate, which is determined by the half life of the element. Accordingly, when a fossil is discovered, scientists are able to back calculate the amount of radiocarbon that would have been present at the time of deposition (Plummer, et al., 2007). The problem is that there are processes that can alter the levels of radiocarbon in these fossils, such as when there is assimilation of carbon by the local environment (Bowman, 1990). An example of this would be a marine environment (Bowman, 1990). When making these calculations, scientists have to account for an error term. Moreover, the amount of radiocarbon in the atmosphere can differ between consecutive years and at different locations within the global carbon cycle, again demanding the need for a correction term in the calculations (Popular Archaeology, 2012). Luckily, in 2012, researchers from Oxford university extracted a core from Lake Suigetsu in Japan that contained fossilized layers of organic matter from terrestrial environments, including leaves and twigs. Prior to this discovery, the highest resolution record of atmospheric radiocarbon was from tree rings, which extends as far back as 12, 593 years ago. In comparison, the core from Lake Suigetsu extends back to 52,800 years ago, thus the discovery of this core extended the 'direct radiocarbon record by more than 40,000 years' (Popular Archaeology, 2012).

Researchers on this team used climate proxies to help make sense and date the fossils in the core. The layers in the Lake Suigetsu core record the number of years, thus the researchers were able to measure the radiocarbon levels in each layer and attribute these levels to specific years (Popular Archaeology, 2012). The researchers anchored the first 12,200 years of data in the core based on the well-established data contained in tree ring fossils, and from there, establish a longer timeline based on the information contained in the terrestrial deposits. This is an important discovery because it allows for a higher resolution, better calibrated time-scale of past geological conditions, such as how early humans reacted to past climate changes (Popular Archaeology, 2012).

All of this evidence goes to show that although we have progressed a long way from ancient times and the theories of former paleontologists, there is still a lot that we don't know. Scientists are constantly searching for new ways to solidify our understanding of the past, but there is, in fact, no definitive way to know for certain. As such, it is likely that new theories and methods will constantly be proposed in this field and will constantly be subject to change, with new thinkers, new pieces of evidence, and advances in technology.

From Anthropoid to Humanoid: The Paleopolitics of Unearthing Human Evolution

The creation of the consensus theory behind human origins is often taken for granted today. However, the journey to arrive at our current level of scientific understanding was intensely political, convoluted, and often took massive steps backwards before it progressed. When discussing the history of research in human evolution, the climate of the global scientific community must be taken into consideration. It is in this context that it can be understood why certain archeological discoveries have been more influential on scientific thought than others. The following chapter will discuss the discovery and classification of the genus Australopithecus, a missing evolutionary link between humans and apes, and why it took over 20 years for the scientific community to accept this discovery.

The Piltdown Man Sets the Precedent

In 1912, the amateur archaeologist Charles Dawson brought skull fragments, a set of teeth, and some primitive tools to Arthur Smith Woodward, Keeper of Geology at the Natural History Museum in London (Natural History Museum, 2018). He claimed they had been found in the village of Piltdown in Sussex, England by workmen who were digging in the gravel beds. Woodward then aided Dawson in the excavation of more fossils. They unearthed complete evidence of a primitive human-like creature that was uniformly deposited within the Pleistocene gravel (Natural History Museum, 2018).

The reconstructed skull was presented to the Geological Society of London where it was classified *Eoanthropus dawsoni*, the most recent 'missing link' between humans and apes. It was estimated to be 400,000 - 500,000 years old (Natural History Museum, 2018; Encyclopaedia Britannica, 2018). The skull was humanlike, and the jaw was that of an ape. It seemed anatomically impossible for the two parts to fit together, leading critics to question the likelihood of them ever being connected (Oakley and Weiner, 1955). However, the wear of the molar teeth overshadowed this concern. The molar flatness was a humanlike characteristic that had yet to be found in other ape or primitive skulls (Oakley and Weiner, 1955). Therefore, this fossil was thought to be another step towards determining the evolutionary history of *Homo sapiens*.

