

CHAPTER 2

THE ORIGIN OF THE EARTH AND OF SPECIES OF ANIMALS AND PLANTS AS SEEN BEFORE THE ENLIGHTENMENT

WHERE DID I COME FROM? THE EARLIEST INTERPRETATIONS

All societies have faced the issue of “Where did I come from?” and have usually assigned a divine cause for creation. Few have pondered the issue more deeply, owing to two factors: First, for all societies, the world is tolerably constant. Second, in western society, the influence of Aristotle, Plato, and the Old Testament, which heavily relied on the assumption of constancy, mitigated against further exploration and analysis, even when logical contradictions were acknowledged.

As is discussed in Chapter 4, page 45, at a given time and place the world appears to be constant. One summer may be warmer or a winter colder than another, and there may be other modest changes in climate or the precise bed of a river, but by and large the old-timers can remember hotter summers or heavier snowfalls. The biological world also appears to be constant and discrete. To take an oversimplified but illustrative example, any reasonably observant person realizes that there are different kinds of birds in his or her neighborhood. In a northeastern urban or suburban neighborhood, for instance, there are pigeons, robins, cardinals, gull, sparrows, mockingbirds, crows, and Canada geese. There are also several others, such as owls and hawks, but they might not be commonly noticed by the casual observer. The point is that one does not mistake one species for another. Pigeons might have many colors, but they are certainly not robins. A female cardinal might be greenish-brown, rather than red, but her body shape, her crown, her beak shape, and her markings make her distinguishable from any other bird in the vicinity. We do not find birds that are half-way between a pigeon and a robin, or birds that we could not with little effort classify and identify. Even if a species becomes extinct, it is known in its last stages as a rare species and, unless one is specifically attempting to document its existence, its disappearance is simply perceived as a lack of a recent sighting until, in a few years, it is forgotten. With these observations, there is little reason for assuming that the world is not as it has always been, other than by the divine placement of humans into the scene. The concept of change does not become obvious until one has a long historical (written) record of the world. Furthermore this record must sufficiently preserve earlier writings and later generations must be able to read them, so that the differences between then and now become apparent.

Ancient Greece constructed a world image that did not depend on divine creation. Thus it was that earlier Greeks, Anaximander, Anaximenes, Empedocles, and Democritus, argued that humans arose from the earth or a primordial moist element, being engendered by the sun's warmth and spontaneously arising as maggots appeared to do in rotting flesh. In general, perhaps by noting the obvious biology and by understanding a hierarchical world in which animation (life) was superior to inanimation (rocks), movement (animals) superior to immobility (plants) and thinking (humans) superior to reactive behavior (animals) they perceived a creation in which plants preceded animals and animals preceded humans. They recognized but did not however address the logical problem of the state of the first human. If the first human appears as a baby, it must be cared for, but then who (or what) cares for it? With divine creation, it is possible to accept the idea of the first humans appearing on earth as adults, but for the Greeks this was a conundrum. As far as we know, they did not pursue this problem with great enthusiasm or to any depth, partly because of the rising influence of Plato and his student Aristotle. Plato felt that each object in the universe was an imperfect representation of an ideal type or archetype, and that the universe consisted of more- or less-successful approaches to that archetype. Note, however, the inference: if there are archetypes, then by definition the archetypes do not change. Therefore, in the biological world, species do not change. A robin is a better or worse approximation of the ideal of "robin-ness" but that ideal, or archetypical, robin persists and will remain in all generations as the goal of robins. Aristotle carried this idea further in attempting to systematize or classify all forms of animate and inanimate nature, in his Scale of Life (page 55). As with Plato, each species was an attempt to replicate an absolute ideal, but beyond that, the archetype of each species occupied a particular rank in nature. Thus animals were above plants, vertebrates were above invertebrates, birds and reptiles (which had perfect or shelled eggs) above fish (which had imperfect or soft eggs), mammals above reptiles and birds, and humans above mammals. He counted over 500 links in the chain, or species. His classifications improved on the earlier versions such as with or without feet or wings. All this is well and good, but it ultimately gets complicated, as the Aristotelian scale allowed no ambiguity or ties in rank. Thus, for instance, a peach tree had to be above or below a cherry tree, a trout had to be above or below a bass, a cat had to be above or below a dog, a sheep above or below a goat. Life could be created, but new organisms would join their appropriate rank. So, by this argument, not only was there no possibility of change of a single species, there was no possibility of movement among species. It was not possible for a goat to pass a sheep, or vice versa. In this world view, evolution is an absurdity. Each species is fixed in its type, and fixed in relationship to every other species. Together with the Judeo-Christian view of Creation, as expressed in Genesis, this view dominated western culture for two thousand years.

