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THE DISCOVERY OF MARINE TRANSGRESSION AND THE EXPLANATION OF FOSSILS IN ANTIQUITY

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ABSTRACT. The adoption of a particular philosophy of science will influence our view of past ideas. The inductivism of Whewell (1847) led him to ignore Greek geological thought because it failed to meet his criterion of science. Conversely, a latter day inductivist like Harrington (1967) believes that some inductively derived "truths" were grasped in antiquity. With the demise of inductivism, these transcendental truths also vanish. Cultural beliefs must be studied in their own context. Neither does the formal similarity of theories across the lapse of time imply identity. Although Lyell (1853) cites Strabo as a uniformitarian, examination of their respective frameworks highlights basic differences.

Rudwick (1972) states that close proximity of fossil to extant shells prompted Greek acceptance of the organic nature of fossils. This is disputed. The ancients found shells at great distances from the sea, particularly in Egypt, and developed an elaborate theory of marine transgression to explain their presence. The theory had a long tradition and explained other anomalous phenomena, notably inland salt deposits. It created a further problem of the mechanism of the sea's retreat. Herodotus believed that Nile silt had forced out the sea. This was endorsed by Aristotle and remained the dominant theory according to Diodorus, although rival hypotheses involving a fall in sea level were proposed by Strato and Strabo. The lack of distinction between geologic and historic time caused Aristotle to seek evidence for Herodotus' deposition theory amongst early records. Similarly, Plutarch compared the position of the island of Pharos mentioned by Homer with its position in his own day to show the process of deltaic growth still in operation.

DRAMATIS PERSONAE OF GEOLOGY IN ANTIQUITY

Late Mycenaean Age

Homer was a travelling story-teller who lived in the 9th century B.C. The *Iliad* was the first long epic of the Greek language, and it heralded the beginning of the Greek intellectual odyssey. The oral tradition persisted many years after Homer before it was finally committed to paper.

Ionian Period

Anaximander of Miletus, early 6th century B.C., adopted the materialist world picture of his predecessor Thales.

Xenophanes of Colophon, later 6th century B.C., spread Ionian thought to Elea in Sicily.

Hecateus of Miletus flourished in the later 6th and early 5th century B.C. Miletus was part of the Persian Empire and crossroads of the world, being visited by ships from Egypt, Phoenicia, and Greece. Hecateus collected the stories of seafarers and himself travelled extensively in the Persian Empire (which included Egypt), bequeathing to Herodotus a wealth of geographical lore.

Italian Colonies

Pythagoras of Samos died at the end of the 6th century. He was a mystic and philosopher who founded a brotherhood in Croton, Sicily. An oath of secrecy in the sect has obscured much of their teachings.

Hellenic Period

Xanthus of Sardis lived in the mid 5th century B.C. in Lydia, Asia Minor. He is said to have been concerned primarily with geology and botany.

Herodotus of Halicarnassus was born in Caria (southwest Asia Minor) early in the 5th century B.C. He travelled widely in Egypt and Mesopotamia and compiled his influential *History* from the geographical, historical, and historiographical material collected.

Thucydides of Athens was a younger contemporary of Herodotus. He also wrote a history, which focused on the war between Sparta and Athens.

Plato (427-347 B.C.) was born in Athens where he founded the Academy for teaching.

Aristotle (384-322 B.C.) was a desciple of Plato at the Academy, leaving before Plato's death to found his own Lyceum. The *Meteorologica* is ascribed to Aristotle. He taught Alexander the Great, who responded by sending Aristotle biological specimens from his distant campaigns. Alexander founded Alexandria in 332 B.C., choosing a site opposite the island of Pharos for its sheltered position.

Theophrastus of Eresus (372-228 B.C.) was Aristotle's pupil and successor at the Lyceum.

Hellenistic Period

Strato of Lampsacus succeeded Theophrastus at the Lyceum. After the founding of the Museum at Alexandria, he travelled there to teach. The intellectual center of the ancient world at this time began to shift from Athens to Alexandria, where "science" became increasingly specialized and found some of its greatest exponents.

Eratosthenes of Cyrene, 3rd century B.C., came to the Museum in 244 B.C. at the request of the third Ptolemaic Pharoah. He wrote geographical works and accurately calculated the circumference of the Earth.

Latin World

Diodorus of Sicily lived in Rome in the century before Christ and wrote a history in Greek about 30 B.C.

Strabo of Amaseia was an older contemporary of Diodorus. He too studied in Rome. The monumental *Geography* is his sole surviving work, and its encompassed the whole of the known world.

Plutarch was a Romanized Greek who lived in the second half of the 1st century A.D. He travelled in Asia Minor, Egypt, Greece, and Italy. The period was one of ecclecticism, and Plutarch's *Moralia* was a compendium of popular knowledge.