The discovery set a precedent that ancestors of *Homo sapiens* should have a similar skull and jaw combination as the Piltdown Man. The fact that the fossils had been discovered in England supported the Eurocentric ideology that was popular at the time. The fossil had unfailing support from multiple renowned British scientists that came together to form the Piltdown Man Committee (Figure 5.24). The Committee included academics such as Dr. Arthur Keith, who was a Fellow of the Royal Society, and Dr. Arthur Smith Woodward (The Geological Society of London, 2012; Clark, 1955). This team of scientists was very influential and made it difficult for less popular individuals to present conflicting evidence. In order to disprove the opinions of these men, one would have to provide large amounts of evidence that the they could not deny or dismiss. However, discovering breakthrough fossil evidence was a separate challenge.

Figure 5.24. Artist's rendition of a Piltdown Man Committee meeting. In order of appearance from back left to front right: Frank Barlow, Dr. Grafton Elliot Smith, Charles Dawson, Dr. Arthur Smith Woodward, Arthur Underwood, Dr. Arthur Keith, William Pycraft, Edwin Ray Lankester.

Fossils in Asia and Africa

In the early 1900s, the integration of scientific research within society and government was not globally uniform. Britain had founded a Geological and Anthropological Society and other government ministries dedicated to the communication, preservation, and advancement of science. Most of the developing world did not have these establishments (Jardine, 2014). However, most ground-breaking paleontological discoveries were occurring in Asian and African countries on the properties of foreign companies that were excavating the land. These countries lacked the political framework to overrule such companies and prevent foreign intervention or acclamation when an anthropological discovery occurred.

For example, in 1888 a mining engineer discovered a fossil skull in the Dutch colony of Java (Geer et al., 2011). It was mere chance that allowed the Java Man fossil to fall into the hands of an expert who could identify its true value. Today, this fossil is classified as *Homo erectus*, a close relative to *Homo sapiens*, and is essential to understanding human evolution (Geer et al., 2011). However, even after this discovery, there was no attempt to preserve the archeological site. The colonist authority within the country was struggling to control the population and could not allocate their resources towards site preservation (Rijks Museum, n.d.). Overall, the scientific value of these sites was not acknowledged, and an abundance of fossil evidence was lost due to mining and excavation. The majority of key paleontological discoveries were made due to the generosity of industries within the area, as well as pure luck (Johanson and Edey, 1990). This is precisely how the Taung Child skull would be discovered 36 years later.

The Taung Child

In 1924, quarrymen of the Northern Lime Company discovered a fossilized skull in Taung, South Africa. The director of the company, E. G. Izod, gave the skull to his son, Pat, who displayed it as a mantle piece in his home. Josephine Salmons, an anatomist at the University of Witwatersrand, was a friend of the family and took an interest in the skull during a visit (Mckee, 2000). The family permitted her to take it back to her university where she immediately gave it to her mentor, Raymond Dart.

Figure 5.25. Photograph of Professor Raymond Arthur Dart, age 75 (above) taken in 1968.

Dr. Raymond Arthur Dart (Figure 5.25) was an Australian neuroanatomist with a reputation for flightiness, unorthodox views and a scorn for accepted opinion (Foley, 2002). Perhaps these qualities clashed with his mentor, Piltdown Committee member Sir Grafton Elliot Smith at the University of Manchester, which motivated Smith to send Dart to Johannesburg to establish an anatomy department at the University of Witwatersrand. In his autobiography, Dart stated "I hated the idea of uprooting myself from what was then the world's center of medicine [University College, London]…to take over the anatomy department at Johannesburg's new and ill-equipped University of the Witwatersrand. I felt I had lived a pioneer's life for quite long enough in my younger days" (1982). It was in 1924, two years into his "pioneer" work, that Salmons presented Dart with the fossilized skull.

