THE *IGUANADON* AND THE ORDER DINOSAURIA: EXTINCT, BUT EVOLVING TERRIBLE LIZARDS

By

SHEILA HILL

B.A. (1985), B.Sc. (1986) The University of British Columbia

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Department of Inter Disciplinary Studies

The University of British Columbia
Vancouver, Canada

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Abstract

Reconstructions of the Iguanodon are an excellent subject upon which to base a study of the relationship between scientific theory and physical evidence. Several fossilized Iguanodon bones were introduced into science, as it then existed, beginning in the early 1820s.

These new fossil-remains were interpreted in 1841 by Richard Owen, the pre-eminent British comparative anatomist of his day, when he presented his "Report on British Fossil Reptiles" paper to the British Association for the Advancement of Science. In this paper, he reconstructed the Iguanodon and created the Order Dinosauria.

Owen's creation of the Iguanodon, the Order Dinosauria, and his subsequent three-dimensional Iguanodon reconstructions of the late 1840s and 1850s can be viewed through a Kuhnian lens as one element of a battle between two clashing scientific paradigms. Owen created the Order Dinosauria and the Iguanodon with encouragement of influential, conservative members of the scientific establishment to support their theory of Divine Creation and to discredit the materialistic theories of evolution being imported into England from Europe.

Owen used his 1841 general review of terrestrial British fossil reptiles to argue against the continuous progressive development of the transmutatory (evolutionary) theories of the period. To overcome what the natural historians of his time believed was a regularity of the progress in fossil record, in which the age of fishes gave way into the age of reptiles which eventually progressed into the mammalian age, Owen employed the extremely limited fossil evidence as a basis for his creation of the Order Dinosauria and his reconstruction of the Iguanodon to establish that dinosaurs were superior to modern reptiles as dinosaurs were rich in mammalian features, from their pachyderm-like posture to active, warm-blooded lifestyles. In contrast, modern reptiles were small, cold-blooded and far removed from the apex of creation. If this was evolution, in was retrograde, and not progressive -- exactly as the Divine Creator could have planned in anticipation of his most glorious creation, man.

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The form of a representation cannot be divorced from its purpose and the requirements of the society in which the given visual language gains currency.

E.H. Gombrich

Chapter 1 : Introduction

The influence of evolving biological theory and a developing fossil record on early nineteenth century reconstructions of the *Iguanodon* in museums, expositions and paintings.

The *Iguanodon* was one of the first dinosaurs discovered in nineteenth century Britain. Scientists of the period made presentations to professional associations and learned societies, and wrote articles for academic journals about the newly excavated fossils. They also worked in partnership with artists to create paintings, frontispieces of popular and scientific books, and other versions of "ink dinosaurs" on paper. These artistic and scientific collaborations grew to include giant, three-dimensional dinosaur reconstructions made of stone, brick, wire and plaster for displays at expositions. *Iguanodon* reconstructions have slithered, crawled and lumbered on four legs, and hopped and raced on two hind legs as paleontologists' interpretations evolved. The *Iguanodon* is an excellent subject upon which to base a study of the relationship between scientific theory and evidence. Several fossilized *Iguanodon* bones were introduced into science, as science existed in the 1820s, by a British amateur paleontologist, Gideon Mantell. These few fossil-remains were interpreted according to the then current theory and practice of natural history. With little additional fossil evidence, several subsequent *Iguanodon* reconstructions show the extinct animal metamorphosing from Mantell's crocodilian reptile into creatures endowed with advanced mammalian features, including a rhinoceros-like pachyderm and a misshapen kangaroo. As natural history theories developed and the known fossil record grew, reconstructions of the *Iguanodon* continued to evolve.

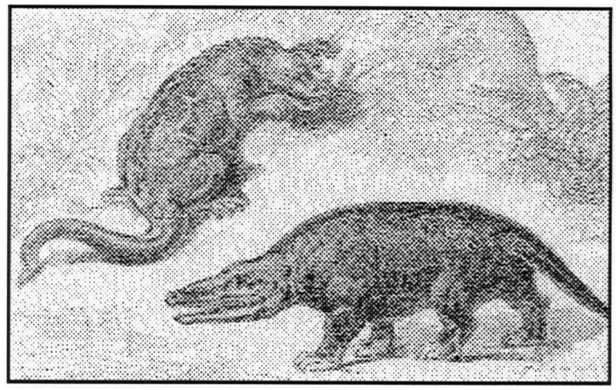

Figure 1: An 1838 reconstructions of *Iguanodon* (left) and *Megalosaurus* (right) closely resemble the reptiles they were modeled after.

The changes imposed upon *Iguanodon* reconstructions are obvious and visible, but the motivations that inspired scientists to implement them are not. An investigation showing how scientists reconstructed the *Iguanodon* may provide an improved understanding of the role theory plays in the interpretation of newly discovered evidence. This paper will examine how and why several British paleontologists transformed the shape of *Iguanodon* reconstructions from one physical form into another.

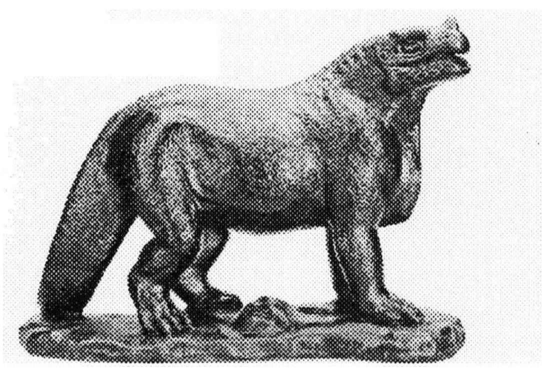

Figure 2: A model of Benjamin Waterhouse Hawkin's *Iguanodon,* created in collaboration with

Dr. Gideon Mantell's discovery and early reconstruction of the *Iguanodon* will be examined and contrasted with Richard Owen's subsequent efforts, including the latter's creation of the Order Dinosauria in 1841. (The Order Dinosauria is no longer used by scientists. In 1887, Harry Grovier Seely separated these animals into two separate categories based on their pelvic structures. Members of the Order Saurischia are "reptile-hipped" and members of the Order Ornithischia are "bird-hipped" (Norman: 1991; 56).) Owen's work is then reviewed through the comments, observations and work of Thomas Henry Huxley, best known as Darwin's Bulldog.

The creation of the *Iguanodon* and the Order Dinosauria can be viewed through a Kuhnian lens as one element of a battle between two clashing scientific paradigms. In his book, *Structures of Scientific Revolutions* (1962), Thomas Kuhn states that science is not merely the patient accumulation of facts; the facts must also be interpreted. The theoretical framework used to impose meaning on the raw data represents a conceptual pattern, a paradigm, that becomes deeply ingrained in the practices and thought processes of the scientific community. A new scientific theory represents a dramatic shift in the way people view the world and how they approach scientific questions. The introduction of a new theory requires the replacement of the old paradigm. The new paradigm rests on conceptual foundations that are incompatible with those previously taken for granted.

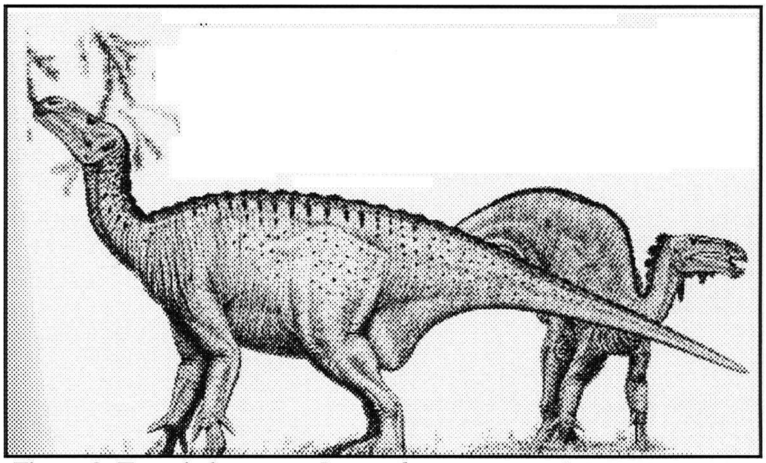
Figure 3: Twentieth century *Iguanodon reconstruction.*

From a Kuhnian perspective, the developments leading up to and including the *Iguanodon* reconstructions could be interpreted in the context of proponents of two scientific paradigms battling each other to obtain victory for their favoured theories. In this scenario, Owen created his dinosaurs to discredit the materialistic theories of evolution being imported into England from Europe. His *Iguanodon* reconstructions and his dinosaurian classification schema can be seen as a presentation of scientific evidence that supports one paradigm while serving to undermine another. Brief histories and descriptions of the predominant theories in the fields of natural history and geology of this period will be given as background in parts of chapters two and three to determine where Owen stood in the dispute between the supporters of conflicting theories and to what ends he may have employed his evidence.

Much of the discussion, debate and scientific activity that is associated with the introduction of evolutionary theory took place in the 1830s and 1840s and not in the 1860s and 1870s as has been previously supposed (Rupke: 1994; 221). The introduction of the evolutionary theory of Charles Darwin and Alfred Russell Wallace in 1859 intensified and popularized this debate. Lamarck, and other natural historians before him, had suggested various theories of evolutionary change. Charles Darwin was to make a materialist interpretation of evolution respectable in the middle of the century by supporting it with great quantities of biological evidence, but despaired at the lack of fossil evidence available to support his theory (1859; 291-343).

Most nineteenth century scientists were not opposed to the idea of change in species over time; they were opposed to the materialistic Lamarckian theory of evolution that removed God from His role of the Divine Planner or Creator. These natural historians and theologians had a variety of existing evolutionary theories to choose from, many compatible with their religious beliefs: theistic evolution (guided and executed by God), orthogenetic evolution (where the evolutionary path of an organism is directed by God or some driving internal force along a single path), or mutational evolution (where organisms mutate from one form into another). To further complicate the issue, there was a great deal of overlap among these theories; it was not uncommon for a scientist to pick and choose various elements from several of them.

In addition to picking their way through a smorgasbord of not entirely compatible evolutionary theories, natural historians also had to select a mechanism to explain the process of change in the fossil record. They had to determine whether: (1) the evolutionary process is controlled by external environmental factors or by forces within the organisms themselves, or both, (2) evolution is a gradual, continuous process or a catastrophic, discontinuous one, and (3) evolution is a process directed by God, or is in some way teleological.

Natural historians and paleontologists were forced to interpret the new fossil evidence in one of several ways: (1) to incorporate the evidence (or lack thereof) into their theories without altering the theory, (2) to modify their theories to make them consistent with the then available evidence, (3) to change theories, or (4) to dispute or ignore the evidence, or cite a lack it.

The scientific merits of the *Iguanodon* reconstructions and the theory used to justify each will be examined. Although fossils do have an objective existence, the human interpretation implicit in the discovery, analysis and description of each paleontological find has always affected our understanding of the fossil record. The fossil record of dinosaurs has now attained a sufficient level of maturity to provide a solid, scientific foundation for an historic case study that investigates the factors which influence a particular interpretation of the fossil record (Dodson and Dodson: 1992; 3). Our current understanding of the fossil record is based on evolving interpretation of the data and a more comprehensive fossil record. The present understanding of the diversity, life and death of extinct species, such as the *Iguanodon*, is the result of a continuing historical interpretation of the fossil record.

The *Iguanodon* was brought to the attention of the early nineteenth century scientific community at a time when knowledge of the fossil record was extremely limited and evolution through the mechanism of natural selection unknown. Known fossils ranged from extinct dinosaur species such as the *Iguanodon* to marine species discovered hundreds of metres above sea level. This evidence influenced the development of biological theory and suggested to scientists studying the fossils that the earth had changed over time.

The interpretation and development of paleontological theories and reconstructions will also be reviewed in the context of the wider social concerns of this period. The study of the sociological and creative aspects of the restoration of the *Iguanodon* and erection of the Order Dinosauria will not eclipse the examination of the scientific issues at hand. There is an inherent difficulty studying nineteenth century natural history (also called natural theology) as what we define as science today is not a view that would have been shared by the natural philosophers of the early to middle 1800s. Natural history was not independent of social factors including religion, and to ignore the influence of these factors on the natural historians of this period would be imposing current values upon historical events and figures of the past.

The interpretation, development and defense of scientific theories are affected by factors other than physical evidence. The creative aspect of building new theories is one portal through which ideological and cultural influences can enter the process. Scientists, including Mantell, Owen and Huxley, may have been influenced by politics, religion, class, race, or other aspects of their culture and may have imported these views into their theories. In the nineteenth century, it was widely believed that nature is a providential order and hence a good template for social order. Biological theories were not supported, resisted, or rejected solely on the basis of what could be observed, deduced or induced about nature, but also according to their potential social implications and meanings. The correct understanding of the natural order of the world, including the history of the earth's flora and fauna, was believed to be vitally important as this understanding should then be applied to human society. The reconstruction of the *Iguanodon* and the creation of the Order Dinosauria will be studied to determine whether, or how, the broader social concerns of the culture in which nineteenth century scientists lived guided their work.

The various reconstructions of the *Iguanodon* reflect changes in natural history theories and the growing base of fossil evidence. A brief outline of the development of nineteenth century natural history will give context for the whiplash-like contortions of *Iguanodon* reconstructions. In Chapter 2, the discovery of *Iguanodon* remains by Dr. Gideon Mantell will be described. A survey of the then current knowledge in the field of natural history upon which Mantell based the analysis of his finds and reconstructed the long extinct animal will be also be conducted. In Chapter 3, a narrative further describing early nineteenth century paleontology to the time of the British professional comparative anatomist, Richard Owen, will be outlined. The theoretical foundations which served as the basis of Owen's *Iguanodon* reconstruction and his creation of the Order Dinosauria will be outlined in this chapter. In the Chapter 4, the evidence available to Owen will be discussed. In Chapter 5, Owen's creation of the Order Dinosauria and *Iguanodon* will be critically examined in context of an evolving biological theory and the growing evidence supplied by an increasingly revealed fossil record. The ethical, moral, and other social concerns which may have helped to shape paleontological thought and action in the late nineteenth century will be also be taken into account. Chapter 6 contains a brief conclusion.

Every great scientific truth goes through three stages. First, people say it conflicts with the Bible. Next they say it had been discovered before. Lastly, they say they always believed it.

Louis Agassiz, Zoologist

Chapter 2: Gideon's World

How Gideon Mantell's discovery of the *Iguanodon* was interpreted by natural historians of the early nineteenth century.

Fossil hunting was very popular in England at the turn of the nineteenth century as amateurs and scientists alike searched for the remains of prehistoric plants and animals. *Iguanodon* teeth discovered in Sussex and on the Isle of Wight may have been among the century's new paleontological finds as early as 1808 (Lessem and Glut: 1993; 226). Other bones unearthed in 1809 in Cuckfield, Sussex were recently re-discovered in the collection of the British Museum and identified as *Iguanodon* fossils (Wilford: 1985; 38).

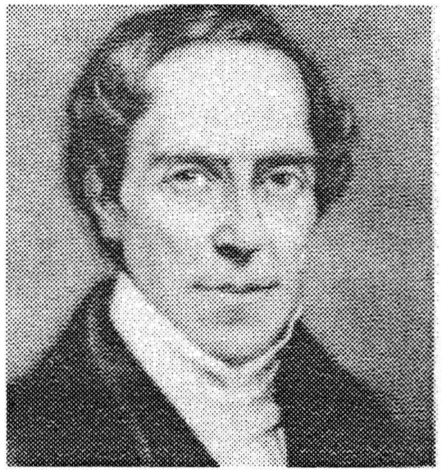

Figure 4: Gideon Mantell.

The credit for the discovery of the *Iguanodon* is generally awarded to Gideon Mantell, an English doctor and amateur fossil collector. Mantell had taken an interest in the Stonesfield Quarries near Cuckfield as early as 1818 and had hired a quarryman named Leney to send him unusual fossil specimens. In 1819, Leney's shipments to Mantell included many mystifying teeth and bones which Mantell believed to have belonged to several large reptiles. Other bones were also delivered to Mantell that year and in 1821 (Wilford: 1985; 30).

In 1822, when Mantell wrote his book, *The Fossils of the South Downs,* he possessed at least six *Iguanodon* teeth and many bone fragments. Mantell wrote that "(t)he teeth, vertebrae bones, and other remains of an animal of the lizard tribe, of enormous magnitude, are perhaps the most interesting fossils that have been discovered in the county of Sussex" (Mantell: 1822; 48). He noted that these animals somewhat resembled existing crocodiles, though they differed "in many important particulars from the recent species" (Mantell: 1822; 48). Whatever they were, these animals had been gigantic. Mantell remarked that they exceeded in magnitude "every animal of the lizard tribe hitherto discovered either in a recent or fossil state" (Mantell: 1822; 48).

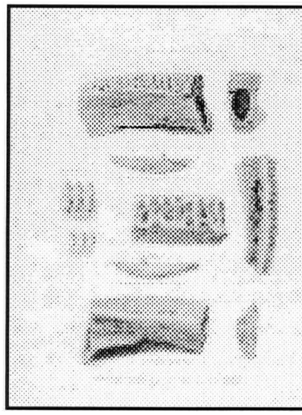

Figure 5: A plate showing Mantell's *Iguanodon* fossil tooth evidence displayed beside iguana teeth.

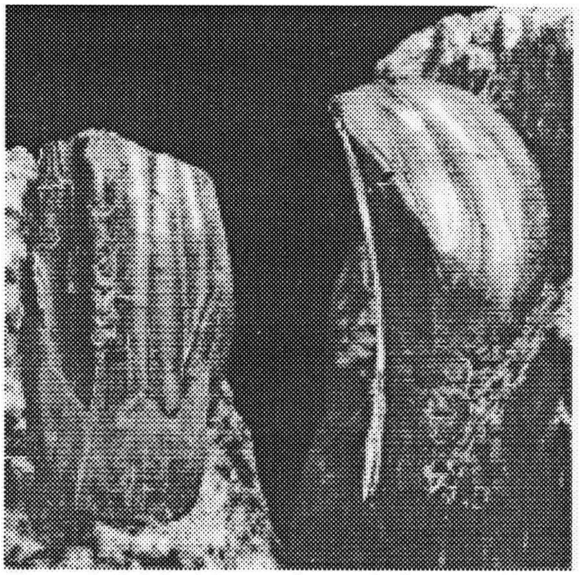

Figure 6: Original *Iguanodon* teeth discovered by Mantell.

Mantell surmised that his fossils had been the teeth of a large herbivore. He noted that the crown of one tooth was worn down into a smooth oblique surface which strongly indicated that it was the tooth of a large plant-eating animal (Desmond: 1975; 15). The tooth reminded Mantell of "the corresponding part of an incisor of a large pachyderm ground down by use" (Mantell: 1822; 52).

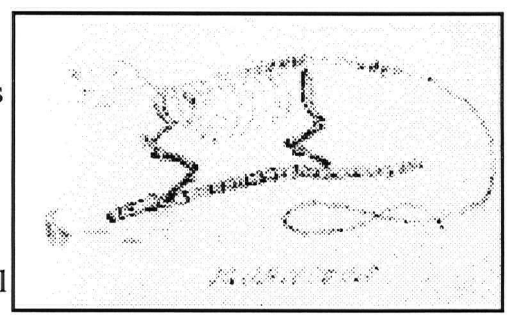

Figure 7: Mantell's illustration of an *Iguanodon* based on his newly discovered fossils.

Mantell, as an informed amateur paleontologist and a professional surgeon, was familiar with the well-established and increasingly sophisticated tradition of European natural history. He based his analysis of the fossil teeth on the science of his day. The interpretation of fossils as the remains of living organisms had become possible only in Europe after the Renaissance when theory changed and the earth gained a history. In the Renaissance, natural history — a system based on Aristotelian science and modified to satisfy Christian requirements — was culturally dominant in western civilization. This divinely created cosmos consisted of a bounded, eternally stable system of revolving celestial spheres with the earth at its centre. The earth was permitted to change and gain a history only after the Aristotelian world, which was static and without the directional change that is illustrated by the fossil record, had been dismembered.

Post-Renaissance European philosophers and naturalists began increasingly to mull over the nature and significance of an increasingly well-developed fossil record and came to believe that the petrified forms represented previously existing animals and plants (Ronan: 1982; 312). Without an awareness of the biological origins of fossils, there had been no comprehension that fossils supplied evidence of the history of life; this discovery created a paleontological herbarium and zoo for natural historians to study.

By the beginning of the eighteenth century a strong tradition of natural theology had developed that included change in the earth and its inhabitants. The study of paleontology had also been encouraged indirectly by the Protestant Reformation which promoted the reading of both God's words and His works (nature). New and improved observational techniques, such as the microscope, made the study of nature possible in new ways and at greater levels of detail. And, with time, abundant and diverse new evidence was presented to the scientists of the day.

The study of geological evidence strongly suggested that the entire earth had undergone massive changes through time. Scientists believed that the history of plants and animals has a pattern or logic, to some extent independent of changing conditions in the habitat or surroundings. Rival theories conceived of change taking place in different ways. Often a limited appreciation of natural change was added to systems in which the earth remained essentially static. Linnaeus's (1707-1778) adherence to the retreating ocean theory is an example of the widespread practice of incorporating new ideas and making adjustments to theories of divine creation.

Another reworking of the divine creation theory involved a progressive development of life that emerged from the temporalization of the ancient concept of the chain-of-being, also known as the Scala Naturae or the Ladder of Perfection (Wilford: 1985; 45). According to this theory, all organisms occupied fixed places in the gradual hierarchy of the chain. The simplest, least complex forms of life were found at the "lower" end of the chain. The "higher" more complex organisms were created later in the history of the earth and would appear later in the fossil record. The chain was designed or "pre-programmed" by the Creator to form a complex web of predator-prey and competitive relationships that upheld the "balance of Nature." The chain itself remained unchanging; it was a predetermined pattern programmed by God. If some links in the chain were empty at the earth's creation, they were planned as such by the Creator and left vacant, to be filled at the appropriate time. It was also inconceivable that a species could become extinct or change its structure as this would leave a gap in the divinely planned "chain-of-being" and tear a hole in the complex web of relationships upon which the balance of Nature rested. *Homo sapiens,* of course, resided at the chain's glorious apex (Bowler: 1976; 2).