Arrian lived in the 2nd century A.D. and wrote an important history of Alexander.

Tertullian, born in the mid 2nd century A.D. in Roman Carthage, was an early Christian Father. Revealed Truth led him to reinterpret fossils in the light of the Mosaic Deluge.

Hippolytus was an ecclesiastical writer of the early 3rd century A.D. who summarized earlier thought.

A Note on the Classical Citations used in the Text

Classical citation is as follows: *Geography* i.3.4. means Book 1, chapter 3, paragraph 4 of Strabo's *Geography*. Occasionally the work is not broken down into chapters, thus *History* ii.15 refers to Book and paragraph only. The conventional reference to Aristotle is, for example, *Meteorologica* 352 a30. These numbers are standard in all translations and can be found on the left hand page of the Loeb Classical Library translation of the *Meteorologica*.

INTRODUCTION

A study of the historiography of geology reveals two major problems. The first is that belief in a certain methodology of science will alter one's view of the past, and the second is that the statements of our predecessors are often exploited for our own ends. Let us examine these two problems.

It is symptomatic of an age that believed *it* had found the key to geological understanding that Schvarcz should cast a disparaging eye upon earlier attempts and produce a book in 1862 with the revealing title *On the Failure of Geological Attempts in Greece.* He takes great pains to excuse his action, claiming it is only curiosity that leads us to discuss "even their unsuccessful attempts (made perhaps inductively) to construct the history of past vicissitudes of our earth" (Schvarcz, 1862, p. iii). But when success is measured by asking those questions that could only have been formulated in the eighteenth or nineteenth century, then the ancients were, by definition, doomed to failure. It is, of course, a commonplace that the interpretation of history varies according to the philosophical vantage point from which one observes. Thus in his *History* *of the Inductive Sciences* (1847), Whewell's inductivist characterization of science led him to exclude geological thought in antiquity because it did not conform to his espoused methodology.

> Since then, our History of Descriptive Geology is to include only systematic and scientific descriptions of the earth or portions of it, we pass over, at once, all the casual and insulated statements of facts, though they may be geological facts, which occur in early writers; such, for instance, as the remark of Herodotus, that there are shells in the mountains of Egypt; or the general statements which Ovid puts in the mouth of Pythagoras. (v. 3, p. 537)

Von Zittel, in the *History of Geology and Palaeontology* (1901), adopted a similar position and added that even though some Greek views "may in part coincide with accepted scientific conceptions of the present day, it has to be remembered that in these cases the early hypotheses were rather happy "guesses at truth," than general theories founded inductively upon a series of accurately observed data" (p. 10). Being unable to find any well-founded anticipations of current beliefs he states that "The geological writings of antiquity have little scientific value, and are therefore only briefly indicated" (p. vi). But all too often such brevity and disinterest lead to inaccuracy; so von Zittel claims, quite incorrectly, that "most of the ancient writers had explained their [the fossil remains of animals and plants] preservation in the rocks as the result of great natural catastrophes which changed the localities of land and water, and brought the swarming denizens of the sea into the middle of continents, burying them there" (p. 13).

The classical inductivist approach was thus harmful in its exclusion of much geological thought from the science historian. On the other hand, recent studies of the geological ideas of antiquity, equally unconcerned with evaluating the relationship between the theories—their causes and explanatory power given the contemporary state of knowledge—and the context in which they were set, have sought rather to uncover these anticipations of modern beliefs. Krynine (1960), for example believes that:

> Democritus discovered shape sorting of pebbles on beaches; Aristotle worked out the mechanical aspects of pebble abrasion; Plato produced truly post-Huttonian descriptions of erosion and deposition around Athens, and he also brought forth, 1900 years before Palissy, the correct, pluvial, theory for the origin of springs and rivers. (p. 1721)

Similarly, the discourses of Herodotus on the origin of Egypt led Harrington (1967) to propose him as the discoverer of the "First Principles of Geology"; principles that had to wait for centuries before being independently rediscovered: Harrington's moral being that we should scour ancient literature and "search out the general truths" (Harrington, 1967, p. 460). Although an inductivist like von Zittel, Harrington, however, believes that the Greeks *did* achieve certain scientific "truths" through inductive reasoning. His approach to the history of science stems from this philosophical standpoint. He states that:

> . . . observational understanding exists at three levels. The lowest one illustrated by the poetic imagery is that of random and isolated citations. The second level is characterised by genetic classification, related order, and the

> formulation of deterministic laws. The third level is distinguished by final and full explanation. (Harrington, 1969, p. 592)