In Genesis, the world was created at one time. Thus all species were formed at that period, and by this argument again, there was no logical means by which species could change or evolve from one type into another. Fish, frogs, reptiles, birds, and mammals first appeared during creation and have been present on earth since then.

Thus, between the teachings of Genesis (written approximately 450 B.C. recounting tales of 1000 years earlier) and the teachings of Plato (427–c347 B.C.) and Aristotle (384–322 B.C.) from a logical standpoint as well as from the evidence at hand, species were fixed and there was little reason to worry about, or even concern oneself with, the relationship of one organism to another. The similarity of monkeys to humans had been noticed, as had the similarity of organs and bones among different vertebrates, but these resemblances were considered to be examples of God's choice or God's wisdom, rather than peculiarities of the world that deserved attention and analysis.

WHERE DID I COME FROM? INTIMATIONS THAT NOT ALL WAS STABLE

By the 17th C, however, the European world had changed. The world now had a long tradition of literacy, coupled with printing presses that made knowledge accessible to a much larger population, and explorers were describing the strangeness of the new continents that they were exploring. Philosophers, who at that time were not distinguished from scientists, were pondering the meaning of all of the new knowledge, and the evidence that life in 17th C Europe was very different from what had been described in the Bible and in Aristotle. They were susceptible to the concept of change. In terms of social structure, economic structure, political order, and even values and mores, the world today (17th C) is different from what it once was. There have been periods of wealth and poverty, pestilence and health, democracy and tyranny; and what had been a rural society (Germany, England, Ireland) became a society with great cities. Islam had appeared in the 8th C and grew strong enough to compete with Christianity, and the religions of the Orient and of the New World were very different.

Thus the world could be restructured, perhaps not in front of one's eyes, but over time. Where did it come from? What caused the restructuring? Was it possible that the natural world could change as well? Perhaps the similarity of the bones of a dog to those of a human told us more than we had suspected.

It may strike many as surprising, but many of the main elements of the story of evolution were well known long before 1859 and were the subject of popular discussion among intelligent and educated, but not professional, members of upper-class society. The Enlightenment had not truly invented but had brought to the forefront of intellectual life several attitudes that continue to pervade our society: an emphasis on material evidence and human logic, as opposed to mysticism or unquestioning faith, as the basis of rationality (Galileo & Copernicus); a powerful sense of the mechanical or physical construction of the universe (Galileo, Newton, Pascal); and a widespread but quintessentially British assumption of continuous progress in the history of the earth, leading of course to the summum bonum (maximum good) exemplified by contemporary British society. Each of the episodes that we now identify as landmarks in the history of science originated in the attempt to address a specific practical problem, and each had generated

spectacular and immediate success. These successes validated the assumption that much could be learned from the physical world, and led to further inquiries about the anomalies of the earth, ranging from curiosity about the origin of mountains to efforts to understand fossils in the context of or opposed to the biblical description of the history of the earth. We will discuss these below, but to give a sense of the pragmatism that allowed natural philosophers to gain ascendancy over theologians and philosophers, we can cite a few examples: One was that motion was associated with life, and thus its laws were worthy of exploration. Furthermore, issues such as the trajectory of cannonballs and, for the purposes of armies and explorers, measuring movement around the earth provided plenty of work for those who would ultimately become physicists. Galileo was well known for his studies of trajectories and compasses. Other needs included the measurement of longitude and interpretation of disease, as is described below.