The question of how to reconcile the fossil record with contemporary interpretations of the Holy Scripture became critical. The Reformation had encouraged an independent reading of the Bible and natural theologians were seeking ways to reconcile the word of God with the "Book of Nature." The biblical flood (Genesis: 7) became a focus of dispute when physical evidence from nature seemed to conflict with the revealed truth of the Bible. Support for the organic origin of fossils grew, however, as diverse evidence was gathered by Europeans exploring new areas of the globe and also from technological innovations in mining that made more of the earth accessible to fossil collectors.

During the Enlightenment, in the eighteenth century, a Newtonian scientific era began in which a new timescale was created. Newton had eliminated the supernatural from physics when he put forward a mechanical explanation of gravity, which operated invisibly, but predictably, across distances of empty space. The concept of what constituted a "mechanical" explanation became much more sophisticated with this discovery. Animate bodies were not longer merely pieces of clockwork, but instead, could be governed by complex, but physical, forces.

The Newtonian approach displaced the literal and miraculous interpretation of the biblical story of creation with the general understanding that the earth and its inhabitants are ancient and have undergone many significant physical changes through their joint history. The natural history theories of Georges Louis Leclerc (1707-1788), the Comte de Buffon and the director of the Jardin du Roi in Paris, dominated thought in the field of natural history in pre-revolutionary France. In 1749, Buffon confirmed the organic origin of fossils by identifying their stony remains as having once belonged to living organisms. In his *Histoire Naturelle,* which eventually spanned an encyclopedic thirty six volumes, Buffon stated that certain fossils belonged to "animals that once existed and no longer do" (Tassy: 1993; 13).

Buffon's endorsement of the organic origin and extinction of fossilized life forms was compatible with his theory of the earth changing over time. Buffon estimated the earth had taken at least 70,000 years to reach its present stage. He hypothesized that the earth had been created when a globe of molten matter was broken from the sun by a colliding comet. The original molten mass had gradually cooled to its present state over its lifetime. Buffon conducted physical experiments using model globes to determine the age of the earth and arrived at an age of at least 70,000 years, though he suspected that millions of years were required to deposit the layers of the earth's strata (Rudwick: 1972; 94). Buffon believed that this amount of time was necessary and adequate for natural Newtonian mechanisms and laws to perform the tasks of earthly creation and maintenance previously assigned to God. In the same century, Immanuel Kant, writing his *Cosmogony,* assumed that the world was many millions of years in age. The possibility that the history of life exhibits a definite pattern of development over time was raised.

Buffon extended his materialistic programme of change to include life. To explain the origin of life, he resurrected the ancient concept of spontaneous generation according to which living things can be produced directly from non-living matter under propitious conditions. Buffon used spontaneous generation, not evolution from a common ancestor, to explain how the ancestral members of each basic organic type had been formed.

In spite of his materialism and his rejection of biblical creation, Buffon described species as eternally fixed organisms in an unchanging natural order. Buffon believed each type, or species, was eternally distinct from all others. He endorsed the modern definition of a species as a group of animals or plants in which reproduction preserves its form from one generation to the next. He criticized Linnaeus and other taxonomists for describing species merely as elements in the abstract pattern of divine creation with no natural processes, such as reproduction, to sustain them. Buffon also broadened the definition of species when he decided that Linnaeus's genus was in fact a species. In this he was encouraged in this view by reports of breeding between types, or species. Even he admitted that his new "genus-specie" showed very well-marked differences in variety. That he continued the tradition of "fixed species" was surprising given his willingness to create grand, innovative, physical theories, such as his cooling earth theory. His physical theories were much more flexible than his ideas about life and cast his static species into an ever-changing environment.

It was the radical materialists of the Enlightenment who came closest to abandoning the idea of a fixed underlying natural order. Writers such as Denis Diderot (1713-1784) and the Baron d'Holbach (1723-1789) wished to change the then existing social order and used the idea of a changing natural world as a symbol in their fight against orthodoxy — and for a new society. Beginning in the 1750s, they argued that nature exhibits no stable, hierarchical plan — natural developments were open-ended and unpredictable and therefore changes in species (and the social order of society) could occur over time. Diderot was fascinated by monstrosities and invoked Empedocles' vision of the origin of natural forms. According to this theory, a trial-and-error process of spontaneous generation produced many forms of life and those lucky enough to be viable would survive and reproduce. Since it was believed that nature could spontaneously generate even extremely complex living structures, the transmutation of species played only a very restricted role in this theory. While their ideas appear to contain the seeds of evolutionary theory, Diderot and d'Holbach did not suggest a detailed theory of organic change. A theory of continuous natural development would only become plausible once the idea of spontaneous generation was limited to the genesis of only the simplest forms of life. Toward the end of the eighteenth century, this type of theory was beginning to be put forward.

Around the turn of the nineteenth century, questions affecting natural history were being addressed by the leading scientists of the day, Jean Baptiste, the Chevalier de Lamarck, Georges Cuvier and Saint-Hilaire Geoffroy. These continental scientists had a strong influence on their British counterparts including Mantell and Owen as there was constant communication between Paris and London, and also between Paris and Edinburgh — the impact of the materialistic French science was to become particularly strong in the "Athens of the North."

Research conducted by Cuvier and Geoffroy at the Paris Museum d'Histoire Naturelle was guided by Baconian, Newtonian and Linnean ideals as the late eighteenth century understood these three influences. Studies conducted by most natural historians at this institution involved the patient collection of careful observations, the search for the simple laws of nature, and the reduction of that variety into a system of rationally based classification. For the most part the influence of Buffon's grand theories, which had dominated French pre-Revolutionary natural history, waned as Cuvier's detailed studies rose in his peer's estimation.

In the early nineteenth century, during the period when Mantell was attempting to identify the creature to which his fossil teeth had once belonged, Georges Cuvier (1769-1832) was chief of anatomy at the Paris museum. Cuvier was recognized as the leading natural historian of his day by his contemporaries and the next generation of scientists. He created and advanced the field of comparative anatomy while emphasizing the importance of Aristotelian functionality and Newtonian laws.

Figure 8: Georges Cuvier.

He used natural explanations for natural events, and like Buffon before him, rejected supernatural explanations. Unlike Buffon, his methodology included the careful study of evidence and he renounced the formulation of grand theories lacking carefully arranged arguments supported by facts. To Cuvier, organisms could be explained in natural terms as all parts of the organism were integrated to produce a functional whole and expressed the "irreducible character of living things." Cuvier's work seemed to justify his hope that anatomy would soon be expressed in terms of Newtonian laws and harmony.

With the publication of Cuvier's *Discours sur les revolutions de la surface du globe et sur les changements qu'elles on produits dans le regne animal,* the approach to the study of fossils took on a definitively modern turn by changing the focus from final to efficient causes. Previously, the question asked had been "why?" Cuvier shifted his attention to the Newtonian question of "how?" The issue of the origin of species and the ensuing study of evolutionary theory were not studied in Cuvier's time as he believed this area of theory to be untestable and therefore outside the realm of science, a view supported by him as there was no evidence or information available to consult on how species had originated. For Cuvier, the implicit concerns that lay behind the questions of natural history were no longer those of natural theology but those of modern science. Cuvier's science also excluded the grand inductive theories of life, such as Buffon and the evolutionary theory of Lamarck.

Cuvier's recent reconstruction of extinct animals in the Paris area and his establishment of the field of comparative anatomy made him the most experienced and knowledgeable authority to whom Mantell could turn for assistance in identifying the newly discovered fossils. Cuvier had formulated two "rational principles" to guide his research in this area. The first principle was the correlation of parts where the interdependence of each of the body's organs was manifested anatomically. According to Cuvier, his method consisted of considering, like a good

Aristotelian, that "every organized being forms an assemblage, a single, closed system, whose parts mutually correspond and participate in the same definitive action by means of a reciprocal reaction. None of these parts can change unless the others also change; and consequently each of them taken separately, indicates and yields all the others" (Tassy: 1993; 17). Cuvier stated, for example, if an animal's intestines can only digest meat, "its jaws must be constructed to devour prey, its claws to seize and tear it, its teeth to cut and divide it; and the entire system of its organs of movement to pursue and capture it . . ." (Tassy: 1993; 17).

The correlation of parts became a heuristic principle with predictive value when applied to fossils. This principle indicated which bones had belonged to which type of animal in a mixed collection. In Cuvier's view, his principle had the supreme virtue of being rational. In practice, the functional significance of many anatomical correlations was unknown and he was frequently forced to rely on empirical observations that certain features were generally associated in a certain group of animals. The success Cuvier experienced from his predictive principles rested more on his extremely wide knowledge of living animals than on the principle of functional coordination.

Cuvier's second principle of comparative anatomy tried to reduce the variety of anatomical organization to a rational order. It was based on the subordination of characters. With this principle, Cuvier also appears to have relied more upon his vast knowledge rather than his newly described principle, as others who tried to apply his principle met with less success.

Cuvier's famous restorations of beasts from past epochs were based on the above two principles of comparative anatomy, then, as well as his wide experience. Whether true or not, Cuvier gained the reputation of being able to reconstruct an entire animal from a single bone. His research established conclusively that in the relatively recent past the earth had been inhabited by animals that were no longer alive. The resurrection of such a spectacular zoo of species of elephant, hippopotamus, rhinoceros, armadillo, deer, and cattle brought him fame throughout the world of science. Cuvier also identified the first of the huge Mesozoic fossil creatures discovered, the *Mosasaur,* as a giant lizard and indicated that these animals were evidence of a past catastrophe that rendered them extinct. Unlike the terrestrial monitor lizards, the *Mosasaur* was adapted to a marine, fish-eating existence, complete with fins and a strong tail for propulsion (Desmond: 1975; 13). His assessment of the *Mosasaur* as a "higher" more complex animal enormously influenced early paleontologists. When the first dinosaur bones were quarried, they were assumed to have once belonged to gigantic lizards similar to Cuvier's fossil creature.

In 1796, Cuvier presented a paper, "On the species of living and fossil elephants." This was the first occasion in which detailed and almost irrefutable evidence of extinction was presented. There were at that time three alternative theoretical explanations for the missing fauna: extinction, evolution, or migration. Cuvier recognized that the question of extinction would not be resolved decisively except by using large terrestrial quadrupeds as evidence. He used the fossil elephant or "mammoth" found in both Siberia and northern Europe, as his prime example. He first determined that it was distinct from either of the living species of Asian or African elephant. He then determined that it could not be found living. Although much of the interior of Africa and South America remained unexplored by Europeans, it was becoming less likely that any large new mammals would be discovered alive. Migration, the third theoretical explanation, was not considered possible for larger terrestrial quadrupeds, but could not be ruled out for marine animals. Cuvier decided that the fossil mammoth was therefore, extinct.

Cuvier's rejection of evolution was primarily a defense of extinction, not of special creation. (The exclusive choice between extinction and evolution may appear to be surprising from a post-Darwinian viewpoint, as today extinction is regarded as an effect of which evolution is the cause.) Extinction as a general phenomenon in the history of life, and the attempt to find a satisfactory explanation for it, dominated paleontological discussion for the next two decades. Cuvier believed that his extinct fossilized menageries of over 90 species were evidence of a succession of closed biological worlds, completely separated from one another by sudden and destructive events, "revolutions" or "catastrophes." In Cuvier's view, it would have taken a sudden and drastic event to overwhelm a successful species so completely. The biblical flood appears in this scenario only as the last catastrophe in a long series of events of the same type.

Cuvier was not the first to form a theory of "catastrophism" punctuated with periodic "revolutions." The meaning of the theory and the term "revolution" changed with time, however. Earlier, when naturalists such as Buffon spoke of revolutions, they spoke of Newtonian revolutions in the manner of planets revolving around the sun and not in terms of the abrupt political upheavals that later became associated with the word. Cuvier lived in the turbulent period of the French Revolution and he used the word in this new way, with its implications of sudden violence.

Cuvier and his colleague, Alexandre Brongniart (1770-1847), suggested a mechanism for these violent, earthly revolutions. It seemed hardly conceivable at the time that mountain building, with all of the contortions of strata involved, could have occurred by a gradual process. Brongniart, in fact, had already suggested a workable mechanism to explain how the Alps had been formed into mountains in relatively recent times, geologically speaking. His mechanism for mountain building and terrestrial revolutions in general was an abrupt and sudden release of the internal stresses in the earth's crust which caused the discontinuous and profound effects seen both the Alps and in the paleontological record. (Today the theory of continental drift is used to explain the formation of mountain ranges. It is believed that mountain building occurs as different continental plates collide.) One of Cuvier's pupils, Leonce Elie de Beaumont

(1798-1874) was later to establish that mountain-building episodes had occurred at many different periods of the earth's history. It was then inferred that these episodes of mountain-building appeared to coincide with the major faunal discontinuities between formations.

By 1806, Cuvier had linked fossil evidence and the geological record together to support and refine his theory of earthly revolutions. He drew evidence directly from the Paris-area fossil record to support his hypothesis that prolonged, local, marine incursions were responsible for the revolutionary changes in fauna. Because the fossils were made up of mammoth bones with oysters and other marine organisms attached to them, it was assumed that the terrestrial bones had been submerged under sea-water for an extended period. These fossil-bearing gravels were limited to low-lying areas and the bones were well preserved, showing little abrasion. From this, Cuvier inferred that they had not been transported from another location and that they were the remains of animals that had lived and died near where they were found. This conclusion was justified methodologically and explained earthly revolutions by way of the Newtonian system of unchanging natural laws. The revealed history of the Bible was rejected as the fossil evidence indicated that a prolonged, local flood occurred in the area rather than the brief violent and global deluge described in Genesis.

The task now became one of tying the fossil record to the geological record and both of these to time. It was already known that successive formations could be broadly characterized by their fossil contents; different strata were characterized by different species of invertebrate fossils. This had already been documented in the monograph of the German scientist, Freiesleben, on the stratigraphy of Thuringia and in the canal work of the British civil engineer William Smith (1769-1839). Cuvier and Brongniart provided further evidence that fossils could characterize a whole formation of strata.

A new concept of the history of life emerged from an attempt to link geology, paleontology and time. The biological world appeared to have been both punctuated by revolutions and changed in a progressive way over time. Cuvier, however, had arranged the animal kingdom into four major "branches" which made the arrangement of a single chain-of-being, or simple progressive order, impossible. Animals within a branch could be placed in an order that reflected some kind of scale from less to greater complexity, but Cuvier did not encourage this. In terms of time, Cuvier posited an age of "some thousands of centuries" for the fossil-bearing strata around Paris, which was as much as he could infer from the data.

Mantell's education included a grounding in the developments of the history of the field of natural theology, also called natural history. He, in particular, was aware of the recent work of Cuvier and tried to base his analysis of his fossil teeth on Cuvier's comparative anatomy and stratigraphical work. The apparent age of Mantell's fossil tooth seemed to rule out a mammalian connection as Cuvier had shown that the remains of extinct elephants and other prehistoric mammals were found only in the upper strata of relatively recent time, not in the more ancient strata from which Mantell believed his fossils came.

The discovery of the fossil tooth in an ancient stratum appeared to link it more closely in time to Cuvier's marine *Mosasaur* reptile. Mantell's thoughts about the origins of the animal, therefore, turned to ancient reptiles (Wilford: 1985; 31). However, a characteristic of modern reptiles frustrated him in this line of thinking. "As no known existing reptiles are capable of masticating their food," Mantell said, "I could not venture to assign the tooth in question to a saurian" (Mantell: 1822; 48).

Some of the difficulties that Mantell encountered when trying to have his fossils identified stemmed from the incompleteness of his specimens. Unlike earlier vertebrate reconstructions by

Cuvier, Mantell's discovery was not known from an almost complete specimen, nor had its skeleton been pieced together, like Cuvier's Montmartre mammals, by painstaking anatomical study of abundant scattered bones. Mantell's *Iguanodon* was known only from a small number of fragments: several teeth, a femur, a few vertebrae and fragments of rib, and a curious conical bone that Mantell inferred to be a kind of horn on the nose of the animal (Rudwick: 1992; 76).

To clear up any confusion about the derivation of his *Iguanodon* fossils, Mantell consulted the leaders in comparative anatomy and paleontology of the period. Mantell took the tooth and other specimens to a meeting of the Geological Society of London. There several scientists dismissed the fossils as rather uninteresting remains of a large fish related to the wolf-fish, *Anarhicas lupus,* or as some mammalian teeth. Only the chemist, William Wollaston, supported the idea that the fossils came from an unknown herbivorous reptile and encouraged Mantell to pursue his investigation (Delair and Sarjeant: 1975; 14).

When Georges Cuvier was consulted for assistance in identifying Mantell's fossil in 1823, he held three of France's most prestigious scientific positions: professor of natural history at the College de France, professor of comparative anatomy at the Jardin des Plantes, and secretary of the Academy of Sciences. Both Cuvier and his English colleague, William Buckland, the leading scientist in Britain, professor of mineralogy and geology at Oxford and president of the Geological Society, speculated that the teeth were from a rhinoceros or a fish. Mantell sent Cuvier several more bones. Cuvier identified these as belonging to a species of hippopotamus (Wilford: 1985; 32).

In spite of Cuvier's impressive credentials, his identification of the fossil tooth and bones did not satisfy Mantell who continued to research the origin of the fossils. Subsequently, on a research-related visit to the Hunterian Museum in London, Mantell encountered Samuel Stutchbury, who had been conducting research on iguanas. After a close examination, Mantell's fossils appeared to both men to resemble the teeth of the Central American lizard (Wilford: 1985; 33). This evidence convinced Mantell that the teeth were reptilian. He published a paper about the *Iguanodon* fossil teeth in 1825 and described them as belonging to an extinct lizard related to the living iguana, a lizard a few feet in length (Lessem and Glut: 1993; 227). At the suggestion of Conybeare, Mantell named the fossil reptile *Iguanodon*, meaning "iguana tooth" (Wilford: 1985; 33).

When Cuvier was informed of Mantell's latest iguana-tooth discovery, he acknowledged his previous errors and offered some new reflections on the long extinct animal's eating habits. Cuvier observed that all of the largest modern terrestrial animals are herbivores, so it seemed reasonable that the largest of the ancient reptiles were "nourished on vegetables." Later dinosaur discoveries have supported Cuvier's suppositions (Wilford: 1985, 34). To put the paleontological diagnoses of Cuvier and Buckland into context, the currently accepted idea that these fossils belonged to giant herbivorous reptiles was a novel concept in the early 1800s; giant herbivorous reptiles were completely unknown in this period (Delair and Sarjeant: 1975; 14).

The lizard-like status of Cuvier's *Mosasaur* made lizards the standard according to which the extinct saurians were reconstructed (Desmond: 1975; 16). Thigh bones, teeth or other various body parts of extinct saurians and contemporary lizards were measured. The total size of the extinct animals was then extrapolated by calculating how many times larger saurian parts were than lizard ones. The fossil bones, especially the limb bones, were frequently fifteen or twenty times longer than those of a lizard. This led to fabulous dimensions for the extinct saurians (Desmond: 1975; 18). Since the fossil teeth were far larger than the living iguana's, Mantell simply scaled the iguana up into a terrestrial lizard of gigantic size (Rudwick: 1992; 76). If an iguana had teeth this size, he speculated, the entire animal would be enormous, some 18 metres long.

Mantell's vision of the *Iguanodon* can best be comprehended by viewing the cover of his book, the *Wonders of Geology* (1838), which was decorated by the artist John Martin's engraving of the *Iguanodon* in violent combat with other fossil lizards, despite the fact that the *Iguanodon* was described by Mantell as a herbivore.

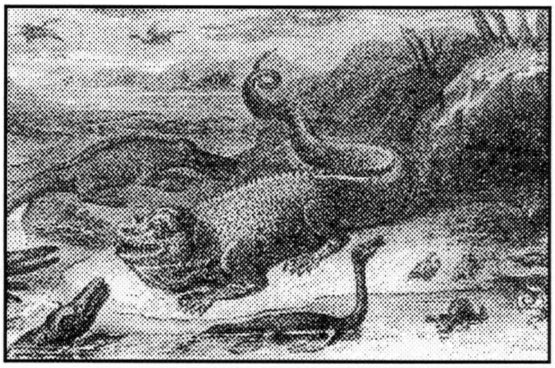

Figure 9: Frontispiece to Mantell's book, *The Wonders of Geology*

Mantell, then, had deciphered the limited fossil clues he had before him and recreated a huge ancient reptile both with the help of, and in defiance of, the explanations of the professional scientists of his time. Through perseverance, by using the most recent discoveries as reference and by applying recently developed practices in comparative anatomy, Mantell reconstructed the extinct *Iguanodon* as an ancient iguana-reptile. He used similarities between his fossil teeth and the structure of living iguana teeth, an earlier developed understanding of the meaning of the ancient strata of the fossil bed in which the fossils were discovered, and Cuvier's reconstruction of the *Mosasaur* as the basis for his reconstruction. Mantell suggested that the *Iguanodon* had walked on four legs, lizard-style and had resembled a scaled-up Central American iguana. Mantell was later found to have misplaced the animal's spiky thumb when he located it on the end of the animal's snout.

The form of Mantell's early nineteenth century *Iguanodon* reconstruction, however, was anything but obvious judging from the various responses of leading authorities of the field to

Mantell's many queries concerning the origins of his bones. Dr. Mantell's paleontological colleagues had not readily accepted his discovery of the first recognized ancient reptile, nevertheless, Mantell created the first "dinosaur" without so naming it.

Facts are not science — as the dictionary is not literature.

Martin Fisher

Chapter 3: Owen's Empire of Evidence

How Owen used empirical evidence to reconstruct the form of the *Iguanodon* and to describe the physical features he used to create the Order of the Dinosauria.

It was Richard Owen (1804-1892), one of the leading comparative anatomists in nineteenth century Britain, who reconstructed the *Iguanodon* and created the Order Dinosauria. There is, however, some dispute about precisely when Owen created the dinosaurs.