The third level has yet to be attained, which is of no surprise since it asks "why?" of scientific laws! The second level, genetic classification or Baconian inductive generalization, correlates isolated observations into laws, whose truth is established by repetition — this is Harrington's "true science". (In fact, that the "truth" resulting from such a procedure has no logical validity was first determined by Hume, 1874, book 1, pt. 3, sec. 6.) Implicit in Harrington's view of inductively derived "truths" is the notion that, because of their universality, they transcend the historically-bound cultures that produce them, and so we are able to single them out from earlier writings. Gould (1970) has justifiably attacked this "approach to history that scans the past for gems of foreshadowed modern truth". Since Herodotus' principles appear true only in the light of modern beliefs, which are themselves presumed true, how are we to recognize such "truths" without the hindsight of their independent "rediscovery" in our own culture? The fallacy of Harrington's argument — and the inductivist approach to the history of science in general — stems from an outmoded philosophy of science. How does he reconcile the fact that, although these prescientific citations were "random and isolated", nevertheless they were, he says, "fully appreciated by the folk intellectuals of the day" without the use of some theory? "Observation is always selective", writes Popper (1972a, p. 46). "It needs a chosen object, a definite task, an interest, a point of view, a problem. And its description presupposes a descriptive language, with proper words; it presupposes similarity and classification, which in its turn presupposes interests, points of view, and problems" (see also Popper, 1972b, p. 71-72, 258-259, and 342-347). In order to be able to make and record "random" observations, one needs a frame of reference consisting of expectations or anticipations (which are only tentative hypotheses); observation, in other words, is theory laden. There is no historical progression toward final truth—truth that may be anticipated prematurely. Rather, the historical reconstruction of science involves a succession of hypotheses, each influenced by its predecessor, but also a function of the phenomena known in, and the prevailing metaphysic of, the age. The apparent similarity of ideas across the lapse of time is a recurrent feature of the history of science. Perhaps it is best understood as convergence in the biological sense of formal similarity without phylogenetic relationship. Von Zittel (1901) almost came to the same conclusion, albeit unwittingly; nowadays, non-inductivists would add that ours are merely "happier guesses", that is, they have a greater empirical content, explaining all that the old theory explained whilst able to predict novel facts.

There is a related problem of returning to antiquity to seek confirmation and a degree of respectibility for current beliefs. Lyell, for example, in the *Principles of Geology* (1853), turns to Ovid's presentation of Pythagoras' views to "find a comprehensive summary of almost all the great causes of change now in activity on the globe, and these adduced in confirmation of a principle of a perpetual and gradual revolution inherent in the nature of our terrestrial system" (p. 10). To Lyell, Pythagoras had grasped the two main tenets of uniformitarianism — that the causes of past changes are still operating, and that these act only gradually to transform the globe. The same was asserted of Aristotle. "From the works now extant of Aristotle, and from the system of Pythagoras, as above exposed, we might certainly infer that these philosophers considered the agents of change now operating in nature, as capable of bringing about in the lapse of ages a complete revolution" (p. 12). Against Censorinus, who attributed to Aristotle both inundations and conflagrations of the globe in the "great winters" and "great summers" (see below), Lyell retorts that this "is a gross misrepresentation of the doctrine of the Stagyrite, for the general bearing of his reasoning in that treatise [*Meteorologica*] tends clearly in the opposite direction. He refers to many examples of change now going on and insists emphatically on the great results which they produce in the lapse of ages". In Strabo, too, Lyell again detects an anticipation of his own doctrine that changes in the past must be explained by events observable today: '". . . *It is proper,*" he [Strabo] observes in continuation, "*to derive our explanations from things which are obvious, and in some measure of daily occurrence, such as deluges, earthquakes, and volcanic eruptions, and sudden swellings of the land beneath the sea* . . ."' (p. 15; Lyell is citing Strabo, *Geography,* i. 3. 10, Lyell's emphasis).

Copernicus' citation of the ancients in support of the heliocentric theory is a parallel example. But the Copernican system resulted from an attempt to reintroduce certain principles (for example, uniform motion) that he found violated in the Ptolemaic system, whereas the Pythagorean central fire was the outcome of metaphysical ideals. So too, the original significance of modern uniformitarianism becomes apparent when we view it as a reaction against the doctrine of catastrophism. The idea of gradualism in geographical transformation that survived for half a millenium in antiquity, however, arose, it seems, as the outcome of bringing the historical record to bear on a theory of marine transgression. There appears, *prima facie,* a similarity of form, but consideration of context reveals a basic dissimilarity of intent.