Immediately, Dart requested that the company send him any more fossils they had found. The initial skull was determined to be a baboon skull; however, the rest of the fossils were not as easily identifiable. Two crates arrived in the fall. They contained an endocranial cast which naturally fit with another unidentified fossil encased in rock. It took a month for Dart to remove the rock from the fossil to reveal an entire jaw and face (Figure 5.26). This was in part because his only tools were a hammer and his wife's knitting needles (Garwin and Lincoln, 2010). What he saw when the rock was finally removed would eventually change scientific opinion on human evolution forever.

Figure 5.26. Photograph of the Taung Child skull after removal of the rock matrix (left).

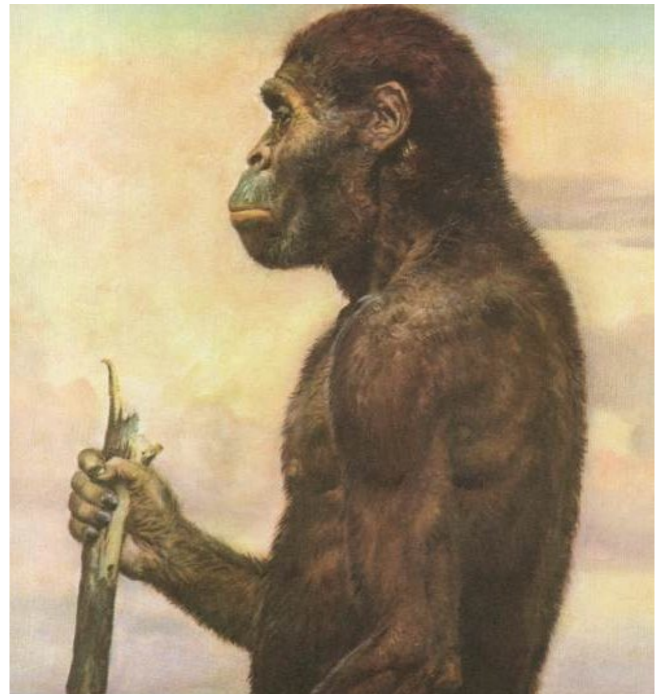


Figure 5.28 Artist's rendition of Australopithecus africanus *based on fossil evidence (right).*

Within forty days of discovering these fossils Dart had submitted an article to Nature entitled "Australopithecus africanus: The Man-Ape of South Africa" (Dart, 1925). The dentition of the fossil indicated that it was around six years old, which inspired Dart to nickname it 'the Taung Child'. He brazenly stated that this species provided evidence of the evolutionary linkage between apes and humans (1925). Dart outlined 3 key characteristics that supported his theory.

Evidence from the Taung Child Fossil

First, he noted that the cranium had human-like features. The lunate sulcus (boundary of the primary visual cortex) (Allen, Bruss and Damasio, 2006) was displaced backwards in the cranium (Dart, 1925). Dart indicated that the displacement was indicative of a larger association cortex, which is the component of the cortex that is essential for complex mental functions (Indiana University, 2018). Dart claimed that the increased size of the association cortex was proof that the brain had greater capacity for sensory stimulation, which would give the Taung Child the potential to articulate speech (1925).

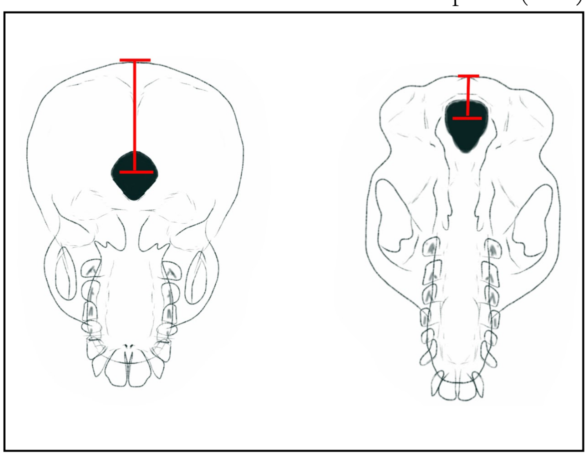


Figure 5.27. Line drawing comparison of foramen magnum on human skull (left) and chimpanzee skull (right). Underside view. Note the anterior placement of the foramen magnum on the human skull.