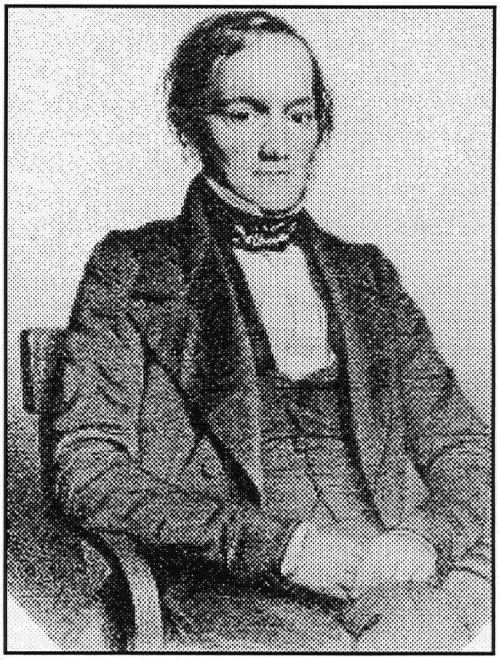
Figure 10: Richard Owen as a young man.

It is alleged that Owen first introduced the dinosaurs to world on August 2, 1841, when he presented the second installment of his report on British fossil reptiles to the British Association for the Advancement of Science (BAAS). (The first installment of his report had been read to the BAAS two years earlier and had surveyed extinct marine British fossil reptiles.) This two and a half hour lecture was the first comprehensive report on terrestrial British fossil reptiles (Desmond: 1979; 226) and was delivered in Plymouth to Owen's scientific peers and an assortment of international journalists covering the event for newspapers and magazines. Legend has it that this is where the concept of the dinosaurs were born, but newspaper reporters covering the event for the *Athenaeum*, the *Literary Gazette,* and publications in France, Germany and America did not record any discussion of dinosaurs in Owen's speech (Torrens: 1992; 41).

The dinosaurs were more likely first introduced to scientists and the public alike nine months later in the published version of Owen's 1841 BAAS report, printed in London in April 1842. The evolution of Owen's ideas through the final stages of the report's preparation are preserved in the printer's records (Torrens: 1992; 42). The new order of Dinosauria encompassed three genera: *Megalosaurus*, *Iguanodon*, and *Hylaosaurus* (Owen: 1841; 102-144).

Owen's British fossil report was widely acclaimed as a major scientific achievement by his peers. Buckland demonstrated his appreciation of Owen's fossil work by conferring the title of "the British Cuvier" upon him — a title previously bestowed by the medical journals on Owen's colleague, Robert Grant (Rupke: 1994; 131).

The well-received BAAS reports were comprehensive descriptive summaries of the developments in paleontology to the end of the 1830s. They encompassed the paleontological work of Buckland, Conybeare, Mantell, Parkinson and other prominent scientists of the day (Rupke: 1994; 131). At the time, major groups of extinct saurians had been known for some decades. Complete skeletons of ichthyosaurs (extinct marine reptiles with fish-shaped bodies and elongated snouts) and plesiosaurs (Mesozoic marine reptiles) had been excavated, many equally colossal in size when compared to the newly christened dinosaurs (McGowan: 1991: 190). The *Megalosaur* and *Iguanodon* bones that eventually were incorporated into the Dinosauria had been known since at least the 1820s. Owen's report on reptiles included anatomic descriptions of sixteen plesiosaur species, and ten ichthyosaurus ones. The majority of these species were named scientifically by Owen in this report. In the second part of the report Owen summarized what was known about crocodilians, lizards, chelonians (tortoises and turtles), ophidians (snakes), and batrachians (amphibians including frogs and toads).

Based on his extensive experience studying European fossil collections, Owen felt qualified to create the Dinosauria and reconstruct the *Iguanodon.* Supported by BAAS funds, Owen had conducted an extensive research programme to gather the data for each of his BAAS British fossil reptile reports; he traveled to the European continent to study fossil specimens in museums and as well as examining fossils in England. Owen also surveyed all of the literature available to him.

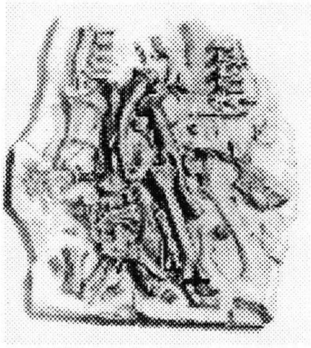

Figure 11: The Maidstone *Iguanodon* fossil evidence. This block is two metres in length.

Specifically, Owen had reconstructed the *Iguanodon* from both Mantell's meagre supply of bones and from a more recent discovery made near Maidstone in England. He created the Dinosauria from fossils that represented the partial remains of nine genera (one classification group above species) of archaic reptiles.

The most obvious reason given for the creation of a separate order for the dinosaurs was that they were all terrestrial, unlike all of the previous saurian specimens, which were marine. While the "gigantic Crocodile-lizards of the dry land," were in Owen's estimation no larger than marine saurians, they were less streamlined in shape (Owen: 1841; 103). This difference in shape of the huge dinosaurs' skeletons (small dinosaurs had not yet been discovered) were a clue that suggested that dinosaurs were very different from the both living lizards and marine plesiosaurs, ichthyosaurs and mosasaurs.

Owen's predecessors had regarded these saurians as monstrous lizards in the vein of Cuvier's *Mosasaurus*, but Owen used skeletal features, especially "vertebrae as fundamental criterion in reptilian taxonomy," in addition to the dental characteristics Buckland and Mantell were using to identify fossils to elevate them into a category of their own. Using this method, Owen defined the Dinosauria as "an order of extinct reptiles, characterized by cervical and anterior dorsal vertebrae with par- and diapophyses (certain protuberances), articulating with bifurcate ribs; dorsal vertebrae with a neural platform, sacral vertebrae exceeding two in number; body supported on four strong unguiculate (with nails or claws) limbs" (Owen: 1841; 103).

Owen gave further anatomical substantiation justifying his decision to collect these fossils into the Order Dinosauria. Unlike the other animals and fossils, all shared the characteristic of having five vertebrae fused to the pelvic girdle. Owen stated that the sacrum, ribs, and extremities "more or less resemble those of the heavy pachydermal Mammals, and attest with the hollow long bones, the terrestrial habits of the species" (Owen: 1841; 103). He went on stating that (Owen: 1841; 110)

> from the size and form of the ribs, it is evident that the trunk was broader and deeper in proportion than in modern Saurians, and it was doubtless raised from the ground upon extremities proportionally larger and especially longer, so that the general aspect of the living Megalosaur must have proportionally resembled that of the large terrestrial quadrupeds of the Mammalian class which now tread the earth, and the place of which seems to have been supplied in the oolitic ages (the ancient time when certain rocks, like limestone, were laid down) by the great reptiles of the extinct Dinosaurian order.

Owen, then, did not envision dinosaurs to the be the lizard-like creatures that Mantell had commissioned Martin to create for his frontispiece. Instead, Owen created a new group in which all of the dinosaur's mixed features could be accommodated. The mammalian features included: five fused sacral bones (of the lower vertebrae) attached to the pelvis; long, hollow limb bones, with prominent processes, or projections, for muscle attachment which indicated that the dinosaurs moved on land; and toe bones which, apart from their sharp claws, strongly resembled those of the rhinoceros, hippopotamus and elephant. The crocodilian features included: double-headed ribs in the chest; and the *Megalosaurus* teeth were embedded in sockets in the jaw. The group's lizard-like features were: complicated shoulder bones; and the *Iguanodon* and *Hylaeosaurus* teeth were more like the teeth of lizards (Norman: 1991; 73). The height, breadth and shape of the spines of the backbone were features not linked to any living animals. (The Order Dinosauria was dissolved in the late nineteenth century. Since this time, most scientists have classified dinosaurs into two separate groups, or orders, that were distantly related. These two orders are based by traditional analysis on hip anatomy. One of these two orders is the Ornithischia, or "bird hips," which had the pubic bone parallel to another hip bone, the ischium. The other order is the Saurischia, or "lizard hips," which had a long pubis pointing forward and down from the hip socket (Lessem and Glut: 1993; 226, 297). It should be noted that *Iguanodon* falls into the Ornithischia, while Megalosaurus has the other type of hip, and is a Saurischian.)

Owen, while seeking to break the reptilian mold Mantell and Buckland had forced these creatures in, paradoxically named them the Dinosauria from the Greek deinos, meaning "terrible" or "fearfully great," and sauros, meaning "lizard." — terrible lizards. In his report, Owen announced that (Owen: 1841; 103)

> the combination of such characters, some, as the sacral ones, altogether peculiar among Reptiles, others borrowed as it were, from groups now distinct from each other, and all manifested by creatures far surpassing in size the largest of existing reptiles, will, it is presumed, be deemed sufficient ground for establishing a distinct tribe or sub-order of Saurian Reptiles, for which I propose the name Dinosauria.

Owen attributed his creation of the new order of Dinosauria to the study of a fossil specimen owned by the London wine merchant William Devonshire Saull (Torrens: 1992; 42). Using his skills as a trained comparative anatomist, Owen was able to recognize similarities in the structure of the *Iguanodon* and the *Megalosaurus.* It had earlier been discovered that a type of vertebrae, the sacral vertebrae, was fused together in the genus *Megalosaurus* and Owen recognized this to be true of Saull's *Iguanodon* specimen also. He described this fusion, which strengthened the sacral vertebrae, as "altogether peculiar among reptiles" and touted it as the key adaption that these animals had made to terrestrial life.

Owen also reduced the hypothesized sizes of the dinosaurs in the written portion of his 1841 Report, unlike Mantell, who stuck closer with his original estimates of their size (Torrens: 1992; 42). Cuvier had set the standard according to which extinct saurians were reconstructed when he determined that the four-foot *Mosasaur* jaws he was presented with had belonged to a gigantic marine monitor lizard. (This analysis is still supported by scientists today (Desmond: 1979; 226).) Cuvier's *Mosasaur* enormously influenced early paleontologists as the title of Buckland's 1824 paper to the Geological Society entitled "Notice on the Megalosaurus or great Fossil Lizard of Stonesfield" indicates (Desmond; 1979; 227). *Megalosaurus* and *Iguanodon* were almost automatically accorded similar lizard-like status (Desmond: 1975; 14). The practice was reinforced by Gideon Mantell's discovery of a saurian herbivore's teeth which resembled the lizard-like iguana's, except for a huge disparity in size (Desmond: 1979; 227).

Cuvier's marine lizard had served as a template against which thigh bones, teeth, or other various body parts of extinct saurians and lizards were measured. The procedure was simply to scale up the fossil bone using a lizard blueprint. The total size of the extinct animal was then extrapolated by calculating how many times larger saurian parts were than lizard ones. The fossil bones, especially the limb bones, were frequently fifteen or twenty times longer than those of a lizard. The outcome of such calculations, even though revealing whale lengths for the "Fossil Lizards" were unhesitatingly accepted by Mantell, and Buckland, although even Buckland was staggered by the resulting dimensions (Desmond: 1979; 227).

Owen believed the lengths attributed to the *Iguanodon* were too large. Using the experience he had acquired dissecting animals from the London Zoo and specimens sent to him from colonies throughout the British Empire, Owen suggested that the calculations for the size of the dinosaurs be based upon the size and number of their vertebrae. (This method is still employed by scientists today.) Using this method for calculating the *Iguanodon*'s length, Owen reduced its length by three quarters to around eight metres (Owen: 1841; 108, 110). This was a complete revision of his thinking about the *Iguanodon*'s size from his comments in his speech at Plymouth eight months before. It is clear from contemporary reports that Owen had believed at the time of his 1841 Plymouth speech to the BAAS that the largest *Iguanodon* was up to six times the size of the largest elephant — making it as much as 18 metres long (Torrens: 1992; 41).

In the process of reassessing the *Iguanodon*'s length, Owen transformed the shape of the animal. Once the body length of the *Iguanodon* had been reduced, its legs became larger in proportion to the rest of its body. Instead of appearing as small, lizard-like appendages, the legs assumed mammalian proportions. Owen argued that the immense weight of the trunk of the body made a splayed out, lizard-like stance impossible. The animal would need to have its legs directly under the body to give pillar-like support for its immense weight. Owen refashioned his dinosaurs standing upright, similar to mammals, with thick, sturdy limbs directly under the body, in the parasgittal plane (Owen: 1841; 108, 110, 142, 144).

Even 150 years later, it is possible to see exactly how Owen envisioned his dinosaurs. Benjamin Waterhouse Hawkins was given the task of building life-size replicas of dinosaurs to adorn the Crystal Palace at the world's fair, the Great Exhibition of the Works and Industry of All Nations in 1851. (Today, paleontologists describe the *Iguanodon* as more like a squat version of an *Apatosaurus* (previously *Brontosaurus*), but with a shorter neck and tail). The *Megalosaurus* was created with a four-legged stance as scientists had not yet divined bipedality (Wilford: 1985; 73).) In 1852, Prince Albert had suggested that models of pre-historic monsters should be placed in the grounds of the newly transplanted Crystal Palace located in Sydenham, a suburb of London. Owen was selected as the expert who was to work closely with a commissioned sculptor, Hawkins, to build the life-size models. Under Owen's guiding hand, Hawkins shaped life-sized restorations of *Iguanodon*, *Megalosaurus,* and *Hylaeosaurus* and other extinct amphibians, crocodiles, and plesiosaurs out of cement, stone, bricks and iron (Wilford: 1985, 73). The *Iguanodon* was the spectacular centre-piece of Hawkins's workshop, which a newspaper artist described portrayed as a stable of monsters (Rudwick: 1992; 142).

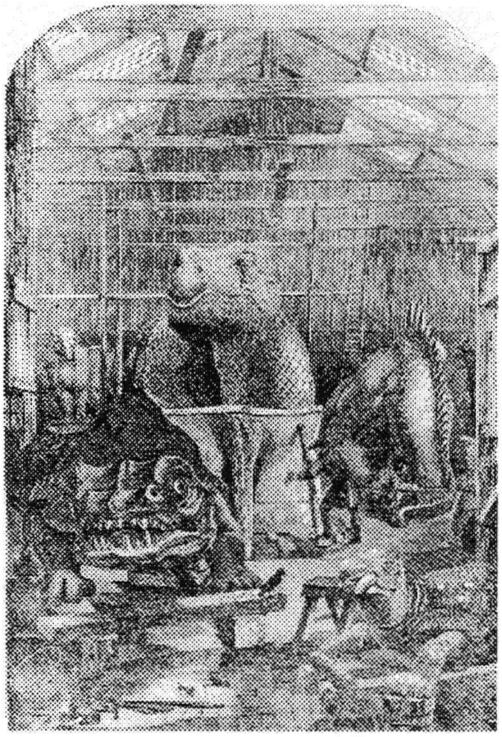

Figure 12: Hawkin's Crystal Palace workshop featuring the *Iguanodon (centre)* constructed under the supervision of Owen.

These replicas created the illusion more was known about these extinct creatures than was the case. The *Iguanodon* resembled a reptilian rhinoceros or hippopotamus (Lemonick: 1993; 39). Owen used the revised length that he had suggested in his written 1841 BAAS "Report on British Fossil Reptiles" for the Sydenham *Iguanodon* models. The length of the *Iguanodon* was reduced from its previously 18 metres to 8.5 metres, although Hawkins made them slightly larger.

In the latter sections of second part of the BAAS report, as in the concrete reconstructions he was to collaborate on with Hawkins, Owen strayed from his focused descriptive approach that was based on evidence he had at hand, and made what he referred to as "bold speculations."

Included in the speculative overlay Owen added to his report were hypotheses about the physiology, lives and deaths of the dinosaurs, including the *Iguanodon.* Before boldly going with Owen where no paleontologist had gone before, some background on the paleontological scene of the 1830s is needed to give context to his speculative comments, and potentially, to provide explanations or motivations for them.

Facts do not speak for themselves; they are read in the light of theory.

Stephen Jay Gould

Chapter 4: Owen's Cosmos

How theory affected the restoration of the *Iguanodon* and the physiology, habits and habitats of the Order Dinosauria.

When Owen reconstructed the *Iguanodon* and created the dinosaurs, he had at his fingertips all the information Mantell had used in his 1820s *Iguanodon* reconstruction. In addition, Owen had another decade's worth of excavated fossil evidence and theoretical developments upon which to base his analysis.

By the late 1830s, Owen had built up an impressive network of amateur and professional scientists and adventurers around the globe who sent him a constant stream of paleontological artifacts. Owen appealed to the patriotic sensibilities of these explorers and amateur naturalists asking them to send him samples of floral, faunal and paleontological treasures from the colonies — this wealth of natural specimens made London the scientific (as well as entrepreneurial) capital of the world (Rupke: 1994; 97). In the 1830s, Owen examined a variety of animals new to science ranging from the recently extinct moa (an ostrich-like bird from New Zealand) to several genera of what were to become the Dinosaurs.

The dinosaur fossil record available to Owen for study included Mantell's *Iguanodon* fossils, and several bones of another big fossil lizard of approximately the same size, a *Megalosaurus*. Buckland described this animal in 1824, but these fossils were much discussed in natural history circles prior to that date. The *Megalosaurus* fossil bones were on display at Oxford as early as 1818 when Cuvier examined them during his visit to Oxford (Charig: 1983; 51). Early constructions of the *Megalosaurus* pictured it as a giant, lizard-like creature. Owen went on to reconstruct it as an elephantine, humpbacked monster with a length of 21 metres (Lessem and Glut: 1993; 297). In 1832, Mantell described the *Hylaeosaurus*, another extinct reptile skeleton from Sussex. (*Hylaeosaurus* was the first armoured dinosaur known. Its body was studded with plates that became smaller toward the tail (Lessem and Glut: 1993; 221).) In 1834, Owen obtained a new *Iguanodon* fossil, including teeth, from a quarry in Maidstone, Kent. Throughout the 1830s, more giant reptiles were discovered, abroad as well as in England, and by 1841 nine different genera had been identified, some from exceedingly fragmentary remains. (A fourth British dinosaur, *Cetiosaurus* had also been discovered in England, but Owen had identified this animal as a crocodile (Charig: 1983; 51).) When he created the dinosaurs in 1841, Owen had only this limited number of bones available to him.

Owen's work had been driven by Cuvierian functionalism in the period up to the 1840s when he was reconstructing the *Iguanodon* and creating the dinosaurs. Cuvier stated that every organism is made up of an integrated system in which all of the parts are adjusted to produce a function in relation to the organism's environment. If one part of the creature or plant is modified, all the other parts must be readjusted to maintain a balance. Each part taken separately indicates how all the other parts, with which it forms a whole, will function. Cuvier gained the reputation of being able to reconstruct an entire animal from a single bone in France. Owen, his disciple, reconstructed a moa from a single bone in England. His work on the reconstruction of the moa became a symbol of the success of the functionalist approach to comparative anatomy in Britain. In 1839, Owen was shown a bone six inches long with both ends broken off. Owen stated that the bone fragment, which was part of the shaft of a femur, belonged to a bird from the order of wingless ostriches. This type of bird was unknown in New Zealand. The confirmation of Owen's reconstruction came early in 1843 when more bones were sent from the antipodean colony to England for analysis.

The example of Owen's moa reconstruction clearly illustrates his adherence to Cuvier's functional anatomy. However, Owen was heir not only to Cuvier's work, which clearly separated religion from science, but also to the work of natural theologians in England, symbolically led by William Paley. When Cuvier's *Preliminary Discourses* had been translated into English in 1813, its tone was given a religious slant by the English Robert Jameson. Since the new science of geology, like Christianity itself, was essentially historical, it was in a position either to support or undermine Scripture. Jameson added editorial notes that identified Cuvier's most recent revolution as the flood in Genesis, confirming the biblical event with evidence of the highest scientific respectability (Desmond: 1975; 14).

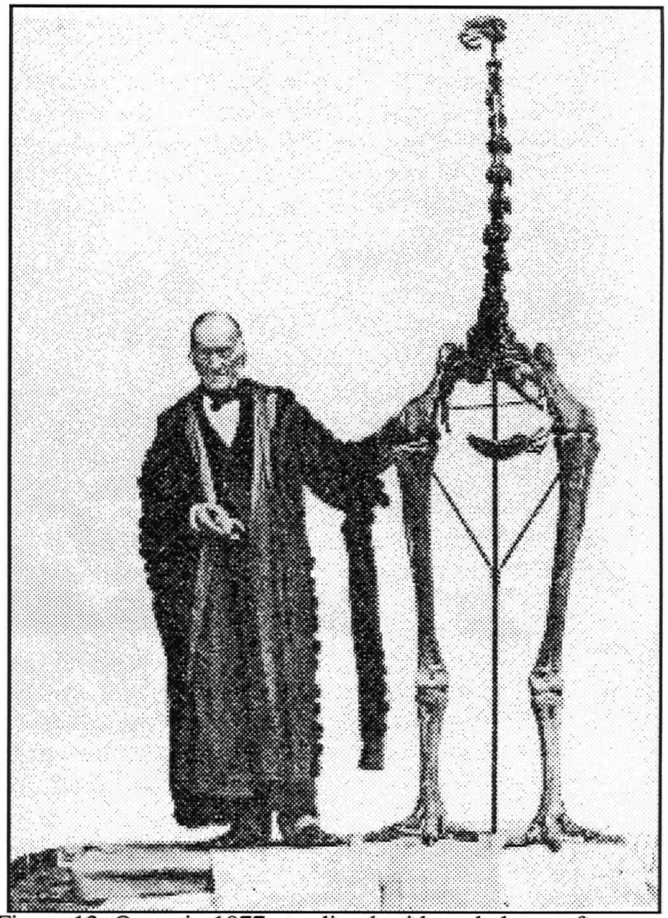

Figure 13: Owen in 1877 standing beside a skeleton of an extinct moa, *Dinornis maximus,* from New Zealand.The fragment of a femur he used to hypothesize the species' existence is in his right hand.

The transformation of Cuvier's localized last revolution into a unique universal deluge was completed by William Buckland (1784-1856), professor of geology at Oxford. Buckland transformed Cuvier's prolonged and local occurrences into a transitory and global event in the *Relics of the Deluge* (1823). Buckland's goal, successfully achieved, was to make Cuvier's work consistent with the Reverend William Paley's "bible" of natural theology, descriptively titled *Natural Theology: or, Evidences of the Existence and Attributes of the Deity Collected* *from the Appearances of Nature.* First published in 1802, it was reprinted almost annually over several decades. Paley began his book with someone discovering a watch on the heath and attributing the work to a watchmaker. He uses this analogy to argue that a complex world calls for a Divine Planner or Creator, God. Paley further stated that the varied and intricate works of nature from plants and animals to humans (not solely animals in his view) have been designed and could not be the result of chance. Paley (1802; 46) sums up:

> there cannot be design without a designer; contrivance without a contriver; order without choice; arrangement, without anything capable of arranging; subserviency and relation to a purpose, without that which could intend a purpose; means suitable to an end, without the end ever having been contemplated, or the means accommodated to it.