The allusions of the Greek geographers and philosophers *qua* geographers to the presence of shells far inland have not failed to be exploited by later writers. Steno (1669), living at the time when the theory of figured stones was dominant (he did not believe that fossils were formed *in situ* under the influence of a *vis plastica*) could look back to antiquity and lament, "Only one such difficulty troubled the ancients, namely the way in which marine objects had been left in places far from the sea, nor was the question ever asked whether similar bodies had been produced in places other than the sea" (Steno, 1669, p. 143). A generation later, in England, the diluvial cosmogonist Woodward had much to say concerning the Greek inference from shells to marine transgressions: "They concluded indeed unanimously that the *Sea* had been *there,* wherever they met with any of the *Shells*: and that *it* had left them behind. And so far they were *right: this* was an *Inference* rational and natural enough" (Woodward, 1723, p. 73). But the ancients, living at a time nearer the Flood, had been deluded since "The *Shells*, being then fair, *sound*, and free from *Decay*, were so exactly *like* those they saw lying upon their *Shores*" (p. 71) that they never questioned that they once belonged to the sea.

> Nay, in those *Elder Times*, and which were so much *nearer* to the *Deluge* than ours are, they found these *Marine Bodies* more frequently, and in much *greater Plenty*, than we *now* do: and most, if not all of them, *fresh, intire,* and *firm*. (p. 70)

Regrettably, many recent historical studies of the early views on fossils have failed to do more than applaud the Greeks for recognizing fossil shells as being of organic origin, with little attempt to give a coherent picture against which such beliefs were set. Rudwick (1972) has laudably attacked this approach and attempted an analysis of the reasons for their beliefs.

> It is therefore not surprising that most of the early writers who have often been portrayed as championing a 'correct' interpretation of fossils are those who are referring to the 'easiest' kinds of fossils. These were generally the shells of marine molluscs of geologically recent date. Such fossils were well preserved; and *they were usually found in unconsolidated sediments on low ground near the sea*. The problem of matter, of form and of position were thus minimal. Isolated comments on the organic origin of fossils can be found in many writers back into classical Antiquity, but whenever localities are mentioned it is clear that they were referring to those fossils at the 'easiest' end of the spectrum. Even the earliest such writer, Xenophanes of Colophon (6th century B.C.), is said to have mentioned Malta and Syracuse, both of which are localities in which finely preserved Cainozoic mollusc shells can be collected in abundance. (p. 39; my emphasis.)

A consideration of primary source material, however, casts doubt on this interpretation. These "isolated comments" display a strict uniformity of opinion within the Greek tradition. A theory of the changing relationship of land and sea was considered necessary to explain the presence of shells many hundreds of kilometers inland; it was advanced as early as the 5th century B.C. and elaborated during the subsequent history of Greek thought. By this means the early writers were able to account for marine shells of any age found *consolidated in rock* that could be *far removed from the sea.* Indeed, these conditions prevail in Egypt, which was the most commonly cited locality of inland shells. I feel that it would, therefore, be profitable to reapproach these Greek observations from the standpoint of their theoretical framework.

GREEK THEORIES OF MARINE TRANSGRESSION

Examination of Xenophanes' beliefs leads to the conclusion that he is not referring to the "easiest" kinds of shells at all; for this reason he had to frame an elaborate theory to explain why shells should be found in strange places. The relevant views of Xenophanes are reported by the 3rd century A.D. Christian Father Hippolytus (*Philosophumena,* i. 12).

> And Xenophanes opines that there was once a mixture of earth with the sea, and that in turn it was freed from moisture, asserting in evidence of this that shells are found in the centre of the land and on mountains and that in the stone quarries of Syracuse were found the impress of a fish and of seals, and in Paros the cast of an anchor below the surface of the rock and in Malta layers of all sea-things. And he says that these came when all the things were of old time buried in mud, and that the impress of them dried in the mud....

(The word "anchor" in this translation by Legge is incorrect—it is also an anachronism, since in Xenophanes' time an anchor was merely a stone on a line. Most translators prefer either "laurel-leaf" or "sprat": Bromehead (1945, p. 103) comments that the word is also used by Aristophanes for purchases found in shopping baskets and concludes "It is safe to assume that Xenophanes alluded to the slabs with innumerable specimens of little fish of the genus *Prolebius* frequently found in the Oligo-Miocene of the Mediterranean region".)

Xenophanes, then, had found shells "in the centre of the land and on mountains", so the localities to which he was referring were distant from the shore and not necessarily at sea level. Since there is mention of a fish "impress" in the stone quarries of Syracuse, we can presume that Xenophanes was aware that these artifacts could be found beneath the land's surface. More than this, he knew they occurred inside the rock, as is borne out by his observation in Paros of the sprat "below the surface of the rock"; here we are obviously dealing with consolidated sediments.