THE USES OF SCIENCE AND THE DISCOVERY OF THE MECHANICS OF THE EARTH

Both philosophical inclination and practical considerations drove a 17th C interest in movement. From the philosophical viewpoint, movement, or at least directed movement, was one of the few features that separated the living from the inanimate. Thus the difference between a dog, horse, or human one minute after death and one minute before death was manifest primarily in movement, of the chest, heart, limbs, or eyes. Thus, as the value of mechanics impressed itself more on European society (see below) attention turned to an understanding of motion as part of the deeply philosophical and even holy quest to answer the age-old question, “What is life?” Rather than address this question from purely theoretical or philosophical terms, thinkers turned to mechanics, or experimentalists, to help them understand. There was plenty of reason to view this approach with optimism.

Greek scholarship had returned to Europe via Spain, since the Islamic unlike the Christian world had never lost it and the Moslems, though eager to keep their distance from “heathens,” nevertheless would communicate through intermediaries, frequently Jews. It was no accident that Maimonides, the greatest of the Jewish philosophers, and certainly a great physician and philosopher by any criteria, had a strongly Aristotelian attitude, including the argument that God’s miracles worked through, and did not violate, physical laws. Likewise, Nostradamus’ writings arose from an effort to reconcile a profound logic with apparent contradictions in holy writings—the effort that gave rise to the Kabala (Page 403). Thus the role of (perhaps) Archimedes (287–212 B.C.) in devising catapults and other instruments of war based on the theoretical understanding of the physics of levers, and the practical benefit of his correlating density of matter with displacement of water, so that he could tell whether gold had been removed and substituted in the king’s crown, were familiar to scholars. The question became whether such approaches could contribute to various practical problems, ranging from the construction of

machines to accomplish the heavy labor of building large buildings or destroying fortress walls in battle to the prediction of seasons and correct assessment of Church holidays. There was even, for the heads of state, a very urgent and large issue. By the 17th C it was very apparent that there was much wealth and resources to be gained (or plundered) from the New World and the now-accessible Asia, and that the power of a country would depend on its ability to assert pre-eminence in that exchange. After all, small and relatively weak countries such as Spain, Portugal, and Holland, were achieving considerable influence at the expense of previously much more powerful England, France, and Italy. However, trans-oceanic voyages were still hazardous and unreliable. A prince might well, at great expense, outfit a fleet to barter, plunder, or otherwise collect the wealth of another land, but if the fleet went down in a storm, was lost in a raid, or otherwise foundered, the entire investment would be lost. Such a catastrophe was far more likely if the fleet wandered off course. Wandering off course was highly likely since ship captains knew how to calculate latitude (distance north or south of the equator) by the height of the sun at noon—again a practical result of the mechanistic approach to the philosophy of what the world was—but they could not calculate longitude, the distance east or west of their home base. This lack of information would have been an inconvenience if the captains had been able simply to chart their own course, for instance in the return trip simply sailing to the appropriate latitude and then sailing due east, but they were sailing ships, and they therefore followed the prevailing winds, which flowed basically westward near the equator and eastward far from the equator, with an area of relatively little movement (the doldrums) in between. Thus they had to be able to assess their positions accurately, lest, in the worst type of scenario, a gold-laden Spanish ship returning from Mexico would find itself, while still at the latitude of England, approaching European shores. The hostile English might well capture the ship. There was obviously a premium on the ability of the fleet to home right into its base port. There was so much of a premium, in fact, that the king of Spain offered serious prize money to the person or persons who could devise an accurate means of calculating longitude. This competition motivated some of the best scholars of the time, including Galileo who, using the newly-invented dual or compound arrangement of lenses to devise a telescope, searched the skies for markers that could be used to assess longitude. He was so assiduous in his search that he even devised a means of determining longitude by noting the positions of the moons of Jupiter! This exploration, of course, led him also to realize that the moon was not a perfect sphere or component of one of the “cool, crystalline spheres” praised by John Donne, and to realize that he could even calculate the heights of the mountains on the moon. This interest in motion and in celestial mechanics even allowed him to address the issue of the motion of tides. Even though his interpretation is now considered to be incorrect, his rules for calculating or predicting the tides were of obvious value in an era in which merchant and military ships were becoming larger and bulkier, riding much lower in the water when fully loaded, but deep water harbors were not yet being dredged.