Implicit in natural theology were beliefs in the divine origins of earth and life (probably quite recent in geological terms), the immutability of species, and the then popular utilitarian view that everything in nature was designed as the means to some end. This end, as expressed in the chain-of-being, was the greater good and glory of man. Thus, it seemed unlikely that paleontologists could unearth a history in which the Designer had put large populations of animals on earth, at a time when they could be of no use to humans, and then further, that He would destroy them as though they had been profligate and wasteful whims.

Cuvier's arguments that different species share similar body plans because they live under similar conditions of functional necessity, but that they cannot bridge the gap between each other (that is, they cannot evolve from one into another) was also welcomed by Buckland and his clerical cohorts as were any ideas that appeared to reject evolutionary theory (Rupke: 1994; 111). Cuvier believed that four separate *embranchements* existed: the vertebrates, which ranged from fish to humans; the articulates, which included insects and worms; the molluscs, which varied from clams to cuttlefish; and the radiates, a group where everything else was lumped together, from jellyfish to sea stars. Cuvier did not arrange his *embranchements* in a linear sequence of increasing or decreasing morphological complexity and denied that their forms were linked in any way. This eviscerated the linear progress inherent to the chain-of-being transcendentalist theories of the time.

The famous evolutionist, Jean Baptiste, Chevalier de Lamarck (1744-1829), was a colleague of Cuvier's and head of the invertebrate section at the same institution, the Museum d'Histoire Naturelle in Paris. Lamarck, however, hailed from the generation previous to Cuvier and this was reflected in his scientific approach. Lamarck has become best known for his theory of evolution, which he put forward in the *Philosophie Zoologique* (1809). (The evolutionary mechanism that Lamarck used to explain how species adapt to their environment is the aspect that caught the imagination of later scientists searching for an alternative to Darwin's evolutionary mechanism of natural selection. "Lamarckism" of the late nineteenth century exploited only a single component of his theory, his mechanism known as the "incorporation of acquired characteristics.")


Figure 14: Chevalier de Lamarck

Lamarck's transmutationist, or evolutionary, theory had also crossed the Channel to England. The majority of British scientists supportive of evolutionary theory had studied in Edinburgh or belonged to the London metropolitan science scene. The independently wealthy Oxford and Cambridge science graduates did not support evolutionary theory as they associated it with materialistic ideas and revolutionary activities; the new science from the Continent was perceived as extremely threatening to the order of science and society. Materialistic ideas were condemned as subversive and detrimental to the religious framework of intellectual life — if the Divine Creator had not planned a hierarchically stratified society, it would remove the moral obligation of the lower classes to acknowledge the superiority of the aristocracy or continue to serve them. Scholars at the universities and other traditional sources of power and influence remained committed to Paley's older notion of plenitude. Lamarck's evolutionary theory opposed much of what Cuvier espoused and undermined all of what Paley had put forward. Lamarck's grand and speculative theory weaved together both traditional influences and radical innovations, revealing more of a flavour of Buffon's science than Cuvier's careful methodical approach.

Life, according to Lamarck, begins repeatedly by spontaneous generation. This idea was ancient, having been advanced in some form by Epicurus approximately 2,000 years before. Lamarck modernized the theory by giving it a new-fangled mechanism in which globules of matter were electrically "vivified" generating primitive forms of life. More complex living structures were produced by progressive evolution over numerous generations.

Lamarck was influenced by the traditional chain-of-being theory popular in the eighteenth century. He altered the theory when he moved away from the idea of a single chain. In doing this, he did not endorse Cuvier's suggestion that the animal kingdom could be divided into four "branches." Rather, he insisted that there were two parallel hierarchies for the plant and animal kingdoms. In observing both the plant and animal kingdoms, Lamarck realized that they did not conform precisely to his prescribed linear patterns. To explain these deviations, he suggested that it was necessary for living things to change with to ever-changing environments. He merged the rather radical notion of these changes, or adaptations, with a more traditional framework when he stated that the structure of any given species is determined both by its position in the hierarchy of complexity — and by the adaptations it has undergone. It remained inconceivable to Lamarck that the insensible gradations of the scale of animals and plants could be marred by imperfect gaps. He rejected Cuvier's theory of extinction.

Lamarck further remodelled the static chain-of-being theory by giving it a temporal aspect in which species changed over time. For Lamarck, species were not fixed and were capable of change. All natural entities were involved in the same process of continual flux over time. Conversely, to Cuvier and later to Owen, the organism was a functionally stable mechanism, and species were, therefore, temporally stable units.

At the beginning of the nineteenth century, Lamarck had suggested that "characters" developed in the lifetime of an organism can be passed on to successive generations. He believed that characters are generated in nature when animals are exposed to a new environment. When adapting to new circumstances, the animals change their habits and in doing so, exercise parts of their bodies more than before. This caused the "subtle fluids" that were flowing all around the body to concentrate in these areas. The subtle fluids produced both movement and change. Lamarck regarded these fluids as unknown, but believed he could identify two types: caloric (heat) and electric (Burkhardt: 1977; 155). The more exercised parts of the body become more developed and the next generation would inherit these augmented organs, and continue to develop them through the same exercise. The most frequently cited illustration of this mechanism is the giraffe's neck which was supposed to have been developed through generations of its ancestors stretching up to eat tree leaves growing high up in the canopy, although Lamarck himself used the feet of shorebirds as examples. Lamarck believed that the subtle fluids were involved in change involving the "tendency to progress" and the striving to fit local conditions.

According to Lamarck, instincts also began as learned habits, that were gradually imprinted upon the species. The habit is a character acquired by the adult organism, which, for a materialist, must correspond to a modification of neurophysiology. If the Lamarckian effect works, then the modified brain structure can become inherited just like an acquired physical modification. It should be noted that Lamarck's evolutionary theory involves no selection — each member of the population acquires the new habit and all participate in the process of self-adaptation which they transmit to their offspring. (Geneticists today believe that acquired characters cannot be inherited because there is no known mechanism by which they can be imprinted on the genes that transmit characters from one generation to the next. Biologists of nineteenth century, however, believed that the process did work.)

Lamarck's insight was to realize that, if the process of acquiring characteristics could be continued over immensely long periods of time, it could provide an alternative to the traditional concept of divine design. Not surprisingly, Lamarck suggested a great age for the earth as part of his theory. This vast amount of time was supposed to be ample for animals to develop characteristics slowly over numerous generations. In this theory, the earth maintained its steady-state, while at the same time changing through erosion and deposition. In its steady-state concept of earth-history, its virtually eternalistic time scale, and its marginal use of fossil evidence, Lamarck's theory has surprisingly strong affinities to James Hutton's theory presented in the *Theory of the Earth* (1788).

When Lamarck did briefly focus his attention on the fossil record, he interpreted the fossil evidence rather differently from his peers. Lamarck used the tropical character of species of fossilized molluscs found near Paris as an argument for a highly speculative theory of slow polar wandering. Ironically, while Lamarck was forming his theory almost without the use of fossil evidence, Cuvier's work on fossils was beginning to indicate that there might be some merit to an evolutionary theory.

Lamarck's evolutionary theory failed to address some of the issues that would become crucial in early nineteenth century science. He virtually ignored the progress of the empirical study of geology, he did not explore the geographical dimension of evolution and he did not comprehend the importance of paleontological evidence. Lamarck objected to the mechanizing of biology, which involved applying the careful, detailed, deductive scientific method encouraged by Cuvier (and still practiced today). Lamarck believed that life was in continual flux, that species were unreal, and that it was impossible that gaps could be left by extinctions in his chain-of-being-like gradation of animals and plants (Rudwick: 1972; 120). Lamarck did, however, introduce the idea that changes in the environment in a steady-state earth could influence the development of flora and fauna over time and replaced the need for divine action. This change of life forms was consistent with Lamarck's fluid notion of species, all of which had their origins as vivified globules at the bottom of the linear chain of either plants or animals.

Lamarck had combined a number of eighteenth century ideas to create a grand scheme of evolution that was in many ways quite different from those of the theory named after him in the following century. A school of radical thought remained active throughout the early nineteenth century which drew upon the idea of evolution as a means of challenging the traditional image of a static world designed by God. Lamarck's theory was one of the vehicles by which the materialism of the Enlightenment was transmitted into the following century.

By the 1820s, Etienne Geoffroy Saint-Hilare (1772-l844), professor of zoology at the Museum d'Histoire Naturelle in Paris and colleague to both Cuvier and Lamarck, was also promoting a theory of evolution. He endorsed Lamarck's idea of nature being in flux and adopted his secondary mechanism of environmental influence. Perhaps as a result of his embryological work, Geoffroy did not follow Lamarck in suggesting that evolutionary change took place in animals as a result of the accumulation of small, gradual changes. His evolutionary mechanism was a natural process in which "saltations" or sudden transitions changed one structure into another. Once triggered, this process resulted in a sudden switching of the growth process causing the individual's development to proceed in a new direction and gave rise to a change in the basic "type" of the mature animal. Like Lamarck's theories, Geoffroy's ideas were unacceptable to Cuvier and Owen. Neither Cuvier nor Owen could accept that species could suddenly change from one into another because this would remove the functional stability of animal organization — each bone was connected to another, and by changing one bone or feature in the animal, the ability of all the parts to function as a working whole would be compromised.

Geoffroy, unlike Lamarck, used current scientific evidence to support his theory. He employed fossil evidence when he cited extinct crocodiles as an example of animals that were transformed into the form of their modern descendants, which he believed to be birds. According to Geoffroy's theory, this occurred when a change in environmental conditions tripped off the transition "switch" to a new growth pattern and, as a result, formed a new species. Geoffroy also hinted that the birds had arisen from the reptiles through this same transition mechanism. "Transcendental anatomy" as this changing of forms was called, revived the case for materialism by suggesting that the relationship between similar species reflected a real genetic link resulting from natural processes of transformation. During this period, anatomists debated the implications of transitional forms such as the newly discovered platypus and the degree to which the structure of the human body indicated a link to apes.

Geoffroy also integrated his evolutionary theory into the contemporary geological theory of a directionally changing environment. His theory of change was progressive with a variable rate. The progressive direction of the history of life was confirmed unexpectedly from studies of fossil plants. Adolphe Brongniart (1801-1876), son of Cuvier's colleague Alexandre Brongniart, concluded that four distinct periods showing progression could be defined in the history of plant life. Between these periods there were abrupt floral discontinuities. Like the progress of animals, the progress of plants was thought to be indicated through time by increasing complexity and diversity. Adolphe Brongniart also determined that the climate of the Coal period had been at least as hot as that of the present tropics, if not hotter. In later floras, he saw evidence of a gradual reduction in the earth's climatic temperature.

The cooling earth theory provided a changing environment to explain the progressive increase in the diversity and complexity of the organisms that Brongniart had observed in the fossil record over time. The "lower," less complex animals and plants of early periods were adapted to the hot conditions then prevailing. Later, as the earth cooled and became more temperate in climate, "higher," more complex organisms came into existence. To Brongniart, the size and density of plant-life suggested a high concentration of carbon dioxide in the atmosphere during the Coal period. It was generally believed by scientists, including Owen, that once atmospheric carbon dioxide levels had fallen (when carbon became locked-up in the coal deposits) and oxygen levels had risen, reptiles came into being. A still greater concentration of oxygen was required before more active mammals could appear.

There was still one major problem that remained unaddressed during the first few decades of the nineteenth century — the question of the origin of new faunas and new species. The origins of species were no longer shrouded in the obscurity of the primordial beginnings of the earth, but instead were visible at definite points in the fossil record. However, Cuvier's assessment of the issue as unknowable, and therefore unscientific, continued to influence scientists and the subjects on their research agendas. The origin of species was not studied.

The radical new Lamarckian approach had attracted too many followers for it to be ignored. Many metropolitan scientists had received their university education in Edinburgh and were not Oxbridge alumni. The majority of Edinburgh graduates supported a different epistemology, that of the German influenced Romantic Naturphilosophie, where the transcendental logic prevailed. These transcendentalists, or pre-Darwinian evolutionists, used the form of organisms, and not functionalist adaptations, to explain the fossil record (Rupke: 1994; 64).

Robert Grant (1793-1846), an anatomist who was educated in Edinburgh and taught at London University, was one adherent of transmutationist theory. Grant interpreted the fossil progression as proof that animal life had advanced through the scale of development as the result of purely natural processes. His opponents agreed that the fossil record showed signs of progress, but undermined his interpretation by stressing the discontinuity of the development. Advances, they said, had taken place in a series of discrete steps, each too large to have been bridged by natural transmutation.

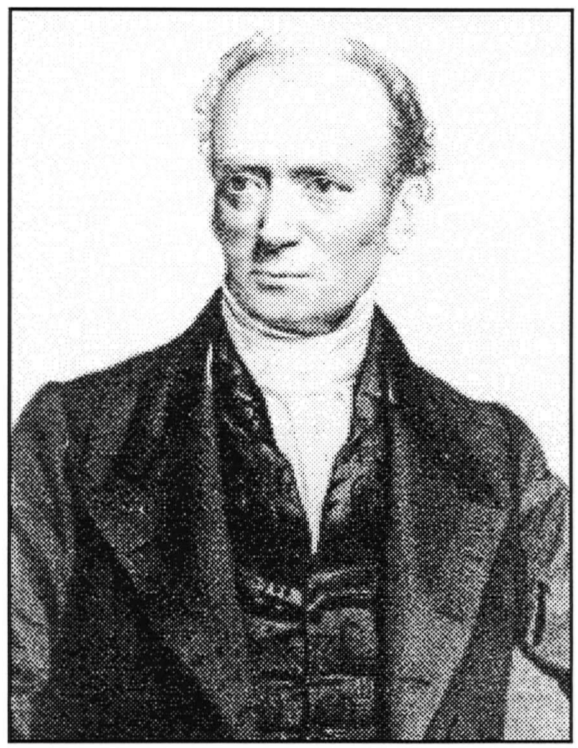
Figure 15: Robert Grant.

Transcendentalist criticism of Cuvier, and by implication of Oxbridge natural history was beginning to sound loudly in 1839. Another member of the Edinburgh-educated metropolitan scientists, Robert Knox, translated the attacks of a French scientist, De Blainville, on Cuvier's functionalism and had them published in the broadly distributed journal, *Lancet* (Rupke: 1994; 128).

Conservative thinkers of all persuasions were forced to modernize their science in response to the transmutationist theories put forward by Grant. One theory supported by conservative Oxford university natural historians reserved a role for God and was an extended version of Paley's argument in which the formerly static chain-of-being was given a temporal aspect. It incorporated new fossil evidence that supported the progress of life. The argument from design was enlarged to include a whole sequence of creations through the ages. Catastrophes killed off old species as the conditions changed making room for the Creator's new populations adapted to the new environment. The cooling earth theory provided an ideal framework for such a model of successive, adaptive stages. The decline in the carbon dioxide content of the atmosphere explained why oxygen dependent animals had been created in the later stages of the earth's history. Leading paleontologists including William Buckland supported this interpretation.

Another school of thought embraced a different divinely constructed pattern of development. Louis Agassiz (1807-1873), the Swiss-American naturalist who studied living and fossilized fishes, was one of the most eloquent and prominent spokesmen for this theory, called the "law of parallelism." This theory can be summed up as "ontology recapitulates phylogeny." Embryologists, such as J.F. Meckel, had tried to establish a parallel between the hierarchy of vertebrate classes and the stages of development of the human embryo. Humans, as the highest, most advanced beings would have already have passed through other lower forms on their way to their present form atop all creation. It was believed that human embryos, for example, had gill slits at one stage of their development because humans had passed through a evolutionary stage of being fish.

The British geologist Charles Lyell (1787-1875) interpreted the history of life in a different manner, rejecting or ignoring the fossil evidence that supported the progressive development of life, and consequently, all of the theories created to explain that progress. Lyell's geological interpretations dominated the science for the decades from the 1830s to the 1860s. Lyell's work was important because it offered a challenge to the established British synthesis of geology.

Lyell advanced his uniformitarian position in his well-known book, *Principles of Geology* (1830), where he declared geological activity was neither more nor less intense now than it had been in the past. This was in the part because the earth's history had not been a directional, progressional process, contrary to the evolutionists and to Buffon's cooling-earth theory, but had been made up of indefinite cycles of minor fluctuations. Lyell's belief that there could be no absolute direction in the history of life was a derivative of his uniformitarian philosophy. Although Lyell's tenacity in defending his views over the next thirty years was inspired largely by his overall cosmology, a small number of other naturalists joined him in rejecting progression altogether, perhaps for the same reasons.

Lyell sustained a campaign against Buckland's diluvial theory and rejected his attempts to manipulate geology in order to reconcile it with the Scripture. The vulnerable point where Lyell attacked diluvialism was in its interpretation of valleys. Lyell resurrected a theory "long ago announced" by Playfair and others. Playfair had shown how the slow excavation of valleys takes place incrementally by the streams now flowing through them. Even effects that appear very small when observed on a human timescale could produce very large effects in the geological time-scale. (The modern explanation of this is that these valleys were radically modified by glacial action.)

Lyell's importance lies, however, not in what he opposed, but in what he created. He established two essential methodological principles to guide geological work. The first principle, often referred to as "actualism," was a version of the traditional simplicity principle; superfluous causes should not be invented when observable ones can suffice. The actualistic policy of using the present as a key to the past was endorsed by Lyell's peers, including Owen, and had even been practiced earlier by Cuvier. All that was disputed was the extent to which the present was an adequate key to the past. Lyell was considered by his peers as unsuccessful in his attempt to apply this principle in paleontology, specifically to the appearance of new species in the fossil record. But for all other phenomena, it was agreed that natural causes must be responsible and Lyell's actualistic methodology was practiced.

The second methodological principle was that of "gradualism," or "uniformitarianism." Here Lyell emphasized the gradual nature of geological and biological changes. At the same time, though, this gradual record of change seemed to reinforce a directional and even a progressive history of life. A distinctive sequence of faunas and floras seemed to unfold through time, changing from lower, simpler organisms to the higher more complex forms. Lyell rejected this evidence and instead shored up support for his theory by criticizing Cuvier. He heaped scorn upon the French scientist and other catastrophists and managed, at least in the English speaking world, to impose the idea that gradualism represented the only scientifically valid concept of the history of the earth. Lyell also coupled catastrophism with religious belief, whether stated or concealed, despite the fact that Cuvier had purposely excluded religion from his science.

Lyell, who was trained as a lawyer, superimposed a third principle upon his methodological principles of actualism and uniformitarianism through some rhetorical artifices. He had suggested in his first two principles that the gradual forces acting in the present have always operated in the past. He then added one clause that created a steady-state earth. The theory became, with its new clause: the gradual forces acting in the present have always operated in the past *with constant intensity*. It was this aspect of Lyell's work that was most contentious. In advocating a steady-state system for the history of the earth and of life, Lyell contradicted firmly established physical and paleontological evidence. He claimed that the progress of life seen in the fossil record was merely an illusion due to the accidents of preservation. A few controversial mammalian fossils had been located in the "age of reptiles" and Lyell cited these as evidence of an unreliable record. He argued that this was simply a period in which reptiles outnumbered mammals because of the then hot conditions.

Lyell believed that species were real units that could be used like clocks to estimate changes in the history of life. Each species was constituted at its origin with definitive characteristics and organization. Time could be measured as species became extinct or were created anew. If the biological world, like its physical steady-state counterpart, was in a state of dynamic stability, changes would occur in the local populations of different species as physical conditions were altered. These changes could lead to the extinction of particular species. Extinct species would be replaced by the piecemeal creation of new species. These extinctions and creations could be used to define the parameters of geological periods. Lyell was not able to cite any actualistic evidence for species creation. Nevertheless, he stated that the creation of a species was very brief when compared to its lifespan, but once created, its organization necessarily remained adaptively stable until, sooner or later, it became extinct.

Although Lyell left the process of species creation an unsolved puzzle, he integrated it into a theory of biological change that parallelled his theory of geological change. Other scientists agreed with Lyell in his emphasis on gradual changes in the past history of earth and of life. Paul Deshayes (1796-1875), the leading conchologist in Europe and Heinrich Georg Bronn (1800-1862), a paleontologist from Heidelberg, had each established that faunal changes were gradual in character, and not sudden or abrupt, through their studies of the fossil fauna and flora (Rudwick: 1972; 190).

In relation to contemporary research of the 1830s, Lyell's grand synthesis was as inopportune in its steady-state theory as it was timely in its emphasis on actualism and on the relatively gradual nature of many geological and paleontological processes. *The Principles of Geology* (1830) undermined the credibility of attempts to reconcile geology with Scripture and vindicated an intellectual programme that accepted only natural causes. By eliminating the necessity for any past events differing in character from those of the historic present, Lyell denied the validity of the evidence for a directionally changing earth and progressively changing life, believing a steady-state system to be both scientifically and theologically superior. The scientific superiority of the theory was attributed to the closer ties it forged between geology and the prestigious science of astronomy; the steady-state theory's theological superiority was evident to Lyell as he felt that a world in perpetual and harmonious balance demonstrated the wisdom of the creation more effectively than a world in which a temporal beginning and end could be envisaged (Rudwick: 1972; 172).

In the 1840s, most geologists and paleontologists, including Owen, saw Lyell's steady-state alternative as completely unrealistic; the basic fossil sequence had clearly revealed its progressive nature to most nineteenth-century naturalists and geologists. Despite Cuvier's warnings, it was still widely assumed that vertebrates were collectively more advanced than any invertebrate type and within the vertebrates, the fish were the lowest class and the mammals the highest. Mammals were obviously superior to all life forms because humans are a type of mammal, and the human race is at the pinnacle of creation.

Even Lyell finally abandoned his steady-state theory. In 1866, Lyell publicly admitted that the fossil record did not support his theory. He conceded that species do change over time, admitting to a certain degree of evolution. Although in 1830, it had been possible to argue that the fossil record was still rudimentary and fragmentary, Lyell agreed with the majority of his scientific peers that this was no longer possible, despite Charles Darwin's protests to the contrary in the 1860s in a chapter "On The Imperfection of the Geological Record" in the *Origin of Species.* Most scientists agreed with John Phillips, one of the leading paleontologists in Britain at that time, when he complained that Darwin had grossly over-stated the case for imperfection of the fossil record. Phillips' review of the fossil record shows clearly that he was aware of the vast scale of geological time, but that he did not feel that this justified Darwin's multiplying the time-scale extravagantly in order to accentuate the gaps in the record and evade the difficulties presented by it.