Second, Dart noted that the exit location of the spinal cord from the cranium, called the foramen magnum, was similar to that of humans (1925). In quadrupedal apes, the foramen magnum is situated further back in the cranium which sends the spinal cord back and downwards (Figure 5.27). Anatomically, this explains the concave body posture and mode of locomotion of the ape (Ahern, 2005). In humans, the foramen magnum is tucked under the skull, which indicates upright posture and bipedal locomotion. Dart inferred that the foramen magnum on the Taung Child was anteriorly positioned, which indicated that the *A. africanus* walked upright. Determining that the specimen had bipedal locomotion indicated that their hands would be free to yield tools and weapons. Dart stated that the hands would become instruments of growing intelligence in carrying out more elaborate and purposeful movements (1925) (Figure 5.28).

The morphology of the fossilized teeth was the last major piece of evidence proving that the specimen was more closely related to humans than to apes. Although Dart had yet to separate the upper and lower jaws to gain access to the chewing surfaces of the teeth, he noted the following characteristics: the incisors were irregular in size, overlapped and were almost vertical, which is similar to human incisors. In addition, the front teeth did not project forwards and there was no gap between the premolars and the canines in the lower jaw. These missing features further deviated the Taung Child from an anthropoid (1925).

Evidence from the cranium lineaments, foramen magnum and the dentition convinced Dart that he had found a novel species within the lineage of hominids.

Initial Reactions

Although he only had a single fossil as evidence, Dart knew he had uncovered something massive. Dart's claim that humans originated from Africa proved Darwin's original hypothesis that man evolved from apes in Africa (Dart, 1982). However, he anticipated that his new theory would not agree with his more experienced, often less radical contemporaries back in England. These individuals had a nationalistic desire to prove that the British Isles were the cradle of humankind, and thus strongly supported the Piltdown man evidence (Falk, 2011). Despite this, it was undeniable that Dart had made a fascinating discovery.

The Johannesburg Star published a front-page spread detailing Dart's finding which preceded the Nature article. The story quickly spread worldwide, and Dart became famous overnight (Falk, 2011). However, four members of the Piltdown Committee, including his old mentor, published a demeaning review of Dart's work in both *Nature* and the *British Medical Journal* less than two weeks after the original *Nature* publication. The Piltdown Committee largely disregarded Dart's precise explanations of the cranial features. They had several main critiques: first, he was basing his conclusions off a single, incomplete skull with no other fossil evidence. Second, the humanlike features he had identified could simply represent a now-extinct species of ape. Third, all juvenile extant apes look more similar to juvenile humans than do mature apes and humans (Falk, 2011). The fact that Dart was unable to date the skull, and that he had yet to separate the upper and lower jaws to gain access to the chewing surfaces of the teeth, meant that the scientific community was even less willing to give the skull the attention Dart thought it deserved (Dart, 1982).

Prejudice Over Evidence

Although these criticisms are valid, they are not cause enough to entirely dismiss the skull. Anyone who examined the Taung Child firsthand over the tumultuous proceeding 20 years was unable to deny its close relatedness to humans. Why, then did most people continue to reject the findings? An active supporter of Dart, fellow South African scientist Dr. Robert Broom, stated that "Presumably the most serious [offense] was that when [Dart] found a very important skull he did not immediately send it off to the British Museum...but boldly described it himself, and published an account within a few weeks of the discovery" (Broom, 1951). In contrast, the Piltdown Man was immediately brought back to the Geological Museum for analysis and classification (Natural History Museum, 2018). Phillip Tobias, a student of Dart's, thought that Dart's views were not accepted because they were too ahead of their time. They did not logically fit into the step-by-step evolutionary scale that scientists were then constructing, with the Piltdown Man as a centerpiece (Falk, 2011). For all these reasons, both overt and underlying, the Taung Child was ridiculed and rejected (Tattersall, 2009).