Science as a Means of Solving Problems

Another hugely important source of wealth was minerals. Coal was known and sought, though not to the extent that it would be later, but a range of other minerals, ranging from marble for construction to iron for tools and weapons to gold, silver, and gemstones for the holding and display of wealth, were high demand. Recall the myths of the desire of Midas, prior to the Christian era, for gold and the opulent garments, sewn with gold thread and encrusted with precious stones, of royalty. The function of these garments, heavy nearly to the point of immobility, was to impress upon others, even flaunt, the wealth and by inference the power of the wearer. The Spanish Conquistadors sought gold with febrile intensity, even melting down wonderful artifacts to ingots and so overloading their ships that they sank in the Caribbean. Needless to say, in this type of atmosphere, the discovery of gemstones and precious metals was too important to be left to chance. Thus there was substantial interest in understanding the characteristics of the earth so that the locations could be predicted and mines dug if necessary. Analytical observers such as Nicholaus Steno, described immediately below (page 27) and pages 40–42 in terms of his contribution to understanding the age of the earth, were sought by the courts of Europe. (It is of note that even stone-age humans had been known to dig ten feet into the ground to find flint, indicating that they understood the structure of the land, and that the Chinese by the 8th C and Avicenna and al-Biruni by the 10th C clearly described sedimentation and the meaning of fossils; and Native American legends likewise gave some suggestion of the massive sedimentation fields of central North America. All of this understanding was unknown to, lost to, or suppressed by, European scholars and theologians.)

Likewise, in medicine, new concerns demanded greater attention to the details and practical aspects of life. Plague had entered Europe in the 13th C and was still a feared disease, clearly related to urban life but of unknown origin (Chapter 27, page 359); kings and queens, entrusted with (and depending on) the welfare of their subjects, needed to understand and control it. Malaria, attributed to the fumes around Venice (literally, “malaria” means “bad air”) could incapacitate even a rich, powerful, and elegant city; an expensive, vast, and well-trained army could be defeated as easily by disease as by its enemy; and, of course, in addition to individual self-interest, there was considerable motivation in terms of inheritance and control of the government in protecting (or discretely terminating) the life of the regent or his or her potential successors. Thus courts had their royal physicians, often as distinguished as Maimonides in the 13th C or William Harvey in the 17th C. Ambrose Paré in the 16th C had improved the handling of war wounds by tying off wounds rather than cauterizing them, and using what was later learned to be moderately antiseptic solutions to wash the wounds. Paracelsus, the great (and arrogant—he gave himself the name ‘Paracelsus,’ meaning “beside Celsus” (a famous Roman physician)) physician, recognized that diseases were carried by and caused by outside agents (confirmed by Pasteur’s germ theory in 1862), and advocated the observational and experimental approach as opposed to following ancient texts. He literally threw the works of the revered Avicenna into bonfires.

Likewise Andreas Vesalius scorned a slavish following of ancient texts, leading the world to a new understanding of anatomy and the function of the body (page 406), in the same year (1543) that Copernicus rejected elaborate mathematical models of the universe in favor of simple calculations based on the idea that the sun, not the earth, was the center of rotation. By the 17th C the experimentalists, like their counterparts in physics and geology, were in charge: Francisco Redi had established that maggots on exposed meat had come from the eggs of flies (page 141), leading Harvey to the conclusion “*Ex ova omnia*” (“All [life] from eggs”). Harvey also showed in 1628 that the heart circulated blood in the body, leading to better insight into the importance of dehydration and bleeding. There were many other scientific activities at the time, including of course the work of Sir Isaac Newton on optics, gravity, and the laws of motion.