Robert Impey Murchison's (1792-1871) work on the successions of rocks in the Welsh Borderland in the late 1830s and following decade undermined Lyell's steady-state theory. Murchison's synthesis helped to establish the Silurian period now recognized as a division of the geological timescale and showed that it was not merely a local series of strata, but existed worldwide. Invertebrates of marine origin were found in these strata and rather than apply Lyell's explanation of an imperfect fossil record to account for the lack of vertebrates, Murchison declared that the Silurian strata had been formed in an epoch prior to the first appearance of vertebrates or of terrestrial vegetation. The progressive character of the fossil record, however, could most clearly be seen in the record of the vertebrates. By the mid-1840s, the major outline of the fossil record had been firmly established in a form that has survived with only minor modifications as late as mid-twentieth century.

The increasing specialization of geology tended to make it less comprehensible to the public and a plethora of popular and semi-popular works on the subject began to be published. In 1844, *The Vestiges of Natural History of Creation* a popular book explaining geology and the fossil record in terms of evolutionary theory was anonymously published by the Scottish journalist Robert Chambers (1802-1871). While most of Chambers's direct sources were English, his proposal for a natural explanation of the creation of species was perhaps nearest to Geoffroy's in its use of embryonic monstrosities, its emphasis on the direct influence of the environment and its acceptance of trans-specific "jumps." Unfortunately Chambers's book was full of inaccuracies which served to make the scientific community hostile to its evolutionary contents.

Chambers's decision to publish his work anonymously was prudent given the furor it unleashed. Behind the almost violent reaction to Chambers's book lay the fear that his materialistic explanation of the creation of life threatened the spiritual status of humankind. While theological difficulties were attached to the study of paleontology as a whole during the mid-nineteenth century, scientists did not simply choose between religion or science. Many scientists, while devout, accepted a "secondary" cause for the origin of new forms of life in the same way that their confreres in the physical sciences adopted Newtonian mechanics to explain how the forces of nature acted, leaving the question of why they acted to the divine realm. Species, like other entities, were governed by God through the "intermediary of natural laws." This intermediary theory, though, did make it far more difficult to conceive of any natural cause that would preserve the sense of design in organisms.

Chambers's work was criticized in the 1840s as much for its scientific gaffes as for its materialistic implications. In the 1830s and 1840s, the debate over evolutionary theory that is usually associated with the publishing of Darwin's *Origin of Species* in 1859 was taking place between camps supporting either Cuvier or Geoffroy in natural history museums and anatomy schools all over Europe. This was the period in which Darwin himself was beginning to develop his evolutionary theory with its mechanism of natural selection. The victory of Cuvier and his supporters in this argument branded evolutionary theories as speculative and unscientific for the next thirty years.

As a leading member in the sciences grouped together under the umbrella of natural history, Owen was aware of all the developments described above when he reconstructed the *Iguanodon* and designed the Dinosaurian Order. (The moa and the *Megatherium*, an extinct giant sloth from South America, were also employed by Owen as examples of functional adaptation during this period.) Natural history, to Owen and to most of his contemporaries, was the systematic ordering of the whole range of diverse, natural entities, as it had been to Linnaeus in the eighteenth century.

Owen's natural history studies were concentrated in the field of comparative anatomy and focused on two areas: functional adaptation in the animal kingdom and the understanding of nature's pattern of organic, divinely planned diversity. Owen's archetypical plan united the two distinct components he used in his comparative anatomy work to generate an understanding of organic order and diversity into one theory. His theory revolved around the concept in which all animals within each major group were variations of an ideal archetype. He believed that the Divine Mind which planned the archetype foreknew all its modifications. Owen was to become a proponent of pre-planned evolution in which organisms did not change beyond the range of "types" that God had defined for them; some diversity and change within a species was provided for in Owen's theory, but this did not include transformations from one species into another.

The first component of the archetypical plan encompassed the adaptation and design manifest in the structure and function of the individual organism. Owen's strong sense of functional adaptation was derived from his hero, Cuvier, and his ideas about organisms remained mechanistic. The second component of Owen's system involved the variety of forms in nature. Scientists had been using Cuverian principles to study the similarities between the structures of unrelated animals which are used for the same functions, such as the wings of birds and bats. Owen named the modifications of the structures used by unrelated animals homologies, and although these similarities had been observed since antiquity, he was able to identify skeletal homologues more successfully than had been done before. Owen believed that homologies could be traced through different classes of animals as, according to his theory, all the animals within each major group were variations on a single theme; all were modifications of a single plan, or archetype. The archetype was a Platonic structural idea and was not an animal that ever had existed or could exist. Nature provided a plan that led to its pinnacle in *Homo sapiens.*

Owen and most of his contemporaries believed that the archetypical plan was his greatest and most lasting achievement. Within this theory, evidence from fossils and living organisms could be ordered and interpreted in harmonious, integrated and designful terms. The theory may now seem implausible because of its relative lack of interest in the causal mechanism by which organic diversity was produced and because of its reliance on an idealistic metaphysics that was later rejected by biologists.

Owen also looked to embryology to help explain the development of life. Several of his colleagues, including the German embryologist Karl Ernst von Baer (1792-1876), Geoffroy and Louis Agassiz worked in both embryology and paleontology. Scientists in both fields were studying the process of coming-into-being of organisms. Paleontologists were searching for an explanation of the emergence of diversity and novelty in organic form and function on the geological timescale of the fossil record. Embryologists were challenged with accomplishing the same feat over the short timescale of an individual life-history. In embryology, earlier attempts to explain complex developmental phenomena in terms of causal mechanistic terms had been abandoned. Attention had turned toward more precisely describing the actual modes of development. In pursuing this line of research, von Baer demolished the older belief that the individual organism ascended the scale of beings during its embryological development.

Owen and the physiologist W.B. Carpenter (1813-1885) were inspired by von Baer's destruction of the linear chain-of-being and began to search the fossil record for non-linear relationships. The two British scientists described how classes first appeared in the fossil record in a very generalized form and subsequently specialized into a number of forms each leading toward a particular way of life. As Owen's archetypical system unified nature through a single underlying form, it was easily able to accommodate the idea of a branching process from a single source. Branching and specialization, then, were the key to the history of each class, and not the ascent of a linear scale towards the next highest form.

The German paleontologist Heinrich Georg Bronn (1800-1862) also began to draw diagrams of the history of life representing the overall process a branching tree. Owen and Bronn continued to believe, however, that the pattern of development represented the unfolding of a divine plan, the expansion of predetermined variations on a theme. Bronn was professor of natural history at Heidelberg and was probably the only paleontologist during this period who was capable of synthesizing the known distribution of organisms in geological time into a useful order. He completed this task in his Physical Sciences Grand Prix winning paper, submitted to the Paris Academy of Science in 1857. His synthesis brought order to the rapidly growing factual information about geological strata and the fossils they contained. Bronn's synthesis laid the groundwork for the acceptance of an evolutionary theory within a few years. Bronn, himself, was sceptical about the adequacy of the evolutionary mechanism of natural selection put forward by the British scientists, Charles Darwin and Alfred Russell Wallace. It is worth examining Bronn's synthesis because it accurately reflects the general state of paleontological thought to the 1850s.

The notion of species had become problematical in paleontological practice. This was indicated by the taxonomic splitting of well-known and established fossil species as they became known in greater detail. Bronn held that species were real units and each species was adapted to its appropriate place in life in the divine plan. Once created, each species was limited in its variability and beyond those limits it would not be viable. Bronn followed Cuvier when he dealt with, or rather, did not deal with, the origin of species. He adopted the methodological tradition of Newtonian physics and argued that scientists are ignorant of the ultimate nature of forces, but can still try to understand them by studying their effects.

Bronn created two "fundamental laws" based on detailed descriptions and interpretations of the fossil record to explain the fundamental characteristics of the creative force. Again, while the creative force itself was unknown, its effects could be understood. The first law was the intrinsic law which governed the progressive trend that was seen in the fossil record. This law accounted for the coming-into-being of novel and more complex forms of existence. The second was an extrinsic law that governed the adaptive potentialities of organisms in relation to their environments. This law could only determine which potential forms of existence could actually survive, given the world as it had been at that time in the past.

Bronn and other paleontologists carried out their studies knowing that the fossil record was imperfect, but with the confidence that the record was becoming more reliable with each new discovery. Bronn believed that organic change was gradual, occurring through the extinction of old species and production of new ones. He did not assume, as Lyell had done, that gradual change entailed a steady-state history of life. As his second extrinsic law stated, the fossil record seemed to show progress in the history of life. According to Bronn's analysis of the fossil record, Lamarckian theories of gradual transmutation of species were without foundation. There was no fossil evidence of missing links showing how one species changed gradually into another.

The paleontological record covered by Bronn's 1857 prize winning summary included many of the discoveries and discussions of the 1840s and 1850s. These discoveries had shown the history of life to be much more complex than had been first thought. Transmutation, when linked to the old idea of an ascent of a linear scale had been rejected as too simplistic. An overall progression from fishes, to reptiles, to birds, to mammals and finally to *Homo sapiens* had been sketched. This ascent was superimposed on an intricate sequence of individual developments that did not seem to correspond to the larger trend. As a result, the idea that all the lower animals were merely immature versions of humankind was abandoned as was the assumption that all extinct populations had been perfectly adapted to the conditions of their own time.

To most scientists, the mid-nineteenth century developments in paleontology seemed to call for a revision of traditional ideas. Like Owen and Bronn, the vast majority of scientists at this time did not attempt to explain the trends seen in the fossil record as the sole result of natural processes. The belief in a divine designer did not blind these scientists to "correct" solutions, but instead influenced the choice of problems that were pursued and in the kinds of solutions found satisfactory. The emphasis on the designfulness of each species tended to discourage speculation about possible mechanism for the origin of species and opposed any evolutionary theory with a natural mechanism. Yet at the same time, the study of natural theology encouraged the functional analysis and ecological reconstruction of individual fossil and living species. It did give an incentive to search for further evidence of organic progress. The majority of scientists of this period were still interested in divine patterns rather than natural processes, although the patterns they were now discussing were of a kind that Darwin was to explain in natural terms.

By the 1850s, when Owen was busy overseeing Hawkins's *Iguanodon* reconstruction, the major groundwork had been laid in the field of paleontology. Paleontology had grown to disclose at least the broad outlines of the history of life. An earth-history of almost inconceivable length in which life had passed through many phases becoming more complex and varied to the present time had been outlined and a geological time-scale still used today was in place.

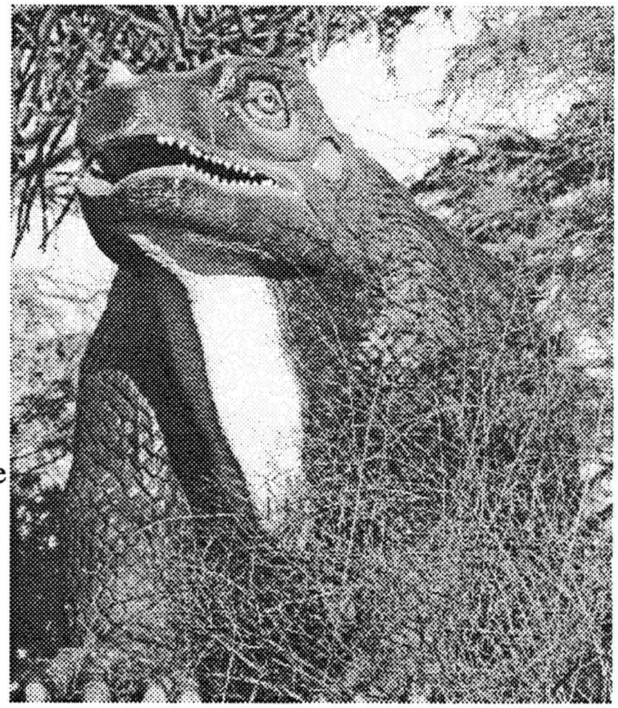

Figure 17: Benjamin Waterhouse Hawkin used tons of bricks, plaster, wood and iron scrap to build his *Iguanodon* model, under the supervision of Richard Owen.

Science is the search for truth — it is not a game in which one tries to beat his opponent, to do harm to others.

Linus Pauling

Chapter 5: Owen's Functionalist Crescendo

The Reconstruction of the *Iguanodon* and Creation of the Dinosauria.

Dinosaurs were first excavated by British natural historians in the early 1800s. The dinosaur restorations in the forty year period from the early 1820s to the late 1850s reflected the paucity of the fossil record, an incomplete knowledge of dinosaur anatomy and prejudices about living and dead reptiles. These *Iguanodon* reconstructions varied so greatly that the models of different scientists appeared to represent completely unrelated species of animals; the enormous lizard-like *Iguanodon* that Martin illustrated for Mantell had little in common with the mammal-like creatures that Hawkins later built under Owen's direction at the Crystal Palace.

Like all reconstructions of extinct animals, the *Iguanodon* models of the early 1800s were human creations. The interpretation of fossil discoveries is not only constrained by the available natural evidence, or fossils, it is affected by human interpretation at every step of the process, that is, during the discovery, description and analysis of each new find. Reconstructions are constrained by numerous factors ranging from the technical and theoretical state of the sciences used to interpret them, including areas such as comparative anatomy, geology, and paleontology, evolutionary theory, and explicitly during this period, religious and social concerns. To interpret these reconstructions as a simple record of paleontological discovery is to ignore important questions posed by the history of the varied and changing reconstructions (Rudwick: 1992; 222); each *Iguanodon* reconstruction embodies an historical attempt to interpret the fossil remains of an extinct species of animal by physically illustrating their form and function.

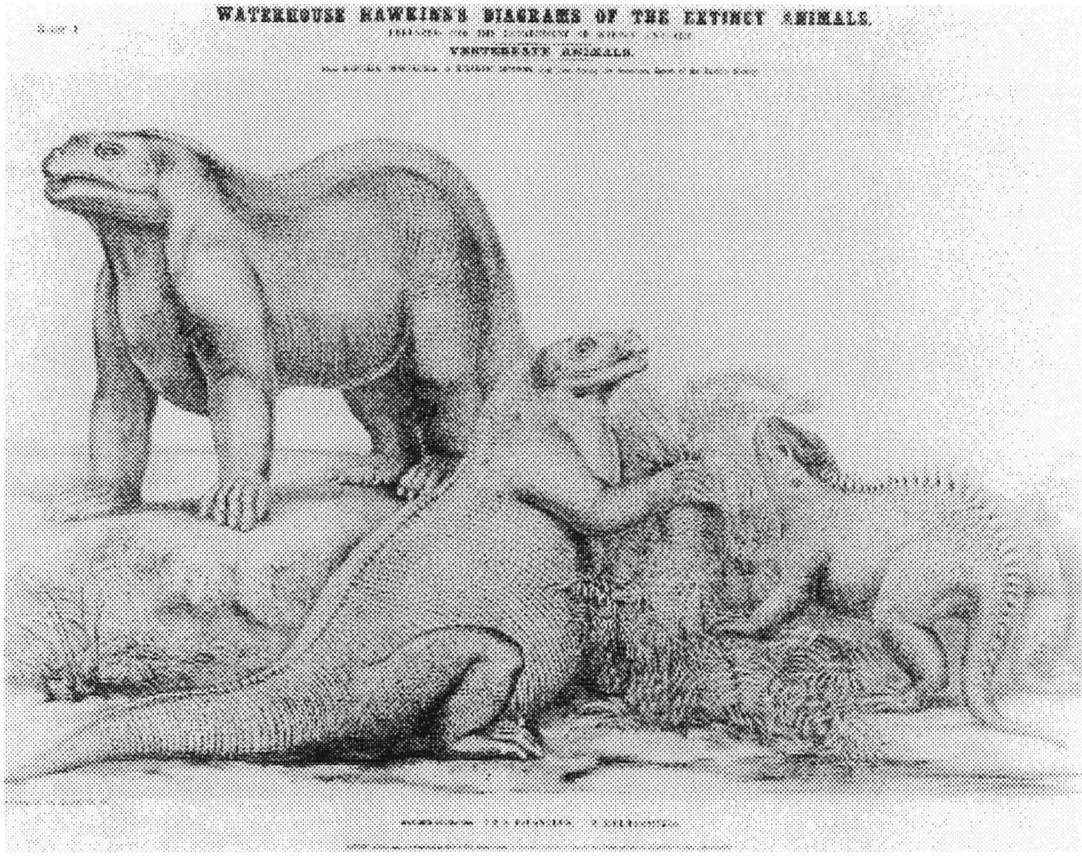

Figure 16: Hawkin's wall poster of the *Iguanodon* and *Hyleosaurus* (right).

The early nineteenth century reconstructions of the *Iguanodon* and the Order created to contain them, the Dinosauria, should not be analyzed using the same criteria that would be applied to modern scientific work. In this period, natural history, also known as natural theology, embraced religion, philosophy and other subjects that are now supposed to be excluded from science and considered to be social factors. To ignore or remove these factors would involve imposing current values upon historical events and figures of the past.

In this section, the history of the *Iguanodon* reconstructions is examined in terms of their value as human constructions rather than as "factual" documentaries of extinct animals. Several models will be used to try to make sense of the contradictions, changes and developments in the *Iguanodon* reconstructions: the "complete fossil record theory" and Latour's "cascade of representations" model will be used in conjunction with the Kuhnian account of scientific revolutions between changes in paradigms.

The complete fossil record theory is useful for examining paleontological reconstructions over time. This theory attributes all changes in reconstructions of animals from the fossil record to an increasingly better exposed fossil record; the greater amount of evidence that is available when the reconstruction is undertaken, the closer the model will be to the extinct animal's living form. Latour's model will be used to study the "snapshot" of the fossil record interpretation that was largely the situation under which the *Iguanodon* reconstructions of Owen and Mantell were created. Kuhn's account of scientific revolutions will be used to examine the theoretical implications of Owen's paleontological work in comparison with the works of colleagues, including those espousing transmutationist, or evolutionary, theories. *Iguanodon* reconstructions were created on the brink of one of the most important revolutions in modern science, the introduction of Darwin's evolutionary theory. Kuhn (1962; 8) states that science is the interpretation of evidence, and not merely the patient accumulation of facts. The influence and interpretations of adherents of the transmutation theory (pre-Darwinian evolutionary theorists) and the older, traditional Divine Creation theories will be examined as both groups worked with and interpreted the same fossil evidence. The interpretation of this evidence by individual scientists will also be undertaken to determine how their own goals and career advancements may have influenced their activities.

Many questions surround the reconstruction of the *Iguanodon* and the birth of the Dinosaurs: why did Richard Owen risk his reputation as the leading paleontologist in Great Britain and Her Majesty's British Empire to reconstruct the *Iguanodon* using the bones from a few skeletons —

a small fraction of the standard amount of fossil evidence normally employed to build such reconstructions — and then create the Order Dinosauria to house these incomplete creatures? why did Owen put aside his established practice of meticulous, scientific analysis and make numerous and extensive "bold" speculative comments about their physiology based on this inadequate fossil evidence? what motivated Richard Owen to depart from his previous scientific practice and create an order of terrible lizards which he then went on to endow with as many mammalian characters as possible?

In his 1841 BAAS report, where he constructed his *Iguanodon* and created the Dinosauria, Owen limited himself to anatomical descriptions of the dinosaurs. The report was a detailed compilation of the work of European and British scientists that encompassed all the known British fossil reptiles. Owen's descriptive work conformed to the careful, methodical, functionalist approach endorsed by Cuvier. In the entire 144 page report, Owen deviated from this approach only a handful of times and then warned his readers that he was about to make "bold speculations" about dinosaur physiology. These speculations were important enough to Owen that he allowed himself to deviate from his usual scientific practice. Owen placed great emphasis on his speculations by presenting them in the introduction to his section on the dinosaurs and in the conclusion of the entire report. While these bold speculations about dinosaur physiology make up only a small portion of the report, they provide an insight into Owen's thought process and his motivations.

Complete Fossil Record Theory

Perhaps the simplest way to explain the different permutations of the *Iguanodon* reconstructions in the early nineteenth century is to cite the later development of a more complete fossil record. The complete fossil record theory attributes all morphological changes in the contradictory dinosaur reconstructions to an increase in the discovery of material fossil remains; all changes in the successive reconstructions of the same species of dinosaur are attributed to the discovery of more and better specimens. Each reconstruction would have only been possible at a certain period in the history of paleontology, and not before then, nor after that time.

Fossils were an essential prerequisite to the reconstruction of extinct animals, but proved to be a meagre resource in the 1800s. The dinosaur fossil record available to Owen and Mantell was extremely limited, but continued to grow. By the time Mantell had acquired his *Iguanodon* fossils, several bones of another big fossil-lizard reptile of approximately the same size had been excavated at the Stonesfield Quarry. Even though Buckland waited until 1824 to publish his description of these *Megalosaurus* fossils, the fossils were much discussed in natural history circles prior to that date. The *Megalosaurus* fossil bones were on display at Oxford as early as 1818 when Cuvier examined them during his visit to Oxford (Charig: 1983; 51). In 1832, Mantell described the *Hylaeosaurus*, another extinct reptile skeleton unearthed in Sussex. In 1834, he obtained a jumbled mass of *Iguanodon* bones, including teeth, from a quarry in Maidstone, Kent. Throughout the 1830s, more giant reptiles were discovered, abroad as well as in England, and by 1841 nine different genera had been identified, some from exceedingly fragmentary remains. (A fourth British dinosaur, *Cetiosaurus* had also been *discovered* in England, but Owen had identified this animal as a crocodile (Charig: 1983; 51).) When he created the dinosaurs in 1841, Owen had only this limited number of bones available to him for study.

Discoveries, including both Leidy's *Hadrosaurus* in 1858 and over 80 *Iguanodons* in Bernisaart, Belgium in 1878, provided later scientists with additional information upon which to design their reconstructions — and these reconstructions do look very different. Modern bipedal portrayals of the *Iguanodon* are based on many complete skeletons and are strikingly different from the giant lizards and the rhinoceros-like monsters of the early to mid-1800's.