Moreover, Hippolytus credits Xenophanes with a physical theory to account for these shells and fish being found *inland* and *in the rock*. They occur inland because the "mixture of earth with the sea" became "freed from moisture"; the idea of the sea evaporating seems to have originated with Xenophanes' contemporary Anaximander, and the same mechanism is presumably implied in this statement. The creatures of the sea were left stranded "in the centre of the land" as the sea retreated "of old time". They became buried in the mud, which then dried to leave the fossils within it.

The use of empirical evidence in support of an hypothesis by a philosopher in the 6th century B.C. is impressive. Kirk and Raven (1957, p. 178) remark that "the deduction from fossils, whether or not it reflects original observation, shows careful and by no means implausible argument from observed fact to general hypothesis—a procedure notoriously rare among the Presocratics". Besides this methodological importance, Xenophanes is significant for his analysis of the event into the interrelated processes necessary to account for (A) the "geographical" locality (that is, inland) and (B) the "geological" position (that is, in the rock) of the fossils.

Unlike Anaximander, for whom the sea never returned to its original position, Xenophanes believed that there were periodic marine inundations; Hippolytus continues: "all men were destroyed when the earth being cast into the sea became mud, and that it again began to bring forth and that this catastrophe happened to all the ordered worlds". This may have been inspired by the Babylonian legends of the flood or be a reference to Deucalion's flood, modified to become a cyclical event. (Aristotle accepted the periodicity of Deucalion's deluge, for "just as there is a winter among the yearly seasons, so at fixed intervals in some great period of time there is a great winter and excess of rains" (*Meteorologica*, 352 a30), although in this great winter it is rain rather than marine transgression that causes the inundation.) Like Anaximander, Xenophanes held that the mud left behind by the retreating sea brought forth new life; the difference is that for Xenophanes this happens repeatedly. (There is an illuminating discussion of the relationship between Xenophanes and Anaximander in Kirk and Raven, 1957, p. 140 and 178.)

Since all mankind was destroyed when the sea re-invaded the land, and life had to arise again from the mud after its retreat, Xenophanes may be implying a universal inundation. If this were so, he differed from later writers, and it is not until the Christian diluvialists, such as Tertullian (2d century A.D.), that the idea is revived, similarly invoking fossils as evidence.

After Xenophanes, marine transgressions were thought to have been purely local occurrences. The reason for the change may be only surmized; presumaby it reflects the transfer of the problem from the speculative Presocratic cosmogonists to the descriptive geographers, who were less prone to sweeping generalizations. The paradigm case of marine regression is Egypt, a land that nearly all subsequent authorities in antiquity thought had been under the sea in the past. Herodotus, writing about 430 B.C., believed that "where now is Egypt there was once another such gulf" as that of the Red Sea and as proof he offers the observation that "shells are plain to view on the mountains" (*History*, ii.12). He advanced a theory of the mechanism by which the sea was forced to retreat and leave these artifacts; the Nile, he thought, had gradually silted up this gulf, just as it would the Red Sea if its course were so diverted. The results of the deposition are plain to see since Egypt is "a land of black and crumbling earth, as if it were alluvial deposit carried down the river from Aethiopia", whereas the soils of Libya and Syria are quite different in their texture.

Was Herodotus the first to advance such a theory? The scribes encountered by Herodotus in Egypt believed that their country had once been marsh (see below), and he credits them with knowledge of alluvial deposition. There is some evidence to suggest that river silting was common knowledge in Herodotus' day. His contemporary, Thucydides, mentions the silting of the River Archelous and the joining of islands to the mainland by such a mechanism. According to Thucydides, Alcmaeon (early 5th century B.C.) saw, during his own lifetime, dry land raised by this river—on which he later lived and became ruler (Thucydides, ii.102).

It is possible that Herodotus gained knowledge of the power of silting from other regions (for example, the Meander alluvial plain) and then applied it to Egypt. More probable is that Hecataeus (a contemporary of Anaximander in the 6th century B.C.) had already described Egypt as "a gift of the river" (Arrian, *Anabasis of Alexander*, v. 6. 5) and that this was known to Herodotus; there is some credence given to the belief that Herodotus even used Hecataeus' books as a guide whilst in Egypt (see How and Wells, 1928, Book 1, p. 24-27). So the alluvial deposition hypothesis probably did not originate with Herodotus, although he did bring new evidence to bear. Strabo states that even Homer's Menelaus "ascended the Nile as far as Ethiopia, and had heard about the inundations of the Nile and the quantity of alluvial soil which the river deposits upon the country, and about the large extent of territory off its mouths which the river had already added to the continent by silting" (*Geography*, i.2.23), although this seems more likely another case of reading one's own beliefs into one's predecessors.