Europe meets the Americas

This increased respect for, and interest in, the mechanics and the tinkerers, led to the subjects of the nascent scientific research becoming a matter of interest for all educated citizenry. In fact, since all exploration costs money; money was available only in the noble and mercantile classes; and merchants were, by and large, too busy trying to earn the money to be very philosophical, scientific exploration was to a large extent a hobby or amateur (literally, lover) occupation of the more relaxed (idle?) nobility. As such, these activities were widely discussed in the upper classes. Curious findings (in the broader, original sense, meaning unusual enough to provoke wonder about their meaning or origin) were considered, marveled upon, and discussed. In the age of exploration, there were many curious findings. New animals and plants, and reports of wonders, were being brought from abroad, and explorations of the geology of Europe were forcing people to ask questions about their meaning. The level of excitement over new wonders can be appreciated in a few anecdotes: chocolate, brought from Mexico, was presumed to be a powerful aphrodisiac, and therefore sequestered to nobility; tulips, brought from Turkey, were considered so precious that there was a tulip frenzy, with rare bulbs being sold, in a stock market-like structure, at today’s equivalent of hundreds of dollars per bulb; and newly-met indigenous peoples were routinely interpreted as being descendents of one of the lost tribes of Israel. As is described in Chapter 7, page 81, the realization that the rest of the world contained novel species initiated the query of how all of this fit in with the story of Genesis, but at home the new-found interest in the structure of the land meant that, instead of simply accepting phenomena, the mechanism-based scientists began to ask how the phenomena came to be. In common terms, the transition was from “Yes, those hills have funny [or pretty] stripes” to “What made those stripes in those hills, and why do they look like the stripes on the hills on the other side of the valley?” This was the basis of Steno’s identification of the principles of geology, but in terms of evolution the argument is much more cogent: “I know that I can get limestone for making my mortar from the white areas of the earth, but those white areas are white because they are filled

with old shells. The shells look a bit like the ones on the beach, but they are not the same and, besides, they are on the top of a mountain. What is going on?"

The Discovery of Anatomy Raises New Questions

Georges Cuvier, the director of the Musée d'Histoire Naturelle, was a master anatomist. As is described in Chapter 3, page 35, there are specific correlations among organs and structures such that it is possible to assess the lifestyle of an animal from its general appearance. Any person, and indeed any animal, can distinguish between a dangerous carnivore such as a shark or a lion and a peaceful herbivore like a zebra or a goose. Our films and our creative fiction exploit this ability, showing dangerous fictitious predators such as werewolves, zombies, and aliens from outer space with the appropriate paraphernalia of a predator: large, sharp, tearing teeth like canines, strong arms with claws or other lethal cutting weapons, and forward-facing, distance-judging eyes. A hypothetical science fiction movie showing people terrified by an invasion of cows or guinea pigs would be laughed out of a theater. Cuvier was one of the men who verbalized these intuitive judgments, but he went much further. To Cuvier, each part of the anatomy necessarily related to every other part, in the sense that, if one takes a femur (upper leg bone) from an unknown animal, the shape of the joints indicate how it attached to the pelvis and the tibia (lower leg bone) and from this one can determine if the animal was truly quadruped (four-footed) or walked upright. In fact, it was said of Cuvier, and he did not deny it, that he could reconstruct an entire animal from a single bone. For this talent, he was justly famous and, in the structure of society at the time, he and his colleague and to some extent mentor Geoffroy Saint-Hilaire associated with and were admired by such prominent literary figures as Wolfgang Goethe, Etienne Balzac, and Georges Sand. (Goethe was also an outstanding botanist, having recognized that flowers and other appendages of plants were modified leaves.) In the midst of the French revolution of 1830, Goethe was far more excited by the prospect of a debate between Cuvier and Geoffroy than by news of the war. Balzac was sufficiently interested in the debate to describe it in his introduction to *The Divine Comedy*.