Earlier scientists, including Mantell and Owen, did not have access to these newly quarried fossils. In the early nineteenth century, when both Owen and Mantell drew up plans for their *Iguanodon* reconstructions, they had access to a similar amount of information about the same fossil record. Even though Mantell, as an amateur fossil hunter, did not share Owen's professional standing, he was able to gain access to approximately the same data and collections through his close ties to major figures in the scientific community of the day, including the influential Oxford professor of geology, William Buckland. Owen, as a curator working in museums, had the advantage of a professional mandate to conduct comprehensive paleontological studies. Owen was a prolific writer and published over 600 scientific papers and 12 books for all, including Mantell, to study (Rupke: 1994; 1).

The complete fossil record theory may be used to explain differences in *Iguanodon* re constructions over time as more paleontological data is revealed, but cannot be applied to explain the profound differences seen among reconstructions created in periods where no significant new fossils are discovered. The *Iguanodon* reconstructions of Mantell and Owen fit roughly into this category; the differences between their reconstructions cannot be attributed to a more complete fossil record as both were working with similar, and extremely incomplete, evidence. Despite their exposure to the same fossil record, Mantell and Owen drew drastically different conclusions about the form and functions of the *Iguanodon*.

Cascade of Representations Model

The cascade of representations model can be used to explore paleontologists' increasingly more detailed reconstructions of the unobservable past, both during periods when the fossil record remains the same and when it becomes increasingly more revealed (Latour: 1986; 27). This model, then, can be used to examine the developments that occur within a single "frame" or "snapshot" of the fossil record when no new fossil evidence is available to scientists, and as the fossil record continues to develop, revealing new fossil remains. The "cascade" process simply repeats with the revelation of new evidence.

Bruno Latour's cascade of representations model describes the process of analyzing paleontological evidence and reconstructing organisms as progressing "from the observed to the inferred, from the specific and contingent to the general and idealized" (Rudwick: 1992; 222). The *Iguanodon* serves as an excellent example, as dinosaurs were the pilot-projects early in the history of the reconstruction of prehistoric animals. The cascade of representations begins with a scientist examining the partial remains of a single animal. It is rare to find a complete skeleton of an individual specimen (and certainly was not the case for the *Iguanodon* in the first half of the nineteenth century). The next step of the cascade theory is to reconstruct a complete skeleton representative of the species based on the partial remains of many individuals. Paleontologists subsequently make inferences about the "soft parts" of their newly re-assembled animal, including unpreserved muscles, based on both the reconstructed skeleton before them and on an anatomical analogies with presumably related living forms. The following stage leads to inferences about the animal's kinetics and habits. These hypotheses are based on a functional analysis of its anatomy and on physiological comparison to related living forms. Finally, scientists can form an imaginative reconstruction of a complete prehistoric scene, including reconstructions for many organisms that co-existed at that time. The backdrop to the faunal reconstructions would be based on ecological analogy with existing habitats based on similar inferences from traces of the botanic fossil record and the inorganic environment (Latour: 1986; 11-29).

The narrative describing the reconstruction of the *Iguanodon* both conforms to and departs from the complete fossil record theory and the cascade of representations model. Cuvier began the cascade by applying his newly developed comparative anatomy practices to a healthy amount of fossil evidence. Cuvier was able to reconstruct complete bodies of a number of marine fossil-lizards and prehistoric mammals by collecting the partial remains of several specimens together to create one (or more) complete skeleton. From these reconstructions, he made inferences about the animals' kinetics and habits. Cuvier led the process of recreating extinct animal reconstructions down the first steps of the cascade with the evidence then available to him.

The model of the cascade of representations can also be used to study the reconstructions of Owen and Mantell. In contrast to all other reconstructions that had been made to that date, including those of Cuvier, the *Iguanodon* reconstructions of Owen and Mantell can be faulted for having been based on extremely limited evidence — only a few teeth and isolated bones (Rudwick: 1992; 222). Owen and Mantell, however, are not alone in their creation of species from extremely fragmentary fossil evidence. In the late 1800s and early 1900s, paleontologists often named new dinosaur species based on as little as a single vertebra or tooth. Two of the worst offenders for naming species based on insufficient evidence were the American paleontologists Edward Drinker Cope and Othniel Charles Marsh. These two scientists used newly named species as a way of keeping score during the infamous dinosaur Bone Wars they waged against each other in the American West. In an attempt to name the most animals, each scientist would assign a name to the bone or fossil he discovered hoping that he had given a name to the bone first, and that he would be awarded priority in the nomenclature race, making his name the correct one. Many of these bones frequently turned out to belong to a previously named species. Of the approximately 330 dinosaur species named, most are known from just a single tooth or bone (Lessem: 1996; 38).

Even when paleontologists are fortunate enough to possess a reasonably complete collection of skeletons, as Cuvier did, they may discover that reassembling the bones of extinct animals in their correct places (where they would have been placed in the living animal) is not always as easy or obvious as it may appear. The initial phase of reconstructing a large dinosaur skeleton is rather like piecing together a gigantic three-dimensional jigsaw puzzle (Michaud: 1992; 51). Although mistakes in assembly of more complete specimens are relatively uncommon, it can be difficult to tell whether certain bones (ribs, phalanges, tail vertebrae) have been correctly positioned. A patently clear example of this occurred in America in 1870 when Cope showed his colleague, Marsh, a plesiosaur skeleton he had reconstructed. Marsh examined the model and commented that Cope had placed the animal's head at the tip of its tail (Michaud: 1992; 35). (This was the spark that ignited the Bone Wars described above.)

While correctly connecting the tail bone to the hip bone to other skeletal bones is challenging, the reconstruction of internal organs is even more difficult. The outer forms of skin patterns and internal organs can only be detected if a mold of some type preserves their shapes. If an animal dies in the mud, for example, it may leave an impression of the texture of its skin in the mud's surface. Alternatively, some mud may seep into the animal's body through a gash or hole, and a negative form of the skin or organ may be preserved.

Fossil evidence, then, even when the paleontologist has a relatively complete specimen, can be challenging to interpret. Yet, the knowledge that other scientists have made unwitting mistakes using complete specimens and that they have conjured up species based upon a single tooth or bone, does not explain why Mantell, and especially Owen, deviated from Cuvier's example of meticulous work based on substantial amounts of evidence and embarked on their recreations of the *Iguanodon* using less-than-complete specimens. It also does not help to explain why Owen, in particular, made so many hypotheses about the physiology, habits, kinetics, and habitats of dinosaurs based upon such limited evidence.

Owen's speculations were in sharp contradiction to the meticulous scientific method of Cuvier, as well as to his own usual practice. Both Cuvier and Owen practiced a mechanical Newtonian science that banished from science grand, speculative theories that were not substantiated with evidence. The practice of science had evolved into a much more careful, detailed method in which the broad brush strokes that Buffon and Lamarck had employed to create theories were no longer deemed acceptable. (Lamarck did apply the then modern scientific practice in his comprehensive botanical and invertebrate studies.)

Revolutionary Explanations: Divine Creation versus Transmutation

The arrival of a transmutationist, or evolutionary, theory on the scientific scene of the early 1800s (without the mechanism of natural selection prior to 1859) must now be superimposed on Latour's cascade of representations. The creation of the *Iguanodon* can be viewed through a Kuhnian lens as one element in a battle between scientists supporting clashing scientific paradigms — the old natural theology theory with its order imparted by a Divine Creator was pitted against the new ungodly, materialistic, transmutationist theory. The new scientific theory represented an unsettling shift in the way people view the world. The divine design theory upholds the belief that the Almighty not only created and designed all things in the universe but that He continues to play a direct and benevolent role in supervising its existence. The removal of a benevolent, father-like God and His replacement with a materialistic mechanism was shattering to the comfort of nineteenth century Englishmen.

The political stakes involved the introduction and acceptance of new biological theories in Victorian times were higher than one might suspect today. Victorians compounded the influence of scientific theories as they tended to believe that what *is* in nature, *ought* to be in society. Given this interpretation, the implications and repercussions of scientific theories were enormous. If nature were revealed to be godless — red in tooth and claw — this would be regarded by some people as a incentive to remove the moral restraints from the underclasses who could gain materially by changing the order of nineteenth century British society. And if science represents a special kind of politics and the history of science is the history of the power blocs and interest groups which constitute society's knowledge (Moore: 1986; 326), the wealthy aristocracy had a huge vested interest in preserving science and society as it existed as this group had the most to lose in terms of wealth and privileges.

Mantell, Owen and Grant employed dinosaurs and different theories of evolution and religious belief in acts of creation as weapons in the growing ideological warfare between these classes (Torrens: 1992; 40). Although these events all took place twenty five years before Darwin was to publish his evolutionary theory, evolutionary ideas were already a divisive issue.

Natural historians who continued to believe that God had created species in their present, unchanging forms — or, as Owen believed, "foreknew" all the modifications — led the attack on Lamarck's materialistic theory. Most early nineteenth century paleontologists believed that beneath the diversity and apparent irregularity of the organic world there existed an underlying order. Their principal objective therefore was to discover and illustrate that order, to define the plan and purpose that existed in nature (Rainger: 1992; 268). In the divine design theory popular in the first half of the nineteenth century, the wisdom and benevolence of the Creator was alone responsible for the complexity of each type or species form and its adaption to the organism's way of life. Nature in itself could never have produced these structures or variations without the Divine Creator's assistance. The Almighty did not randomly modify form, although nineteenth century scholars of life came increasingly to believe that He did allow variations on fixed themes, that is, variation within species. The purpose of the universe, of course, was to provide a satisfactory home for humans.

In 1809, Lamarck postulated that there was an intrinsic tendency of organisms to strive toward perfection; they evolved progressively from simpler to more complex forms. Species, according to Lamarck, did not so much disappear as gradually grow into something different, and in his mind, improved. Lamarck supported the idea of evolution, but, of course, not extinctions. This was, he said, the "observed" trend in nature (Lamarck: 1809; 102). His British followers emphasized the notion of progression in Lamarck's evolutionary theory, in which creatures become more complex and "advanced" over time.

Owen billed the newly created Dinosauria as the most advanced of all reptiles (Owen: 1841; 200).

> The *Megalosaurus* and *Iguanodons* rejoicing in these undeniably most perfect modifications of the Reptilian type, attained the greatest bulk, and must have played the most conspicuous parts, in their respective characters as devourers of animals and feeders upon vegetables, that this earth has ever witnessed in oviparous and cold-blood creatures.

Owen argued that the dinosaurs were the earliest known members of the class Reptilia and were the "highest" form of reptile — the crown of cold-blooded reptilian creation. Living reptiles were established as a much "lower," or less advanced, form than their megalithic ancestors.

Owen was "probably responding to the developmental theories of Robert Edmond Grant" when he created the Dinosauria and established the *Iguanodon* as its most prominent symbol (Desmond: 1979; 224). Owen did not share Grant's materialistic, evolutionary views and believed that his reptilian fossil discoveries gave him evidence that made the evolutionary speculations of Lamarck indefensible (Desmond: 1975; 21). In the 1841 BAAS speech in which he created the Dinosauria, Owen continued to involve a Creator and Lawmaker and to believe that species had been created in their present, unchanging forms — or, evolved according to some Divine plan in contrast to the unplanned, materialistic, Lamarckian transmutationist approach. Owen based his work on the idea that species did change over time, but in a preplanned pattern ordained by God. Owen believed that each animal within each major group was a variation of the "ideal archetype" of that group and that the "Divine mind which planned the Archetype also foreknew all its modifications" (1841: 200).

Owen undermined Grant's Lamarckian schema when he commented that there was no gradation or evolutionary passage from one type of fossil reptile into another. For Owen, the fossil reptiles were each "distinct instances of Creative Power, living proofs of a divine will and the works of a divine hand, ever superintending and ruling the existence of our world" (Owen: 1841: 202). Owen's preplanned evolution was antithetical to the ideas of Lamarck. Lamarck's form of evolution deposed humans from their privileged place atop all of creation, lacked a benevolent and guiding Divine Creator and His purpose for man's existence, and did away with Owen's archetypical forms.

To further rebut the claims of the intrinsic progressiveness that the Lamarckians claimed to see in animal remains discovered in the fossil record, the ancient reptile dinosaurs were made to possess a more "advanced" anatomy and physiology than that of living reptiles, including iguanas and crocodiles. Owen strengthened his argument against the progressive evolutionists when he bestowed a suite of mammalian characteristics upon the long extinct *Iguanodon* and made the animal superior to its extant descendants. As part of his dinosaur reconstruction program, Owen radically transformed Mantell's *Iguanodon* from a huge, crawling lizard into an upright mammalian, rhinoceros-like creature supported by four stumpy legs. Mammals, including humans, were understood to be located at the apex of creation — the most advanced group to have ever graced the face of the earth — and with the *Iguanodon* closely linked to living mammals, including elephants and rhinoceroses, Owen was ensuring that his peers understood how much superior the dinosaurs were to their distant offspring, the living reptiles.

Owen refuted the simple chain of progressive transmutation when he speculated that the dinosaurs resembled mammals anatomically as well as physiologically, implicitly making the currently living modern reptiles even more primitive in comparison to their extinct ancestors (Desmond: 1979: 226). The inferiority of the living reptiles to their ancestors, the mighty, complex and mammal-like dinosaurs effectively turned the simple chain of progressive transmutation on its head. (Reptiles had long been regarded as "morally corrupt," rather low sorts of creatures, as expressed in Victorian natural history books with their tales of cold-blooded crocodiles and strange and terrible dinosaurs. The moralistic view of natural history prevalent in Victorian times no doubt encouraged misjudgments concerning the dinosaurs (Benton: 1991; 40).) Owen's *Iguanodon* reconstruction gave him a solid base from which to argue that if a Lamarckian progression from simplicity to complexity had occurred, reptiles in our modern era would not be such comparatively inferior creatures when compared to their predecessors (Owen: 1841; 201).

> The period when the class of Reptiles flourished under the widest modification, in the greatest number and the highest grade of organization, is past; and since the extinction of the Dinosaurian order, it has been declining. The Reptilia are now in great part superseded by higher classes: Pterodactyls have given way to Birds; *Megalosaurs* and *Iguanodons* to carnivorous and herbivorous mammalia; but the sudden extinction of the one, and abrupt appearance of the other, are alike inexplicable on any known natural causes or analogies.

Owen suggested that the peak of reptilian development had been achieved eons ago as *Iguanodon* fossils revealed dinosaurs to be "the crowns of reptilian creation" and "the nearest approach to mammals" (Owen: 1841; 201). Since that long ago period when dinosaurs had reigned on earth, the reptiles had sunk very low in terms of superior "organization" with the mammals having surpassed them. Lest there be any mistake in what this meant, Owen (1841; 200) wrote:

> If the present species of animals had resulted from progressive development and transmutation of former species, each class ought now to present its typical characters under their highest recognized conditions of organization: but the review of the characters of fossil Reptiles, taken in the present Report, proves that this is not the case.

Owen, then, argued that a decline in reptilian "organization" had occurred and this refuted the transmutationists' progressive evolutionary theory in which life forms became more complex or "higher" through time. Owen (1841; 201) further speculated that dinosaurs in general had led more vigorous lives than extant reptiles:

> Their superior adaptations to terrestrial life were further evidence that they enjoyed the function of such a highly-organized centre of circulation in a degree more nearly approaching that which now characterizes the warm-blooded Vertebrata.

Despite referring to the dinosaurs as "cold-blooded," Owen repeatedly likened the crowns of reptilian creation to pachydermal mammals in terms of their physiology. Discussing the Wealden formation, Owen observed that it "is likewise characterized by the prevalence of those dinosaurian Reptiles which in structure most nearly approach Mammalia" (Owen: 1841; 142).

This early suggestion that dinosaurs may have risen above the stereotypical reptilian cold-bloodedness (Wilford: 1975, 70) may have been based to counter Lamarck's own criterion of vascular anatomy (Lamarck: 1809: 280). The extinct saurians had previously been segregated from the warm-blooded birds and mammals, joining the Reptilia and therefore the "lower vertebrates." With this statement, Owen had postulated that these prehistoric saurians showed the closest approach in a reptile to the warm-blooded classes.

Nineteenth-century naturalists used their warm-blooded/cold-blooded dichotomy to classify all vertebrates into two grand divisions, the warm-blooded creatures being "higher" than the "lower" cold-blood ones. The "higher vertebrates" included two classes, Aves and Mammalia.

At the bottom were the "lower vertebrates," the classes without metabolic control of their body heat. All the fishes, the Amphibia, and the Reptilia were lumped together in this category. (Scientists today believe that there is a spectrum of metabolic ranges; there are now thought to be five or six different kinds of endo- or ectothermy. The current consensus (if there can be said to be any) is that dinosaurs were not strictly ectothermic, but fell short of full-fledged endothermy (McGowan: 1991; 154).)

Owen (1841; 204) also stated that the dinosaurs' "thoracic structure" indicated they may have had four-chambered heart similar to those of modern mammals.

> The Dinosaurs, having the same thoracic structure as the Crocodiles, may be concluded to have possessed a four-chambered heart; and, from their superior adaptation to terrestrial life, to have enjoyed the function of such a highly-organized centre of circulation in a degree more nearly approaching that which now characterizes the warm-blooded Vertebrata.

Owen presumed that, like crocodiles, dinosaurs needed good circulatory systems to survive in the warmer climate he believed they lived in. Owen endowed the dinosaurs with a four-chambered heart, complete with a division in the middle separating the carbon dioxide-laden venous blood from the oxygen-rich arterial blood, similar to a mammal's heart, but differing from a reptile's. In the lizards Cuvier used as the model for his fossil-lizard, the venous blood mixes with arterial blood in the heart. This is less efficient for the production of energy as the tissue in these reptiles receives only partly re-oxygenated blood (Desmond: 1975; 22). Due to a lack of pertinent evidence, even today, scientists debate about what type of hearts dinosaurs may have had. Theories from four to eight chambered hearts circulate (Lemonick: 1993; 61) as do theories about a multiple number of hearts (Bakker: 1988; 363).

Owen concluded his report with a comment about the ecological importance of the dinosaurs and put their physiology into an historic perspective for the reader (Owen: 1841; 200).

> The *Megalosaurs* and *Iguanodons* rejoicing in these most perfect modifications of the Reptilian type, attained the greatest bulk, and must have played the most conspicuous parts, in their respective characters as devourers of animals and feeders upon vegetables, that this world has ever witnessed in oviparous and cold-blooded creatures. They were as superior in organization and in bulk to the Crocodiles that preceded them as to those which came after them.

Owen delivered what was probably the first theory to account for the extinction of the dinosaurs. Dinosaurs had not evolved from some lower reptilian stock but had been created by God (Owen: 1841; 202).

> The evidence . . . permits of no other conclusion than that the different species of Reptiles were suddenly introduced upon the earth's surface, although it demonstrates a certain systematic regularity in the order of their appearance.

The Creator had placed dinosaurs on earth at a particular time in the Mesozoic because that was when the atmospheric conditions of the planet were most suited to them. Owen inferred that the Mesozoic atmosphere was oxygen-deficient from the abundance of giant cold-blooded Mesozoic reptiles and the absence of any significant warm-blooded mammals in the same period (Wilford: 1985; 70). He continued this line of thought, stating that cold-blooded reptiles were less energetic and therefore required less oxygen than warm-blooded mammals would have required. (An endothermic mammal can remain active regardless of ambient temperature, within extremes, but requires a much greater intake of oxygen and energy to release the energy necessary to sustain protracted activity (Desmond: 1975; 188).)

Owen used the absence of endothermic mammals and the presence of dinosaurs, which he assumed were reptile-like and, therefore, exothermic, to support his theory of an oxygen-deficient Mesozoic environment. Owen further hypothesized that the atmosphere was denser at the time because it could support airborne pterodactyls. Owen employed his anatomical skills to study the pterodactyls. As a result, he greatly doubted that the "lowly" physiology of these reptiles could have sustained energetic flapping and instead believed them to be gliders and floaters (Desmond: 1975; 22).

Owen also explained that the rule of reptiles was not to endure forever, for the assumed continuing "invigoration" of the atmosphere rendered the planet uninhabitable for the Dinosauria (cause unknown) and they died en masse at the end of the Cretaceous (Wilford: 1985; 70). This scenario was in complete accord with the uniformitarian school of thought, although the uniformitarians were primarily preoccupied with geology. The change in habitat allowed "the beautiful adaptation of the structure of birds to a medium thus rendered both lighter and more invigorating" (Owen: 1841; 203). The discovery of the remains of a pterosaur, an extinct flying reptile, in the Wealden strata of the Cretaceous was cited as evidence of the beginning of the process of "invigoration" at this time (Desmond: 1975; 22). The invigoration of the atmosphere was evident as it was now dense enough with oxygen to support a soaring pterosaur aloft. But paleontological finds in the Wealden strata indicated the *Iguanodon* and *Hylaeosaurus* dinosaurs were also present in this more invigorating environment (Wilford: 1985; 22). These finds weakened Owen's hypothesis as these dinosaurs were alive and well in the more invigorated climate that was supposed to have brought about their demise. Owen solved this problem toward the end of his report (Owen: 1841; 203) when he speculated that these particular dinosaurs may have led more vigorous lives than their predecessors.

According to Owen, what ensued during geological history was a degeneration of the advanced and impressive dinosaurs into the present "swarm of small Lacertians" (reptiles) (Owen: 1841; 203). While emphasizing the superiority of the dinosaurs over living reptiles, Owen reasoned that if this was evolution, it was backwards — a retrograde evolution. The dinosaurs were, of course, long since dead and their reptilian replacements did not measure up by any criteria; they were simpler creatures, not of their predecessors statures in any way. Owen had exposed a weakness in the progressive concept of evolution and capitalized on it by populating his Mesozoic with dinosaurs as a ploy against the evolutionists.

Owen himself recognized that he had made extremely bold conjectures in his address declaring that "a too cautious observer would, perhaps, have shrunk from such speculations" (Owen: 1841; 204). Owen likely saw his role as an heroic one where he fitted into the model established by his friend, the Romantic Thomas Carlyle. Owen fit the heroic mold as he had an autocratic, larger-than-life personality and had made numerous contributions to the fields of comparative anatomy and paleontology. In Carlyle's view, subscribed to by many at this time, heroes or leaders should be addressing the issues and problems of the day. The hero-leader's legitimacy stemmed from talent and expertise, not from ties to privileged families or long-established institutions (Rupke: 1994; 66).