If the Nile were diverted into the Red Sea, speculated Herodotus, "what hinders that it be not silted up by this stream in twenty thousand years? Nay, I think that ten thousand years would suffice for it" (*History*, ii.11), although the Nile gulf, being of greater size, would presumably have required longer. How did Herodotus derive this numerical value? From the scribes he had learned that during the reign of King Moeris, 900 years earlier, the Nile flooded the Delta if it rose 8 cubits in height, whereas in his own time it had to rise 15 or 16 cubits for flooding to result, so the Delta was much lower in earlier times. Also from the scribes he learned that at the time of the first ruler, Menes, the land below Thebes was a marsh. It seems probable that from such historical considerations, Herodotus extrapolated back to the time when all Egypt was a sea. How and Wells (1928, Book 1, p. 165) similarly infer that "Probably he allows '20,000' years, because this was roughly his conception of the duration of Egyptian history".

Unmistakably influenced by Herodotus, Aristotle (384-322 B.C.) cites Egypt as "a land which is obviously in the process of getting drier, and the whole country is clearly a deposit of the Nile" (*Meteorologica*, 351 b28). For Aristotle the sea and land are constantly changing position. From Herodotus he derived the idea of silting and the land's encroach upon the sea; to this he added a reciprocal action by the sea: "the sea too must change. For wherever it has encroached on the land because the rivers have pushed it out, it must when it recedes leave behind it dry land: while wherever it has been filled and silted up by rivers and formed dry land, this must again be flooded" (*Meteor.* 351 b5). Alluvial deposition in the delta forces back the sea, thereby raising the sea level and causing inundation. Aristotle concluded that the process took place over so long a period of time as to "escape our observation because the whole natural process of the earth's growth takes place by slow degrees and over periods of time which are vast compared to the length of our life, and whole peoples are destroyed and perish before they can record the process from beginning to end" (*Meteor.* 351 b8). Aristotle's commitment to cosmic—and thus terrestrial–eternity certainly permitted, and probably stimulated, this belief in the extreme gradualism of geographical change.

Aristotle then contradicts his statement of the imperceptibility of the marine transgression and attempts to show that Egypt had changed

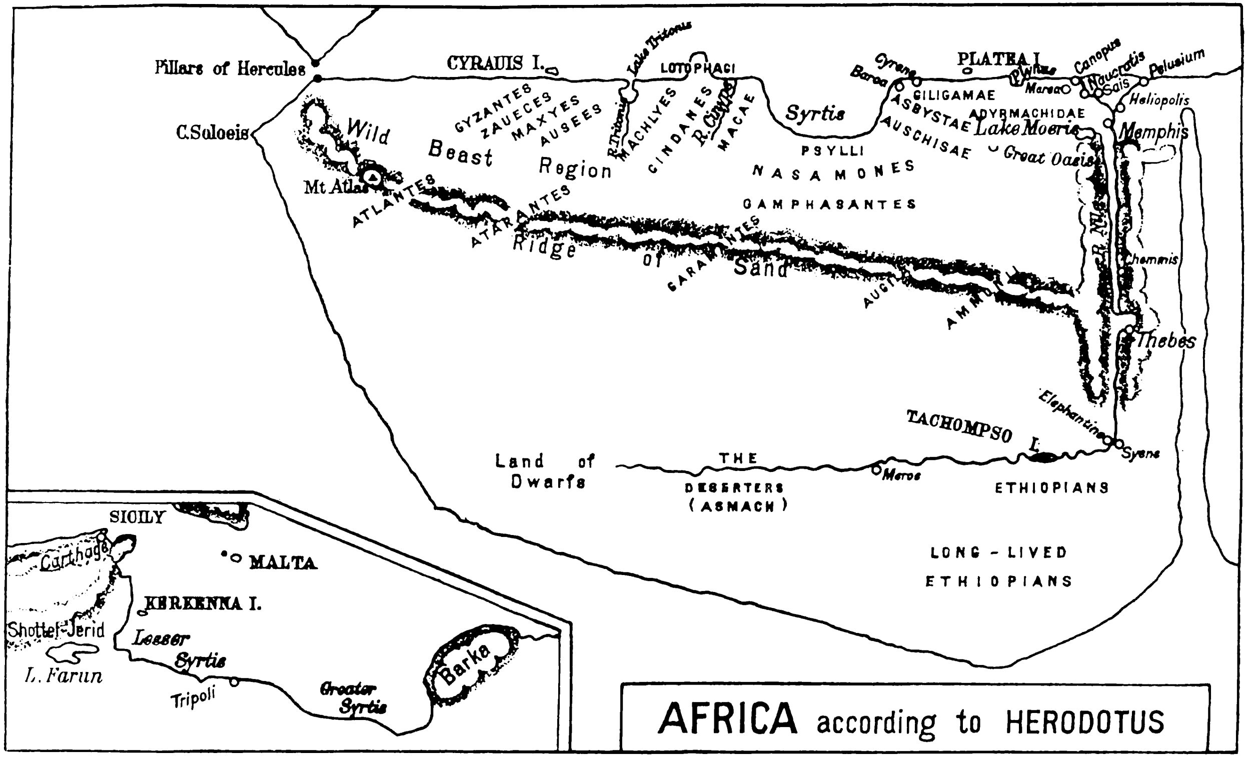

Fig. 1. From this map of Africa, according to Herodotus, we may readily see the similarity between the Red Sea and the conjectured 'Nile Gulf' of former times. Silt deposition from the Nile had entirely filled this gulf, just as it would the Red Sea if the Nile were diverted into it. (From How and Wells, 1928.)