The social structure however is another story, and told at greater length and in more detail elsewhere (see bibliography for books by S. J. Gould). Of interest here is what Cuvier learned from his skills and knowledge. First, he realized that the fossils in his museum and being collected at an increasing pace represented real animals, and ones that he could classify and for which he could describe lifestyles. Second, as Geoffroy would summarize in an aphorism ("There is only one animal."), all the tetrapod (four-legged) vertebrates had essentially the same bones in their limbs, whether the limbs served for swimming (whales), flying (birds or bats), walking (dogs), digging (moles) or carrying (humans). Third, many of the animals represented by the fossils were unlike anything seen on earth. Fourth, understanding Steno's principles of stratigraphy pages 40–42, the ones most like today's creatures were closest to recent times, and they never appeared in the earlier layers. Fifth,

many species had finally disappeared. Geoffroy had studied the anatomy of different organisms to the extent of trying to identify in fish the homologs (parts related by ancestry) of the bones of the inner ear of mammals. To the logical and analytical Cuvier, the data had only one interpretation: the stratification of fossils told the history of animal and plant life. The creatures found on this earth had changed over time, with some types of animals completely disappearing from the record. The similarity of bones betokened a common ancestry. He stated this argument clearly in his first major book on the subject, in 1812, *Research on the fossil bones of quadrupeds, from which one reestablishes the characteristics of several species of animals that the upheavals of the earth² appear to have destroyed*. Could one state more clearly the concept of extinction and possibly evolution? Why then do we mark 1859, the year of the publication of “*Origin of the Species*,” as a turning point, rather than 1812?

Cuvier saw what had happened, but he lacked two crucial points: First, he understood sequence, but he had no conception of the time that it took. In other words, if you live in a big or industrial city, you are familiar with the fact that every day a little bit of soot accumulates. You can imagine that, over the space of 1000 years, on an undisturbed space a few inches will accumulate—let’s say, five inches. If you now find a soot layer four feet deep, you might reasonably conclude that the soot had been accumulating for approximately 10,000 years. However, suppose that there is a volcano not too far away. A single eruption of a volcano might produce a foot of ashfall, or two feet of ash, or four feet of ash. You surely can establish the sequence of the accumulation, but without sophisticated modern technology, can you unequivocally argue that it represents 10,000 years of accumulation, as opposed to a single day of volcanic eruption, or anything in between?

The second problem that he had was the inability, because of lack of this sense of time as well as the social context that led to his asking the specific questions, to conceptualize a new, grand theory of mechanism. In the world of Cuvier and Saint-Hilaire, the issue was much more how the fact that vertebrate bones were homologous would demonstrate the wisdom and beneficence of God. What was the genius of using the same basic plan for all vertebrates? There was surely method, but what advantage did it bring? The great debate of 1830, fervently followed by the intellectual community and continued with follow-up books and pamphlets, was not over the issue of evolution, but whether God’s plan ordained specific types of creatures, each containing a modest variation on a theoretical ideal type (Geoffroy) or whether God’s wisdom was displayed in the excellent fit that He had constructed from a basic sketch to serve each animal’s unique needs (to swim, run, fly, walk, or dig—Cuvier). What Darwin brought to the picture was the certainty that the fossil record was a true representation of a sequence of historical events; that the species had changed rather than been replaced; that the earth was old enough to account for

² The French title that I have translated as “upheavals of the earth” is “les révolutions du globe,” literally “revolutions of the globe” but the term “révolution” is more similar to the meaning “revolt” or “American Revolution” than to the concept of turning in a circle.