Regardless of Owen's heroic ambitions, his self-proclaimed speculative comments do not bear up under close scrutiny. Desmond (1975; 22) believes Owen to have been presumptuous in forming the Order Dinosauria from only three species with terrestriality and five fused vertebrae in common. Owen's speculations about the varying oxygen levels of the earth's atmosphere were related to the rule of the dinosaurs over the mammals in the "Age of Reptiles." Oxygen levels were low because the reptiles were ectotherms (sort of) and required less oxygen than the less prevalent endotherms, or mammals. Equally dinosaurs were ectotherms (sort of) because there was not enough oxygen in the atmosphere for them to be anything else. His argument concerning the density of the earth's atmosphere may have had some anatomical justification as Owen believed that pterosaurs were incapable of muscle generated flight — the atmosphere had to be dense and thick to hold them up in the air. But gliding birds still exist today in a less dense atmosphere, although they are much smaller than the pterodactyls. And, finally, the reasoning cited to describe the demise of the dinosaurs was weak, with some dinosaurs continuing to live during the wrong periods for the purposes of his argument. Owen compensated for the late arrival in the geological record of the *Iguanodon* and *Hylaeosaurus* by making them more vigorous than the earlier dinosaurs. For that matter, why the inferior lizards survived in the new, invigorated climate where the superior, more mammalian dinosaurs could not is a puzzle.

The creation of the *Iguanodon* and the Dinosauria were inspired by very little fossil evidence, unlike Cuvier's fossil reconstructions which were comprised of fossil-bones from a number of individuals of the same species and made up at least one nearly complete skeleton. In comparison, Owen's fossil evidence is unimpressive with the dinosaurs being brought to life "on the basis of some teeth and a few bones" (Rudwick: 1992; 141). A peer of Owen's noted that the "since only a few bones, teeth, and fragments of the jaws of these animals have been discovered, it has been necessary to trust to imagination for the greater part of their restoration" (Unger: 1851; 107).

Owen's justification of the Dinosauria lay in "non-evidential facts"; facts derived from religious belief, not by examining the Book of Nature. The reasoning based on the non-evidential facts was not shared, or acknowledged as valid, by the transmutationists. Owen's non-evidential facts included several ideas with massive repercussions, namely: humans were created by the Divine Planner to fill the position at the apex of all of nature; the purpose of everything that has existed on earth was to prepare for the birth of humankind (Buckland took this reasoning a step further when he declared that earlier periods in the earth's history had been lush with plants so that they could die and decay, producing coal for the needs of the British Empire.); humans arrived at a time when the correct conditions on earth had been prepared for them; and, all changes in the earth's history were pre-planned. When Owen's non-evidential facts are taken into consideration, his reconstruction of the *Iguanodon* and creation of the Dinosauria are credible.

Owen's Dinosaurian order can also be interpreted as the product of contemporary advances in taxonomic practice, however. Buckland and Mantell had relied heavily on dental characteristics, and to these Owen added skeletal features, in particular "vertebrae as fundamental criterion in reptilian taxonomy" (Rupke: 1994; 134). The anti-transformist implications of Owen's reptilian reports were a welcome side-effect and part of Owen's overall Cuvierian, functionalist mission, but this was not the formative concern.

Following this line of argument, the driving purpose of Owen's dinosaurian work was not a fear of Grantian transformism as discoveries in the fossil record were already revealing that the simple progressive lineages of the transmutation theory did not match the stratigraphic sequences of the fossils that were being quarried. Around 1830, Geoffroy presented memoirs to the Academie des Sciences in Paris which were subsequently published as his *Recherches sur de grands sauriens trouves a l'etat fossile* (1831). In his *Recherches,* Geoffroy documented his reptilian research and described an evolutionary theory in which the transmutation, or evolution, of species was caused by environmental changes, especially through compositional changes in the atmosphere (Rupke: 1983; 175). Geoffroy traced the changes in various reptilian forms, including the ichthyosaurs, plesiosaurs, pterodactyls and teleosaurs (an extinct crocodilian animal), through time and hypothesized that they made up a sequence, each type having given rise to the next. The teleosaur, finally, had given rise to early mammals, such as the *Megatherium.*

Buckland countered Geoffroy's argument in favour of transmutation by showing that the various reptilian forms described in Geoffroy's reptilian lineage were excavated from the same geological stratum, and not successive strata. This established that these animals co-existed and did not show that they lived sequentially through time. Buckland continued his argument, referring to the four basic groups into which Cuvier had divided the animal kingdom and stating that they all occur at the same time in the oldest fossil beds. These groups, then, could not have descended from each other either. Buckland went on to state that the basic anatomical plan of each group had remained unchanged, despite the many successive creations through time. For good measure, he added that creative design was proved by the existence of these animals because each wave of newly created creatures was perfectly adapted to changes in the environment during that period. Buckland added that this could not be explained using either Lamarck or Geoffroy's evolutionary mechanisms (Rupke: 1983; 175). The debate remained open, with both sides citing and interpreting different evidence.

Owen's inclusion of the following note in his 1841 Report describing Grant's theory in great detail (1841; 197) is difficult to explain if Owen's purpose was not to counter Grantian evolution. Owen seems to have purposefully included this quote so that he could dismantle it piece by piece later.

> The following are the latest terms in which the transmutation-theory has been promulgated, as supported by Palaeontology: The life of animals exhibits a continued series of changes, which occupy so short a period that we can generally trace their entire order of succession, and perceive the whole chain of their metamorphoses. But the metamorphoses of species proceed so slowly with regard to us, that we can neither perceive their origin, their maturity, nor their decay; and we ascribe to them a kind of perpetuity on the earth. A slight inspection of the organic relics deposited in the crust of the globe, shows that the forms of species, and the whole zoology of our planet, have been constantly changing, and that the organic kingdoms, like the surface they inhabit, have been gradually developed from a simpler state to their present condition.— Dr. Grant's Lectures on Comparative Anatomy, Lancet, 1835, p.1001.

Owen's arguments, then, appear to have been aimed very much at undercutting the progressive theories of the materialistic evolutionists, or transmutationists, including those of Grant. He employed the fossil record to negate the evidence supporting an unabated ascent of organisms from "lower" levels to "higher" levels of development — evidence the transmutationists felt they needed to support their progressive theory of evolution (Desmond: 1975; 23). As a comparative anatomist and paleontologist, Owen understood how the transmutation theory could be refuted. He showed that the progressive trend in the fossil record was an illusion by trying to demonstrate that a Lamarckian ascent from simple to complex organisms was non-existent. The long extinct *Iguanodon* and its dinosaurian brethren were more complex creatures than extant reptiles. Owen reconstructed his land dwelling dinosaurs with huge, pillar-like limbs which gave them a superficial resemblance to the large pachyderms — elephants, rhinoceroses and hippopotamuses — currently inhabiting the earth and near the apex of the scale of complexity. These dinosaurian creatures were also superior endotherms, as Owen believed they could control their body temperatures internally, unlike the modern reptiles. The group was also united by the possession of five fused vertebrae welded to the pelvic girdle. The huge skeletons of the dinosaurs also suggested that they had much more massive bodies than the previously discovered terrestrial and marine lizards (small dinosaurs had not yet been discovered).

Owen believed that *Iguanodon* and *Megalosaurus* fossils revealed that dinosaurs stood at the apex of reptilian development and were the nearest approach to mammals. Owen's Dinosauria were the "crowns of reptilian creation," and each and every one of their reptilian replacements was a simpler form of ectotherm — inferior in anatomy and physiology from their gigantic predecessors. Lizards are lower on the transmutationists' hierarchical scale of complexity while appearing much later in the timescale — a fact which contradicts a linear ascent of species. If today's species are the result of a progressive development of earlier species, Owen argued, each ought now to be in its most highly organized form living on the planet. According to this argument, the most advanced reptiles ever to exist most definitely should not be extinct. If this was evolution, Lamarck and the transmutationists had it backwards — it was a retrograde, not progressive, evolution. Owen emphasized and exploited this weakness, stressing the superiority of the Dinosauria, living in their glorious "Age of Reptiles."

In the "Summary" of his 1841 Report, Owen employed the same evidence to undermine the tranformists' theory of increasing complexity and progression through time while dismissing the remarkably resilient diluvial theory which involved a series of floods covering the earth, culminating with Noah's Flood as described in Genesis. The spatial distribution of reptiles through the rocks, Owen stated, did not reveal brief inundations of water washing over the many life forms as proscribed by the diluvial theory. The stratigraphic distribution of fossils also provided him with evidence of how the various fossil species had been distributed through time, in a non-progressive manner (Owen: 1841; 203).

Owen, however, did not stop at creating his dinosaur reconstructions on paper. He and Benjamin Waterhouse Hawkins collaborated to create huge sculptures of the *Iguanodon* and other dinosaurs for the 1851 World's Fair. These dinosaur reconstructions were later moved to Sydenham, a suburb of London, for permanent display. In building these reconstructions, Owen and Hawkins perpetuated the illusion that more was known about these creatures than it was prudent to suggest in the 1850s. Only extremely incomplete skeletons remained available upon which to base the reconstructed the *Iguanodon* as a lumbering quadruped. An Austrian botanist of the time, Franz Unger (1851; 107) noted that the

> strange nature of ... the gigantic bony-crested *Iguanodon* and the monstrous *Hylaeosaurus* hold the prominent places. Unfortunately, since only a few bones, teeth, and fragments of the jaws of these animals have been discovered, it has been necessary to trust to imagination for the greater part of the world of their restoration, but we shall have less and less occasion to have recourse to its aid; for as new discoveries are made, less difficulty will be found in divining approximately or ascertaining accurately the physiognomy of these strange beings.

Iguanodon was not uniquely misrepresented at Sydenham. Other species of prehistoric creatures were miscast as large turtle- or frog-like animals. These models, the first life-sized reconstructions of dinosaurs, still stand in London's Sydenham Park (Lessem and Glut: 1993; 227). The *Iguanodon* resembled a reptilian rhinoceros as Hawkins gave it a horn on its end of its nose, similar to the one Martin had given it in "The Country of the *Iguanodon,*" the frontispiece to Mantell's *The Wonders of Geology* (1838). According to Rupke (1994: 132), Owen's influence was not all encompassing; Owen had correctly observed that the horn was in fact a claw-bone, or, more precisely, a spiky thumb.

To increase publicity, and reinforce the public's understanding of Owen's Cuvierian functionalist science, Hawkins invited Owen and twenty other scientists as guests to a New Year's eve dinner to be held inside the belly of a partially completed reconstruction of the *Iguanodon*. Owen was honoured with a position at the head of the table under a portrait of Cuvier. Owen commented (Barber: 1980; 164)

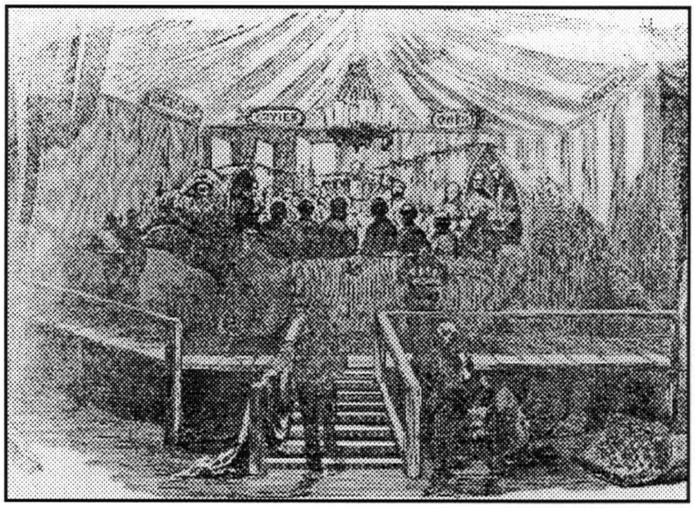

Figure 18: The completion of the Crystal Palace *Îguanodon* reconstruction project was celebrated New Year's Eve in Hyde Park, 1853.

> (u)pon the course of reasoning by which Cuvier, and other comparative anatomists, were enabled to build up the various animals of which but small remains were at first presented to their anxious study; but which, when afterwards increase, served to develop and confirm their confident conceptions — instancing the *Megalosaurus*, the *Iguanodon*, and *Dinornis* as striking examples.

The *Iguanodon* dinner was in some ways the culmination of the early nineteenth-century Cuvierian tradition. Ironically, the Sydenham reconstructions are Richard Owen's best known fossil work and are an example where his confidence in the Cuvierian functionalist/comparative anatomy method had over-reached itself. The way with which flesh and additional bones had been added to the very few *Iguanodon* fragments actually known served to disprove the myth that the whole animals could be accurately reconstructed from a few of its constituent parts. Later evidence, primarily from a herd of *Iguanodon* excavated from a mine shaft in Bernisaart, Belgium in 1871, revealed that Owen's *Iguanodon* model was seriously flawed in a number of respects, most obviously in its quadrupedal position.

Richard Owen's Advancing Career

To determine where Owen may have stood in the dispute between the supporters of conflicting theories, and what motivation he may have had to employ the evidence he had at hand to support different theories, an examination of his career will be undertaken.

Owen's background and professional allegiances pulled him in opposite directions. His education, training, social status, and lack of privilege and wealth all pulled him in one direction: toward change in society and the organization and practice of science. The museum committees that he reported to and controlled his career advancement all members hailed from backgrounds of wealth, power and prestige and were bent on maintaining the status quo in which they controlled society. Owen's actions appear as complex as the situation he found himself working within. His career will be dissected with particular attention to his biological training and experience, what he believed science should reflect to society (his politics), for whom he worked, and upon whom he depended for advancement.

Owen's motivations for creating his unique form of *Iguanodon* may have been inspired in part by his need to advance his career. Owen was not born to independent wealth. Unlike many of the natural historian gentlemen scientists of his day, he had to earn his living through a profession.

Owen was unable to afford a university education, apart from attending the University of Edinburgh during the autumn of 1824 and spring of 1825. Instead, he earned his way in the field through a series of apprenticeships. His 57-year museum career was spent at two institutions: the Hunterian Museum and the British Museum, both in London. Owen joined the Royal College of Surgeons' Hunterian Museum at the age of 22 as Assistant Conservator, and was promoted in 1842, at age 38 to Conservator. In 1856, at 52 years of age, Owen became superintendent of the natural history collections at the British Museum. He retired in 1883, at age 79.

When Owen did manage to land a professional job, the Museum paid him little for his curatorial work at the Hunterian Museum; his salary ranged from 120 to 500 pounds per year over the 29 years he worked there. This was the same amount that many of the surgeons on the Museum Committee were paid for their minimal duties at the Association. Owen's position was not secure; when cost cutting measures were suggested, the well-paid Museum Committee members suggested that Owen's meagre salary be reduced instead of theirs (Rupke: 1994; 19).

Owen's advancement was dependent upon the support of a group of wealthy Oxford and Cambridge (or Oxbridge) graduates and fellows, Tory peers, and other leading conservative members of society (Rupke: 1994; 49). He mixed with these leaders of English society when he served on many committees and joined (by invitation) several London clubs. The Oxford graduates backed Owen in his clashes with the Museum Committee at the Hunterian Museum, obtained Crown support for him, and diverted considerable funds from the BAAS to his projects (which allowed him to work on the British Fossil Reports described above). This group also controlled the allocation of funds for museum building in England through museum committees and members in the governments of the time. Nearly all of England's great museums were built in Owen's lifetime and he strongly believed that establishing museums was part of professionalizing science and attached great value to it. Owen's cooperation with the Oxbridge group paid off in terms of career enhancement, cash injections, a knighthood, a pension and supplementary income from the government (Rupke: 1994; 54).

The patronage of William Buckland, in particular, gave Owen access to a circle of Oxbridge educated museum trustees. For Buckland, who was Dean of Westminster, only design arguments were acceptable as anything else would be incompatible with the Church's teachings. Buckland, however, was not only a churchman, he was also professor of mineralogy and geology at Oxford where natural history was part of the curriculum. At Oxford, between 50 to 60 percent of the graduates were destined for Holy Orders (Rupke: 1994; 59) so materialistic evolution was excluded from the Oxford curriculum.

Owen's conservative supporters likely would not have offered to assist him in his professional career had his science not seemed to support their ends — a stable and hierarchical society with their class at the apex of all humanity, which was, of course, at the apex of the natural kingdom, as decreed by the Almighty. The materialistic theory of transmutation was believed to be one of the destabilizing influences on the European continent and was thought to be in part responsible for undesirable political activity, such as the French Revolution, which this class desperately sought to keep from Great Britain.

Owen was sensitive to the spirit in which this help was given as "his reports were strategic masterpieces: scrupulously documented papers, often ending in attacks on Lamarckism and tacit support for the clerisy's socially stratified cosmos" (Desmond: 1989; 354). The reports had to support the social status quo where the world was a perfectly functioning whole designed by the Creator. This served to sanctify the privileges of the ruling classes.

The exposure of his work made Owen the best known scientist in the British Empire at one point in his career (Rupke: 1994; 13). This fame was of great help in promoting his, and his supporters', theory of Divine Creation with all of its socially stabilizing ideological effects. It also served Owen as it increased his professional stature and his job security. Owen's work on the *Iguanodon* and the Order Dinosauria in general, was especially sensitive in that it had sparked an enormous interest in the public. The dinosaurs that Owen created met with two audiences, the conservative Oxbridge group who supported him and the general public.

Owen's models appear to have been heavily influenced by the message they were expected to communicate to the popular audience for which they were built. Earlier reconstructions of prehistoric, fossilized creatures had been created by natural historians for their peers (Rudwick: 1992; 236). The audience for Owen's dinosaur reconstructions quickly was broader, reaching the general public in magazines, newspapers, periodicals and as the life-size sculptures created by Hawkins and Owen that were seen in the first World's Fair by thousands of people.

The "popularization of science," however, is not simply a one-way process from the informed scientists to their general public in which scientists simplified and translated their work, or allowed someone else to translate their findings; the process is a more complicated, where "knowledge" may be significantly, and intentionally, altered during the process of interpretation, and may be used to promote social objectives that have little to do with the supposedly disinterested character of science (Shapin: 1989). The reaction of the intended audience can also influence the creator's work.

The scientists' popular works were also influenced by the artists with whom they achieved these collaborations, sometimes whether the scientists agreed to the "improvements" or not. Leading scientists contributed to the genre as advisers to more popular authors or artists: Mantell's collaboration with John Martin and Owen's role as adviser to Hawkins on the Crystal Palace exhibits, described above, are examples of this trend. In a collaboration between artists and scientists, scientists generally have a huge influence on the artists as they guide their artistic partners through the anatomical nuances of extinct creatures (Lessem: 1996; 37). However, the influence of artists on scientists has also been observed. Hawkins, in constructing his *Iguanodon* at Crystal Palace, elected to decorate his model with a "tusk" on its nose and not to heed Owen's advice to the contrary.

To increase his professional independence from museum committees and benefactors, Owen became one of the driving forces in the Victorian movement to develop independent, institutionally supported positions for professional natural historians to expand the field beyond being a hobby for clerics and gentlemen with time on their hands. To this end, Owen worked ceaselessly to provide accommodation for museum collections, to expand such collections, and to turn these to educational and research purposes.

Owen's many-pronged ventures may have also resulted in struggles with other professionals who were also seeking to support themselves through their scientific labours. After Cuvier's death in 1832 there was a power struggle in England about who should lead the Oxbridge functionalist faction and inherit the French comparative anatomist's scientific mantle (Torrens: 1992; 40). The leading candidates, or combatants, included Richard Owen and his colleagues, Gideon Mantell and Robert Grant. Owen was a well-connected professional working in London, Mantell was a surgeon and provincial amateur who discovered the *Iguanodon*, and Grant was a poorly paid comparative anatomy and zoology professor at London's University College who supported Lamarckian evolution as means of producing the varied character of the fossils (Torrens: 1992; 40). None of these three scientists were men of independent means, and each required a salary to support himself.

To the extent that there was a hidden, competitive agenda buried in Owen's saurian taxonomy, it may have been directed toward Mantell (Rupke: 1994; 134). Mantell's reputation as a natural historian was based upon his discovery of the *Iguanodon* and the *Hylaeosaurus*; in the early 1830s, he had brought "the age of the reptiles" to life in 19th century Britain. Owen usurped Mantell's intellectual ownership of the saurian creatures by naming, creating and placing the dinosaurs in a taxonomic group of their own. This may have been the cause of Mantell being described as Owen's "arch-hater" in an 1845 journal entry of Thomas Henry Huxley, who at that time was an aspiring young naturalist (Rupke: 1994; 6).

One benefit of the alleged hidden competition and intellectual appropriation of Mantell's monsters was that it may have improved Owen's likelihood of obtaining financial support for his research. The provincially based BAAS had supported the British fossil reptile research of Owen, the metropolitan scientist with its limited funds, while the London-based Royal Society was encouraging Mantell. Robert Grant, the third British researcher in the field at the time, had to make do with what little he could earn from teaching (Torrens: 1992; 42). Owen may have used the "appropriated" dinosaurs to impress his funders and gain grants for himself while arguing that he was the scientist in the best professional position and could make the most efficient use of the funds ensuring greater progress in the research.

Owen was not supportive of the advancement of his colleagues. In the early 1830s, he blocked Robert Grant's appointment as comparative anatomist to the Zoological Society of London (Desmond: 1979; 225). To put Owen's veto of Grant's career advancement in context, Owen was regarded as a very difficult character who crossed every prominent paleontologist in Britain at some point in his long career. (Even Rupke, Owen's strongest defender in the history of science literature, has commented that Owen was known to be petty, and failed to act with the magnanimity which, given his position and fame, he could well afford (Rupke: 1994; 8). Huxley, who at that stage in his career posed no threat to Owen, noted: "The truth is, he is the superior of most, and does not conceal that he knows it, and it must be confessed that he does some very ill-natured tricks now and then" (Huxley: 1901; 101).)

In the first half of his career, Owen was dependent upon the favours of a small but influential group of conservative Oxford men. Owen, however, had his own agenda in addition to fulfilling his obligations to this group. He was attempting to build a profession which would leave natural historians independent of these political constraints. The leader of this newly developed profession was to be Owen — and not any of his colleagues.