In 1929, Dart finally travelled to England and presented his skull firsthand at a meeting of the Zoological Society of London. In his autobiography, he wrote about his feelings of inadequacy when comparing his presentation to that of his peers. He remembered fumbling his words while holding his skull at the front of the room, while others had plaster casts of their fossils to pass around and well-rehearsed presentations accompanied by lantern slides (1982). This embarrassing meeting with his original critics, as well as the rejection of his book for printing, likely hurt Dart's pride (Falk, 2011). Although he continued to wholeheartedly believe in his original claims, he stopped actively searching for anthropological answers and instead dedicated his time to teaching and improving the Faculty of Medicine at the University of Witwatersrand (Dart, 1982). Until 1945, Dart faded into the background of the scientific community.

The Truth Prevails

The only major supporter of Raymond Dart during this time was Dr. Robert Broom, who continued to search for fossils and piece together the story of *Australopithecine* in Dart's absence. From 1936 to 1938, Dr. Broom found and classified two species closely related to the Taung child: *Australopithecus transvaalensis* and *Australopithecus robustus*, which were the first mature specimens of the Taung Child's proposed genus (Figure 5.29). The *Australopithecus transvaalensis* skull was later reclassified as *Australopithecus africanus*. This refuted the Piltdown Committee's criticism that the juvenile Taung skull simply resembled