these changes (this information was inaccessible to Cuvier but was widely believed forty-some years later); and, above all, a MECHANISM by which it could have occurred. The mechanism, the Logic of the ELF triumvirate, was obligatory for a theory of evolution. The function of the preceding discussion is therefore to argue that the evidence of the fossil record had been available, and that its implication—the true existence of antecedent animals, and their successive replacements over time—was well accepted. Furthermore, there was extensive knowledge of the anatomy of common and exotic animals, and their relationships were puzzled over, from the obvious homologies of the bones even to bewilderment over the existence of vestigial and completely useless pelvic bones in walruses and some whales. They worried about such issues as, if the failure of the skull bones to fuse before birth in mammals is Divine provision to allow the head to be smaller and to mold during birth, thus demanding less distention of the birth canal, why were the skull bones of birds not fused before hatching? All the birds had to do was to break the shell, not push through the narrow pelvis of the mother. These issues were being hotly debated in England as well, most notably by Richard Owen, “the British Cuvier,” who likewise was deeply concerned by the similarity of bones in limbs of such different functions. As he wrote in 1848, “The recognition of an ideal Exemplar for the vertebrate animals proves that the knowledge of such a being as man must have existed before man appeared. For the Divine mind which planned the Archetype also foreknew all its modifications.”

Embryology was also appearing on the scene, as microscopes and techniques improved to allow the first embryologists to preserve, dissect, and observe the typically tiny, watery, and mushy early embryos of animals. What Ernst von Baer observed and correctly interpreted by 1828 was quite startling: embryonic humans had tails like other mammals, and all vertebrate embryos had gills. Human tails disappeared by failing to grow at the same rate as the rest of the embryo, ultimately being seen as the internal curved end of the spine, the coccyx. In land animals, the gills ultimately ended up as (morphed into) structures of the throat. If he had not traced their development, he would have never recognized the relationship in the adult. In any event, to von Baer it was clear that the embryo of a human contained also the embryonic stages of aquatic and tailed creatures. He considered that they were there by inheritance, but did not extend the argument. Once the story of evolution had broken, Ernst Haeckel made the connection with his famous aphorism, “Ontogeny recapitulates phylogeny,” meaning that the developmental stages indicate the evolutionary line of descent.

What do the Relationships Mean?

Jean-Baptiste Lamarck is today somewhat unfairly ridiculed for one of his extrapolations of his findings, but at the beginning of the 19th C his careful observations and interpretations contributed another step on the ladder to the story of natural selection. What Lamarck saw was the marvelous fit of form to function, such that wings of birds allowed them to fly while the limbs and overall shape of porpoises were well adapted

for swimming. Giraffes had long necks to feed on tall acacia trees, and ducks had webbed feet to allow them to swim. The perfection of these matches, according to Lamarck, could only be explained by (God's generosity in arranging) the adaptation of animals to their needs. Taking his cue from the obvious adaptation of individuals to changing circumstances—muscles grow in individuals who do hard physical labor, and atrophy in immobilized limbs, and plants send leaves toward the light and roots to the soil—he proposed that the adaptations of animals to their surroundings was a direct growth or other response to their situation. Furthermore, he studied fossil mollusks, which are shells often with a long and continuous history. He saw, in the series that he studied, substantial evidence for a gradual change in form and size from the archaic to the modern forms. From what he knew and saw, he proposed that animals adapted to their environments and that the adaptations would be inherited. In this latter point he was wrong, as he had no idea that the cells of inheritance, the germ cells, which produce the gametes (eggs and sperm) are independent of the body cells (somatic cells) and cannot pick up what we today call acquired characteristics. This distinction was discovered only in 1888 by August Weismann (page 178), in direct test of Lamarck's theory, and even Darwin assumed that the body's characteristics drained into the gametes. However, the fundamental observation that species changed over time was provocative. It challenged Linnaeus' assumption that the species were fixed, instigating a controversy and opening the speculation as to exactly what would have been taken onto Noah's Ark. What was important to this story is that he put onto the table for all, including Darwin, to see the evidence that species were not fixed. He did not believe in extinction, which substantially undercut his argument. Although many argued vehemently with his theory, emphasizing such evidence of imperfect adaptation as vestigial organs and the massive teeth of sabertooth tigers, the evidence of the gradual change of at least the molluscan species was not denied. Cuvier later demonstrated that many fossils represented creatures no longer found on earth. As Pietro Corsi notes, Lamarck's was "the first major evolutionist synthesis in modern biology" (quoted in Browne).