The Next Cascade of Representations

Opinions began to waver in the late 1850s about the correctness of Owen's models — even his own research pointed to a number of inconsistencies. Unfortunately for Owen's reputation, Thomas Huxley who was to gain fame as Darwin's bulldog, was to examine Owen's *Iguanodon* in light of newly exposed fossil evidence and question Owen's Cuvierian assumptions.

In 1858, four years after Owen's Sydenham dinosaurs were erected, the American paleontologist Joseph Leidy commissioned Hawkins to paint and reconstruct the duckbilled *Hadrosaurus* using fragmentary fossils discovered in southern New Jersey. Leidy had found a

Hadrosaurus thigh bone almost twice the length of the humerus of the upper arm. The result was the first mounted skeleton of a dinosaur which stood nearly erect and was propped up by a huge tail, rather like a giant kangaroo (Lessem: 1996; 38). Leidy (1858; 105) state:

> The great disproportion of size between the fore and back parts of the skeleton of *Hadrosaurus*, leads me to suspect that this great extinct herbivorous lizard may have been in the habit of browsing, sustaining itself, kangaroo-like, in an erect position on its back extremities and tail.

Huxley re-examined the *Iguanodon* keeping in mind Leidy's hypothesis that the *Hadrosaurus* was bipedal. As the front legs of *Iguanodon* fossils had yet to be discovered, it was impossible to know if this dinosaur had a bipedal stance. Trackways of large three-toed fossil-footprints in New Jersey seemed to match the fossil footprints of the *Iguanodon* and supported the bipedal theory. Huxley's re-examination, then, involved launching an attack on Owen's functionalist methodology and the results he obtained using this approach. Huxley began by critiquing Owen's version of Cuvier's functionalism. Owen had achieved his best known successes using this methodology to describe dinosaurs, cephalopods, the *Glyptodon* and the *Nautilus* and cephalopods. Huxley argued that Cuvier had worked empirically and not according to the law of necessary correlation of parts. "Therefore, whatever Cuvier himself may say, or others may repeat, it seems quite clear that the principle of his restorations was not that of the physiological correlation or co-adaptation of organs." (Huxley: 1856; 111). Huxley capped these assertions with the claim that a law simply does not exist, stating that "we have no proof that the various organs which we find combined within a single animals must, of necessity, go together" (Huxley: 1856; 102).

Huxley also described the hindquarters and three-toed foot of the *Iguanodon* as "wonderfully approaching" those of birds. The *Iguanodon*, contrary to the quadrupedal image of Owen's Crystal Palace exhibit, may have been capable of erect posture and of hopping or running on its hind legs (Wilford: 1975; 98). This only served to emphasize the paucity of fossil material upon which Owen based his restorations in the 1850s.

Huxley's criticism of Cuvier threatened to destroy the credibility of Owen's Cuvierian functionalist research, including his work on the *Iguanodon*. Huxley's critiques of Owen's work were not without political motivation as well. Huxley began his critiques of Owen's work in 1854, when he was first a lecturer at the Museum of Practical Geology. Huxley was beginning to carve himself a professional niche, and it was well before he adopted any evolutionary trappings. The result of demolishing Owen's Cuverian credibility, which had served the needs of his Oxbridge patrons so well, was to reduce Owen's substantial base of power in the museum while increasing his own (Rupke: 1994; 136).

Figure 19: Reconstruction of *Iguanodon* walking on its hind feet and walks or hops.

According to Owen, Huxley misrepresented Cuvier's law by exaggerating its claims of accuracy. Owen continued by saying that Cuvier had acknowledged that some bones, features of bones, and especially mammalian molars, carry more correlative information than others do (Owen: 1860; 134). He then admitted that the law of correlation is based on empirical coincidences, "but these must have a cause, and once this cause is known, the coincidences become correlations, and enter into the category of higher law" (Owen: 1860; 132). In case Huxley had missed the point, Owen added that the critics were simply not as skilled as he or Cuvier were (Owen: 1860; 133).

> The truth is that Cuvier's 'Law of Correlation' is like Ulysses' bow: it is not every one that can use it: and those who are loudest in decrying it are also those to whom palaeontology owes least for the reconstruction of extinct animals from a single bone or tooth.

Huxley's re-interpretations were based on an increasingly well-developed fossil record. He used this newly acquired evidence to criticize the results of Owen's functionalist method. The criticisms did have an effect on Owen in that they prompted him to respond to them, prompting him to state that even Cuvier had noted that certain bones have more correlative importance than others (Rupke: 1994; 137). He also accused Huxley of an attack on divine design and theist belief. Huxley's comments did not act as a catalyst for change in Owen's Cuvierian research methodology. Owen's support of the method he used to reconstruct the *Iguanodon* and for his adaptation-focused studies, such as the *Monograph on the Aye-aye* (a nocturnal lemur from Madagascar) (1863), reaffirmed his deep and long-term commitment to functionalism.

Figure 20: Richard Owen in old age.

Owen continued to study dinosaurs later in his career, publishing occasional memoirs on fossil reptiles under the auspices of his own Palaeontographical Society, a printing club instituted in 1847.

The outcome of any serious research can only be to make two questions grow where only one grew before.

Thorsten Veblen

Chapter 6: Conclusion

Wherein the history and forms of the *Iguanodon* reconstructions and the creation of the Dinosauria are discussed.

Early nineteenth century *Iguanodon* reconstructions are more valuable today as an historic record of human interpretation of the fossil record than they are as accurate expressions of the form and physiology of the long-extinct animal.

Owen's *Iguanodon* reconstructions were created in the 1840s and 1850s during the period when a paradigm shift began in biology from Divine Creation theory to evolutionary theory. Transcendentalist criticism of Cuvier, and by implication of the Cuvier-inspired form of Oxbridge, functionalist, Divine Creation theory, was rearing its head in 1839. The two theories were separated by the inclusion or rejection of religious thought in the natural sciences. The arguments of Owen, and the majority of early nineteenth century scientists, supported the belief in a Divine Planner who infused the universe with order, plan, and purpose. The transmutationists did not require an omnipotent God to create or maintain their world as their theory relied solely on mechanical causes.

Owen used his 1841 general review of terrestrial British fossil reptiles as a basis for argument against continuous progressive development of the transmutationary theories and to overcome what the natural historians of his time believed was a regularity of the progress in fossil record, in which the age of fishes gave way into the age of reptiles which eventually progressed to the mammalian age. This interpretation reversed any argument for progress in the reptilian ancestry.

To achieve this reversal in the progression of life and refute the evolutionists, Owen deviated a handful of times in his lengthy BAAS report from his normal scientific practice — the systematic, rationally-based, search for the simple laws of Nature through the reduction of a collection of careful observations. When he made these deviations, he warned his readers he was about to make "bold speculations." These speculations involved dinosaur physiology and were based on a few bones and teeth from the three fossil species of dinosaurs known at the time. Owen's interpretation of the dinosaurs transformed them from gigantic "Fossil Lizards" into super-reptiles rich in pachydermal-mammalian features.

Owen destroyed the evolutionists' narrative of unbroken ascent while creating an unfolding plan of organization — compatible with a Divine Planner. His precise arguments appear too well-tailored to exposing the weaknesses and combating the "unworthy speculations of the evolutionists" to doubt his target. Owen did not attack the uniformitarians, or degradationists, or any of those who can be sheltered under the umbrella of natural theology and thus did not challenge the role of the Deity. Owen, then, supported the traditional side of the conflict that consisted of a raft of natural theology conceptual schemata formed in harmony with traditional, though not literal, biblical interpretations. He battled against the opposing side of the natural history schism, presented by the materialistic evolutionists whose theory of evolution rejected the Divine participation in natural history.

Owen was beholden to a group of conservative, wealthy, Oxbridge educated men for job security and financial support of his museum-building projects. These men associated evolutionary theory with coarser materialism and social upheaval. It was vital to these supporters that the work of the best known scientist in the British Empire, Owen, reflect their values and reject materialistic evolutionary theory. Owen's paleontological efforts were extremely well-known as his work received a great deal of press coverage in magazines, newspapers and periodicals of the day. Through all this publicity, Owen's *Iguanodon* reconstructions reached a huge audience throughout Great Britain and its English speaking Empire. Owen and Hawkin's Crystal Palace dinosaur reconstructions alone were viewed by hundreds of thousands of people in London. The influence of Owen's work was amplified due to a widespread belief in the nineteenth century that what *is* in nature is what *ought* to be in civilized life.

Today, biology is no longer supposed to be beholden to theology, nor is it expected to underwrite prescribed values for our society. Although scientists must still satisfy funding criteria and serve defined user groups, interests or audiences, these criteria, too, have changed. In the past century, scientists have become professionals trained for the exercise of their skills. They continue to build their professions and advance their careers, where Owen and his successors pioneered the way.

With the introduction of Darwin's theory of evolution by way of natural selection, the evolutionists could shift emphasis away from progression in the fossil record (although it took some time for this to occur). In Darwin's evolutionary theory neither adaptation nor progression could be seen as indications or agents of supernatural plans or control. This meant that there could be no preordained pattern of development and no proscribed progress toward higher forms. Progress was replaced as the fundamental trend of evolution by divergence and specialization. The rise and fall of the progressionist viewpoint is a key factor in the process by which the modern theory of evolution emerged in the course of the nineteenth century.

Although Owen used the fossil record as authoritative evidence against Lamarckian evolution, in later years he, like the majority of his English scientific peers, opposed Darwin's evolutionary mechanism of natural selection rather than the idea of evolution itself. Owen wrote one of the first and most important critical reviews of Darwin's *Origin of Species* in which he criticized Darwin and cited a lack of fossil evidence to support evolutionary theory. While Owen's criticism was not a defense of biblical literalism or of special creation, it is difficult to discover how far his strong sense of designfulness of the organic world was grounded in theological conviction and how far in biological experience or other motivations.

Bibliography

Primary Sources

Buckland, William. 1824. "Notice on the Megalosaurus or Great Fossil Lizard of Stonesfield." in *Transaction of the Geological Society of London*, Vol. 21.

Cuvier, Georges. 1812. *Reserches sur les Ossemens Fossiles des Quadrupedes.* 4 vols. Paris.

1796. *On the Species of Living and Fossil Elephants.*

Darwin, Charles. 1859. *On the Origin of Species.* London: Murrays. Repr. 1988. London: Penguin Books.

Geoffroy Saint Hilaire, Etienne. 1831. *Recherches sur de Grands Sauriens Trouves a l'Etat Fossile.* Paris: Memoires du Museum d'Histoire Naturelle, Vol. 17, pp. 209-229.

Huxley, Thomas H. 1856. "On the Method of Palaeontology." *Annals and Magazine of Natural History,* Vol. 18, pp. 43-54.

Lamarck, J.B. 1809. *Zoological Philosophy: an Exposition with Regard to the Natural History of Animals.* Repr. 1984. Chicago: University of Chicago Press.

Leidy, Joseph. 1858. "Remarks Concerning Hadrosaurus." in *Proceedings of the Academy of Natural Sciences,* Philadelphia, Dec. 14, 1858.

Mantell, Gideon A. 1838. *The Wonders of Geology: or, a familiar exposition of geological phenomena. Being the substance of a course of lectures delivered at Brighton, from notes taken by G.F. Richardson, Curator of the Mantellian Museum etc.* 2 vols. London: Relfe and Fletcher.

1831. "The Geological Age of Reptiles", *Edinburgh New Philosophical Journal,* Apr.-Oct., pp.181-185.

1822. *The Fossils of the South Downs.* London.

1825. "Notice on the Iguanodon, a Newly Discovered Fossil Reptile, from the Sandstone of Tilgate Forest, in Sussex." *in Philosophical Transactions of the Royal Society.* London: p.115.

Owen, Richard. 1837. *The Hunterian Lectures in Comparative Anatomy, May - June 1837.* London: Natural History Pub. 1992.

1860. *Palaeontology.* Edinburgh.

1854. *Geology and Inhabitants in the Ancient World.* 4th Ed. London: Crystal Palace Library.

1849. *On the Nature of Limbs.*

Owen, Richard. 1841. "Report on British fossil reptiles. Part 2." *Reports of thee British Association for the Advancement of Science*, pp. 60-204.

Scientific Memoirs of Huxley. 1898. Eds. Foster, Michael and E. Ray Lankester, Vol. 3, passim. London: Macmillan and Co. Ltd.; New York: D. Appelton and Co.

Secondary Sources

Bakker, Robert. 1988. *The Dinosaur Heresies.* New York: Zebra Books, Kensington Pub. Corp.

Barber, Lynn. 1980. *The Heyday of Natural History.* London: Cape.

Benton, Michael. 1991. "The Myth of the Mesozoic Cannibals." *New Scientist,* Vol. 132, No. 1790, pp. 40 - 44.

1990. *Vertebrate Paleontology: Biology and Evolution.* London: Unwin Hyman.

Blum, Ann Shelby. 1993. *Picturing Nature: American Nineteenth-Century Zoological Illustration.* Princeton, N.J.: Princeton University Press.

Bowler, Peter J. 1992. *The Environmental Sciences.* New York: W.W. Norton and Co.

1989. *The Invention of Progress: the Victorians and the Past.* Oxford: Blackwell.

1986. *Fossils and Progress: Paleontology and the Idea of Progressive Evolution in the Nineteenth Century.* New York: Science History Pub.

1983. *The Eclipse of Darwinism: Anti-Darwinian Evolution Theories in the Decades around 1900.* Baltimore: Johns Hopkins Press.

1976. *Fossils and Progress: Paleontology and the Idea of Progressive Evolution in the Nineteenth Century.* New York: Science History Publications.

Burkhardt, Richard W., Jr. 1984. "The Zoological Philosophy of J.B. Lamarck." in Lamarck, J.B. 1809. *Zoological Philosophy: an Exposition with Regard to the Natural History of Animals.* Repr. 1984. Chicago: University of Chicago Press.

Campbell, John H. 1985. "An Organizational Interpretation of Evolution." in *Evolution at the Crossroads: the New biology and the New Philosophy of Science.* Eds. David J. Depew and Bruce H. Weber, London: MIT Press.

Challinor, J. 1959. "Paleontology and Evolution" in *Darwin's Biological Work: Some Aspects Reconsidered.* Ed. P.R. Bell, Cambridge: Cambridge University Press.

Charig, Alan. 1983. *A New Look at Dinosaurs.* New York: Facts on File.

Colbert, Edwin H. 1968. *Men and Dinosaurs.* New York: E.P. Dutton and Co. Inc.

Delair, Justin B. and William A. S. Sarjeant. 1975. "The Earliest Discoveries of Dinosaurs." *Isis,* Vol. 66, pp. 5-25.

Desmond, Adrian. 1989. *The Politics of Evolution: Morphology, Medicine, and Reform in Radical London.* Chicago: University of Chicago Press.

1982. *Archetypes and Ancestors: Paleontology in Victorian London 1850 - 1875.* London: Blond and Briggs.

1979. "Designing the Dinosaur: Richard Owen's response to Robert Edmond Grant." *Isis,* Vol. 70, pp. 224-234.

1975. *The Hot-Blooded Dinosaurs.* London: Hutchinson Radius.

1974. "Central Park's Fragile Dinosaurs." *Natural History* Vol. 83, pp. 64-71.

Desmond, Adrian and James Moore. 1991. *Darwin: the Life of a Tormented Evolutionist.* New York: Warner Books.

Di Gregorio, Mario A. 1982. "The Dinosaur Connection: a Reinterpretation of T.H. Huxley's Evolutionary View." *Journal of the History of Biology,* Vol. 15, No. 3, pp. 397-418.

Dinosaurs and Their Living Relatives. 1985. London: The British Museum, Natural History, and the Press Syndics of the University of Cambridge.

Dinosaurs Past and Present. 1987. Eds. Czerkas, Sylvia J., and Everett C. Olson, 2 vols. Seattle and London: University of Washington Press and Natural History Museum of Los Angeles County.

Dodson, Peter and Susan Dodson. 1992. "Making the Fossil Record of Dinosaurs." *Modern Geology.* Vol. 16, No. 1-2, pp. 3-16.

Gay, Peter J. 1969. *The Enlightenment: The Science of Freedom.* London: Norton and Company.

Gombrich, E.H. 1969. *Art and Illusion: A Study in the Psychology of Pictorial Representation.* Princeton, N.J.: Princeton University Press.

Gould, Stephen Jay. 1987. *Time's Arrow, Time's Cycle: Myth and Metaphor in the Discovery of Geological Time.* Cambridge, Mass.: Harvard University Press.

1977a. "Eternal Metaphors of Palaeontology." in *Patterns of Evolution as Illustrated in the Fossil Record.* Ed. A Hallam. New York: Elsevier.

1977b. *Ontogeny Recapitulates Phylogeny.* Cambridge, Mass.: Harvard University Press.

History, Humanity, and Evolution: Essays for John C. Greene. 1989. Ed. James R. Moore, Cambridge: Cambridge University Press.

Hodge, M.J.S. 1990. "Origin and Species Before and After Darwin." in *The Companion to the History of Modern Science.* Eds. R.C. Olby, G.N. Cantor, J.R.R. Christie and M.J.S. Hodge, New York: Routledge.

Hodge, M.J.S. 1971. "Lamarck's Science of Living Bodies." *Brit. J. Hist. Sci.* Vol. 5, pp. 323-352.

Huxley, Leonard. 1901. *Life and Letters of Thomas Henry Huxley.* New York: D. Appelton.

Kuhn, Thomas S. 1962. *Structure of Scientific Revolutions.* Chicago: Chicago University Press.

Johanson, Donald C. 1996. "The Dawn of Humans: Face-to-Face with Lucy's Family." *National Geographic.* Washington, D.C: National Geographic Foundation, pp. 96 - 117.

Lanham, Url N. 1983. *The Bone Hunters.* New York: Columbia University Press.

Latour, Bruno. 1986. "Visualization and Cognition: Thinking with Eyes and Hands." *Knowledge and Society,* Vol. 6, pp.1-40.

Landau, Mishia. 1991. *Narratives of Human Evolution.* New Haven: Yale University Press.

Laudan, Rachel. 1990. "The History of Geology, 1780-1840." in *The Companion to the History of Modern Science.* Eds. R.C. Olby, G.N. Cantor, J.R.R. Christie and M.J.S. Hodge, New York: Routledge.

Lemonick, Michael D. 1993. "Rewriting the Book on Dinosaurs. " *Time.* Apr. 26, 1993, pp. 36-44.

Lessem, Don. 1996. "Bringing Dinosaurs to Life." *Earth.* Apr. pp. 37 - 43.

Lessem, Don and Donald F. Glut. 1993. *Dinosaur Encyclopedia.* New York: Random House, Inc.

Lucas, Spencer G. 1994. *Dinosaurs: the Textbook.* Dubuque, Iowa: Wm. C. Brown Publishers.

McGowan, Christopher. 1991. *Dinosaurs, Spitfires, and Sea Dragons.* Cambridge, Mass.: Harvard University Press.

Michaud, Jean-Guy. 1992. *The Reign of the Dinosaurs.* New York: Harry N. Abrams.

Moore, James R. 1986. "Geologists and Interpreters of Genesis in the Nineteenth Century." in *God and Nature: Historical Essays on the Encounter between Christianity and Science.* Eds. David C. Lindberg and Ronald L. Numbers. Berkeley: University of California Press.

Moore, John A. 1993. *Science as a Way of Knowing: the Foundations of Modern Biology.* Cambridge, Mass.: Harvard University Press.

New American Bible. 1980. Wichita, Kansas: Catholic Bible Publishers.

Norman, David. 1991. *Dinosaur!* New York: Macmillan.

Outram, Dorinda. 1984. *Georges Cuvier: Vocation, Science and Authority in Post-Revolutionary France.* Manchester: Manchester University Press.

Paul, Gregory S. 1996. "The Art of Charles R. Knight." *Scientific American,* pp. 86 - 93.

Rainger, Ronald R. 1982. "Paleontology and Philosophy: A Critique." *Journal of the History of Biology,* Vol. 18, No. 2, pp. 267 - 287.

Richards, Robert J. 1992. *The Meaning of Evolution: the Morphology and construction and Ideological Reconstruction of Darwin's Theory.* Chicago: Chicago University Press.

Ridley, Mark. 1985. *The Problems of Evolution.* Oxford: Oxford University Press.

Ronan, Colin A. 1982. *Science: Its History and Development Among The World's Cultures.* New York: Facts on File Publications.

Rudwick, M.J.S. 1992. *Scenes from Deep Time: Early Pictorial Representations of the Prehistoric World.* Chicago and London: University of Chicago.

1986. "The Shape and Meaning of Earth History." in *God and Nature: Historical Essays on the Encounter between Christianity and Science.* David C. Lindberg and Ronald L. Numbers. Berkeley: University of California Press.

1972. *Meaning of Fossils: Episodes in the History of Paleontology.* London: Macdonald.

Rupke, Nicolaas A. 1994. *Richard Owen: Victorian Naturalist.* New Haven: London: Yale University Press.

1983. *Great Chain of History: William Buckland and the English School of Geology (1814 - 1849).* Oxford: Clarendon Press.

Secord, James. A. 1986. *Controversy in Victorian Geology: the Cambrian-Silurian Dispute.* Princeton, N.J.: Princeton University Press.

Shapin, Steven. 1989."Science and the Public." In *A Companion to the History of Modern Science.* Ed. R.C. Olby, G.N. Cantor, J.R.R. Christie, and M.J.S. Hodge, pp. 990-1007. London: Routledge.

Spaulding, David A. E. 1993. *Dinosaur Hunters.*Toronto: Key Porter Books Ltd.

Sloan, Philip R. 1990. "Natural History, 1670-1802." in *The Companion to the History of Modern Science.* R.C. Olby, G.N. Cantor, J.R.R. Christie and M.J.S. Hodge Eds. New York: Routledge.

Tassy, Pascal. 1993. *The Message of Fossils.* Toronto: McGraw-Hill Inc.

Torrens, Hugh. 1992. "When did the dinosaur get its name?" *New Scientist.* pp.40 - 44.

Unger, Franz-Xaver. 1851. *Die Urwelt in ihren verschiedenen Bildungsperioden. 14 landschaftliche Darstellungen mit erlauternden Text.* Vienna: Beck in Rudwick, M.J.S. 1992. Scenes from Deep Time: Early Pictorial Representations of the Prehistoric World. Chicago and London: University of Chicago.