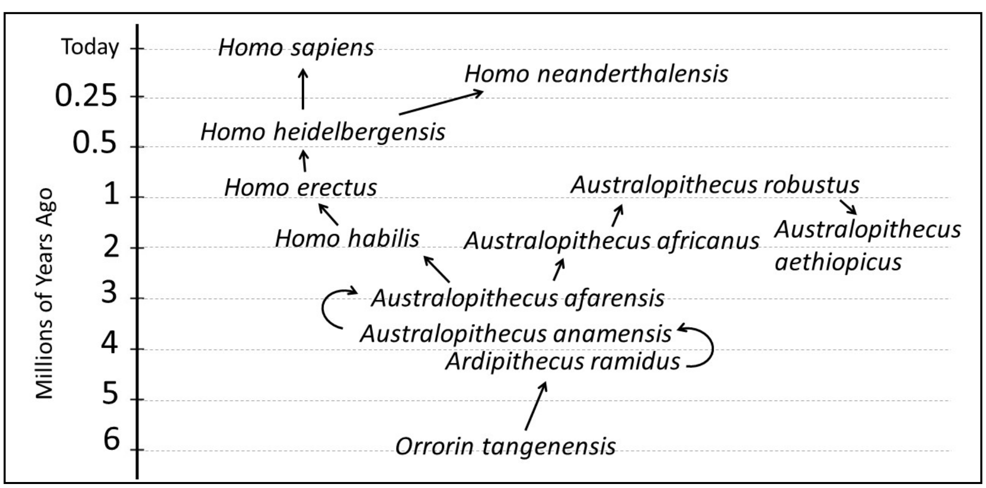


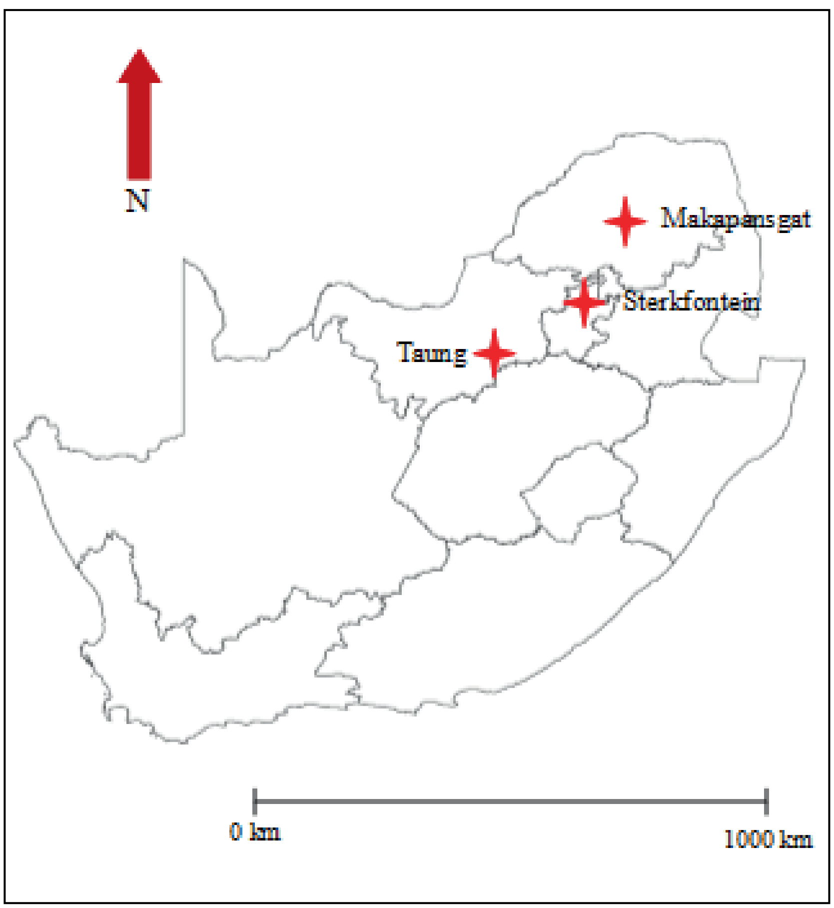
Figure 5.29. Modern depiction of hominid evolution. Note the evolutionary location of A. africanus *and* A. robustus.

humans because it was an infant. Still, many scientists worldwide scoffed at the claims, unable to reconcile the idea that man emerged in South Africa with the more Eurocentric understanding of the period (Tattersall, 2009). Undeterred, Dr. Broom continued to persevere, and he slowly gained greater recognition for his work.

In 1938 William K. Gregory, a very influential paleontologist and comparative anatomist from the American Museum of Natural History, travelled to South Africa to examine the fossils. Although he had originally rejected Dart's research, his in-person examination of the fossils led him to change his opinion. In a meeting of the Associated Scientific and Technical Societies of South Africa that year, he stated that "The whole world is indebted to these two men [Broom and Dart] for their discoveries, which have reached the climax of more than a century of research on that one great problem, the origin and the physical structure of man" (Tattersall, 2009).

In 1945, after years of refusing to aid in any research related to *Australopithecine*, a student convinced Raymond Dart to examine a new site called Makapansgat (Figure 5.30), from which researchers had found a 'baboon' skull that too closely resembled the Taung Child skull to be ignored (Falk, 2011). Twenty years after his initial publication in *Nature*, Dr. Raymond Dart picked up his chisel and hammer and re-entered the field of anthropological research. He was right to do so. In 1947, the researchers found fossil evidence of a new species, and named it *Australopithecus prometheus*. The structure of the pelvis made it clear that the species walked fully upright, and the morphology of the teeth was too similar to humans to deny that humans were descended from the genus (Dart, 1982). Although there remained sceptics, more proof was mounting in support of *Australopithecine* as a 'missing link' between humans and apes, and shifting the origin of man to Africa.

Figure 5.30. Map of South Africa with the three main locations where Australopithecus *fossils have*



Today's Understanding

Further discoveries continued to corroborate Dart and Broom's claims. As these discoveries were being published, Sir Arthur Keith (an original critic of Dart's in the seminal response to his publication in *Nature* in 1925) wrote "I am now convinced of the evidence submitted by Dr. Robert Broom that Professor Dart was right and I was wrong." (Keith, 1947). In fact, Keith was wrong about more than just the Taung Child. In 1953 new dating techniques determined that the Piltdown man was, in fact, a group of modern skull fragments that were manipulated to influence scientific opinion to place the origin of man in Europe (Natural History Museum, 2018).