since the time of Homer. Because the poet, when discussing Egypt, had only referred to Thebes (*Iliad*, ix. 381) and had not mentioned Memphis, Aristotle assumed that in Homer's time Memphis did not exist or was not, at least, an important center. This was explained by Aristotle as follows: since the alluvium on which Thebes, in Upper Egypt, was founded had dried out and become inhabited long before Memphis in Lower Egypt, then the latter must still have been water-logged in Homer's time, "For the higher lands were inhabited before the lower-lying, because the nearer the place is to the point where silt is being deposited the longer it must remain marshy" (*Meteor.* 351 b34). Aristotle's debt to Herodotus is clear: the idea of populations moving north to colonize derives from Herodotus (*History*, ii. 15), as does the notion (see above) of the area north of Thebes having been marsh in early historical times (*History*, ii. 4, 10).

After Aristotle, this use of historical records, focusing on Homer, became an important method of detecting changes. Aristotle's belief that the process was continuing meant that the waters off the Delta were still becoming shallower as alluvium from the Nile raised the height of the sea-floor; indeed, Herodotus had observed the alluvium far out to sea — even at a day's sail mud was brought up on the sounding line. So the emphasis shifted to adducing evidence for deltaic growth. In the *Odyssey* (iv. 351-357) Menelaus had described the island on which he was becalmed by the gods thus: "Now in the surging sea an island lies,—Pharos they call it,—as far from the river [of Egypt; that is, the Nile] as in a day a hollow ship will run when a whistling wind blows after". Both Strabo and Plutarch construed this as a day's sail *out to sea* (Homer could have meant along the coast from the river) and contrast it with the position in their own day, when Pharos had become part of the mainland. (At the founding of Alexandria the island stood a mile off shore but became incorporated into the port by the construction of a mole of seven stades length (Tozer, 1897, p. 146). In the light of this, Ovid's attribution in the *Metamorphoses* (xv. 287) to Pythagoras of the knowledge that Pharos had once been an island but had become part of the mainland is anachronistic, in Pythagoras' time it *still* was an island; the knowledge is better considered Ovid's.) Since Strabo accepted only a limited application of Herodotus' deposition theory and had developed an alternative theory to account for marine inundations and recessions (see below), he was therefore less inclined to allow such a spectacular proof of Herodotus' theory (that is, that since Homer's time deltaic growth by alluvial deposition had been so great as to incorporate an island that was originally distant a day's sail). Strabo accepted that although Pharos had, indeed, once been an island and had subsequently become a peninsula—which confirmed Herodotus, but only with respect to the Delta—nevertheless, he believed that Homer had greatly exaggerated the distance between Pharos and the mainland "for the sake of the fabulous element" (*Geography*, i. 2. 30; see also i. 2. 23), leading to a greater apparent growth of the Delta than was actually the case.