THE SEARCH FOR MEANING AND THE DISCOVERY OF TIME

The other major limitation to a theory of evolution was time. To anatomists and interpreters of fossils such as Cuvier, the biblical accounting, as interpreted by Ussher and others, was dubious, but they had no measuring rod against which to judge the scale of events. This measuring rod, if not precisely constructed, was at least given a meaningful existence by Charles Lyell. Lyell, who combined a scientist's precision and attentiveness to detail with a persuasiveness derived from his career as a lawyer, had set out to deny the theory of catastrophism, the theory that all events and changes on earth had resulted from (bible-described) catastrophes and cataclysmic events. He argued that the great changes now recognized on earth could result from gradual changes over great periods of time. For instance, one might encounter massively folded sedimentary rocks (see Chapter 2, page 27) overlying or underlying horizontal layers. (Fig 2.1). According to Steno's rules (page 41),



Figure 2.1. Upper. Strong uplift of originally sedimentary rock. On these mountains in Alaska, the originally horizontal surfaces, distinguished as individual jagged edges, have been lifted to nearly vertical. Nevertheless, the original plane of the land can be distinguished as described in the text. In the middle of the photograph is the origin of a glacier, which gives evidence of flow. See Chapter 6. Lower. Strongly folded sedimentary rock. Folds like this indicate considerable activity and plasticity of the earth. Credits: Photograph:—Phil Stoffer, U.S. Geological Survey <http://3dparks.wr.usgs.gov/goldengate2/large/ribbonchert.html>

it was no longer seriously argued that the layering was not due to sedimentation, but the catastrophists argued that the sharp discontinuities indicated catastrophic events. Lyell argued, quite reasonably, that sedimentation occurred only in a time of heavy water flow. If a stream meandered quietly to the sea, it would not have much sediment to deposit in the sea. Similarly, if the water level changed, then sediment would accumulate only where the water met the sea. If the sea level dropped, the area of sediment accumulation would move farther out. If the beach front eroded, the area of sediment accumulation would move farther inland. Therefore, a line of sharp discontinuity could reflect a period during which sediment was not accumulating, suggesting a very slow process rather than a sudden one. Although Cuvier had attributed the changes in the fossil records to catastrophes, in reality all the major changes in the land could be produced by gradual processes such as those noted in current times, but these would require vast amounts of time, surely orders of magnitude greater than the biblical record.

Of course there were many other intellectual currents. Lord Kelvin's measurements of temperature (Chapter 8), Linnaeus' efforts to classify all organisms (Chapter 5) and the observations and theories of social scientists such as Malthus and Adam Smith (Chapters 7 and 10) all were part of the intellectual ferment of the 19th C and will be discussed in relation to the topics that they influenced.

REFERENCES

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STUDY QUESTIONS

1. Making your best judgments as to how life is organized, build your own "Scale of Life". Explain the criteria by which you make the judgment, and compare your scale to those of Aristotle and Linnaeus.
2. What are the criteria by which modern "Scales of Life" are built?
3. Is it fair to call today's groupings of animals and plants a "Scale of Life"? Why or why not?
4. Look around your environment and note any evidence that the physical world is stable, has changed, or is changing. If you feel that it is changing, estimate how rapidly it is changing. Be prepared to defend your arguments in class.
5. Assume that you are talking with someone who has never left the region and has little knowledge of the geography, biology, or history of the rest of the world. How would you convince him or her that species can vary?
6. What hypotheses can you generate to explain the differences of animals and plants among the five continents?

7. In single sentences, describe the major contributions of at least five of the historical figures mentioned in this chapter.
8. To what extent was the concept of evolution prior to Darwin hindered by the failure of ELF logic?
9. Would it have been possible to develop the theory of evolution without exploring the world? Why or why not?
10. Argue for or against the proposition that the person who contributed most importantly to the development of the theory of evolution was Thomas Malthus. (The subject is discussed in Chapter 10. Considering the question at this point will help you to understand the issues.)