The continued discovery of *Australopithecine* fossils in South and Central Africa has resulted in a fairly universal belief that the *Australopithecine* are a missing genus connecting humans to their anthropoid ancestors. Dart faced many obstacles due to the paleopolitical climate of the early 1900s, as well as his own pride. However, the perseverance of his peers and the shift from reputation- to evidence-based science allowed the current understanding of human origins to develop. The story of Dr. Raymond Dart teaches us that today's knowledge of the history of the Earth is only the *most* correct answer, and not necessarily *the* correct answer. Only an open-mindedness to new discoveries will allow us to get closer to an understanding of human origins.

Foodprints: Stable Isotope Analysis of Fossilized Enamel

Figure 5.31 Fossilized Australopithecus africanus *tooth (above). Dart could only have looked at the tooth morphologically. Today, we can chemically analyze it to gain more information.*

The study of teeth as an indicator of an organism's diet, habits, and taxonomic group is not a new paleontological concept. In Raymond Dart's time, teeth were used to determine whether a new archaeological find was a contender to be a human ancestor. However, scientists of the time were limited by the lack of technology that existed. They could only gain information from the teeth by comparing their morphology to that of extant animals and other fossils. Modern technology has allowed anthropologists to go beyond morphological analysis by investigating the chemical composition of fossilized enamel from these teeth.

Teeth have many characteristics that make them ideal for the study of ancient humans. Since they are the hardest structures in an organism, they are also some of the best-preserved (Ross, 2016) (Figure 5.31). This allows researchers to obtain the earliest information possible. One of the most important pieces of information we can gain from these structures is the diet of the individual. Diet gives researchers valuable information about the organism's habitat, age, and lifestyle.

LA-GC-IRMS

The development and application of modern technology has allowed scientists to analyze teeth from new perspectives. One such novel technology is laser ablation-gas chromatography-stable isotope ratio mass spectrometry, or LA-GC-IRMS. This technology is currently the most effective method of analysing isotopic composition of oxygen and carbon in modern and fossilized tooth enamel (Leichliter et al., 2017). In this procedure, the tooth is placed in a glass chamber with helium gas and subjected to short bursts of low-level radiation, causing the tooth enamel to outgas carbon dioxide. The CO_2 from these ablation events is then passed through a gas chromatography column and mass spectrometer to determine the molecular masses of the atoms in the CO_2 molecules (Passey and Cerling, 2006). The molecular masses determine the proportion of the ^{13}C isotope relative to the more abundant ^{12}C in the tooth enamel.

Next, the $^{12}C/^{13}C$ ratios are compared to modern analogue values. This allows paleontologists to determine whether the organism had a diet consisting of primarily C3 or C4 plants. C3 organisms, such as fruits and leafy plants, are more commonly found in forests and have a very low affinity for the slightly heavier ^{13}C isotope. C4 plants such as grasses and sedges are comparatively more abundant in the ^{13}C isotope and are common in arid environments such as savannahs (O'Leary, 1988). Therefore, if the tooth enamel has a comparatively high ^{13}C ratio, the organism likely lived in arid environments and ate C4 plants such as grasses and sedges. These ratios can give insight into the habitat of the organism and factors that influenced its evolutionary progression.

Application to *Australopithecine*

This carbon ratio technique was used to gather more information about the diet and lifestyle of Lucy, the first almost entirely preserved Australopithecus skeleton (Ross, 2016) (Figure 5.32). Carbon ratio analysis of her teeth determined that she had a fairly high proportion of ^{13}C, meaning her diet consisted primarily of C4 plants. This indicates that hominins had switched from forest to savannah foods by Lucy's time, around 3.5 million years ago (Smithsonian National Museum of Natural History, 2016). It is currently estimated that African forests began to diminish 10 million years ago due to increasing global temperatures. Therefore, we can infer that the alteration of the hominid diet was caused by a change in environment (Joyce, 2013).

Figure 5.32 Artist's rendition of Lucy, Australopithecus afarensis. *Based on fossil evidence, it is likely she would be found in an arid savannah environment such as is pictured.*

Conclusion

The development of new isotopic ratio analysis techniques has resulted in a more detailed understanding of human evolution. Through tooth analysis, scientists can begin to gain a more comprehensive view of prehistoric life.

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