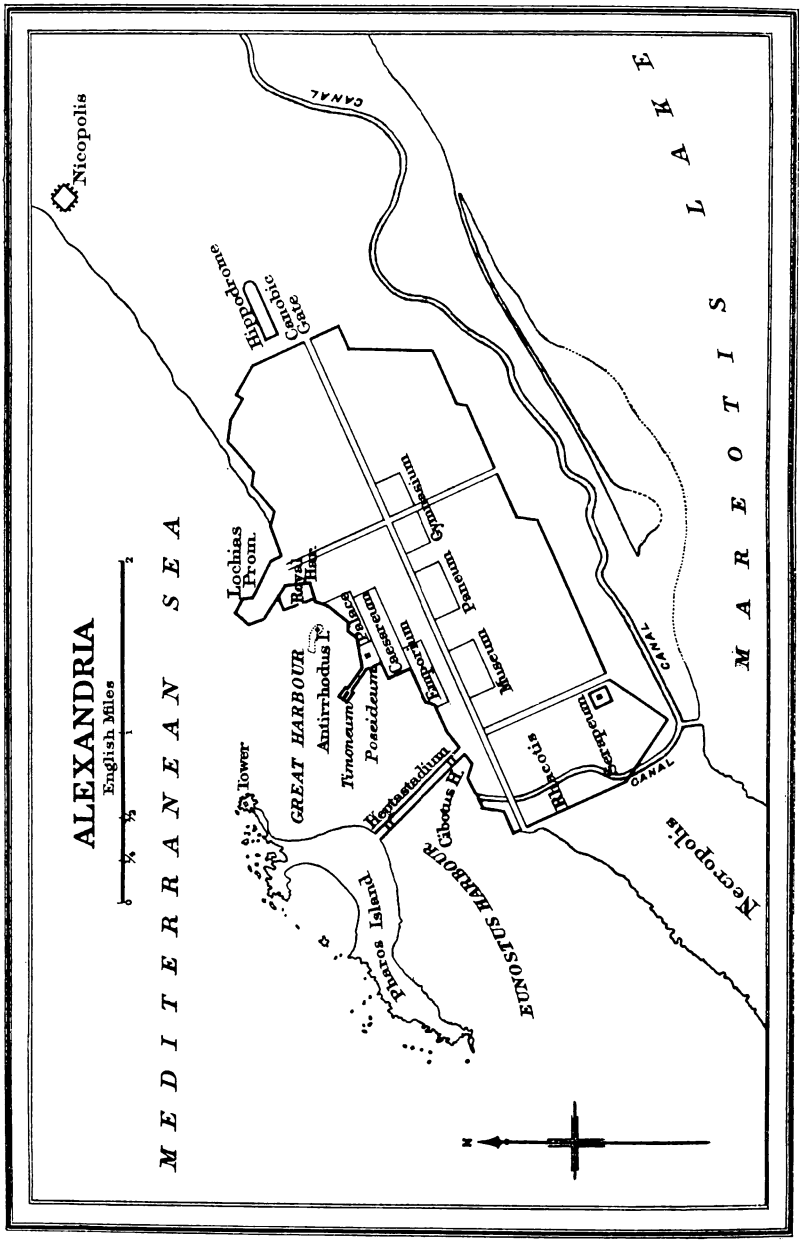

Fig. 2. The relationship of Pharos to Alexandria in Hellenistic times. (From Tozer, 1893.)

Plutarch (*fl.* 100 A.D.), however, deviated but little from Herodotus, claiming "Egypt used to be all a sea, and, for that reason, even to-day it is found to have shells in its mines and mountains" (*Moralia*, 367B). He fully accepted the alluvial deposition theory as an explanation of the sea's retreat, for which reason he was more inclined to look to Homer uncritically for proof.

> . . . and the Nile forced out the sea and revealed the fertile land, which it filled out with its alluvial deposits. This has support in the testimony of our own observation; for we see, even to-day, as the river brings down new silt and advances the land, that the deep waters gradually recede and, as the bottom gains in height by reason of the alluvial deposits, the water of the sea runs off from these. We also note that Pharos, which Homer knew as distant a day's sail from Egypt, is now part of it; not that the island has extended its area by rising, or has come nearer to the land, but the sea that separated them was obliged to retire before the river, as the river reshaped the land and made it to increase.

But what of the alternative theories? Strato, too, had travelled in Egypt, having been summoned there to tutor the second Ptolemaic Pharoah in about 300 B.C. Like Herodotus, he was led to believe that the land had once been covered with sea, since "even to-day, when the salt-lands in Egypt are dug up, the excavations are found to contain sand and fossil-shells, as though the country had been submerged beneath the sea and the whole region round Mt. Casius and the so-called Gerrha had once been covered with shoal water so that it connected with the Gulf of the Red Sea" (reported in Strabo's *Geography*, i. 3. 4). Strato knew of the effects of silt deposition; he observed that the large number of rivers emptying into the north and east of the Euxine (Black Sea) were causing the sea to become shallower — a fact known to Aristotle. Yet this was not the cause of the sea's retreat from Egypt. The Mediterranean and Atlantic had formerly been discontinuous, the shallower Mediterranean having its waters contained by an ancient bank of earth at the Pillars of Hercules. The volume of water in the Mediterranean basin was increased by the rivers flowing into it and the "passage at the Pillars was broken through when the sea had been filled by the rivers, and at the time of the outrush of water the places that had hitherto been covered with the shoal-waters were left dry". So, for example, the temple of Ammon, which had formerly been on the sea shore (how else to account for its popularity?) was now situated in the interior because of the outpouring of the sea.

Strabo does not accept Strato's explanation and points to its obvious inconsistencies, and although Strabo acknowledges silting as an agent of deltaic growth, still he believes that the main cause of transgressions and regressions is the concomitant shifting of the sea floor: "the beds of the sea themselves sometimes rise, and, on the other hand, sometimes sink, and . . . the sea rises or recedes along with its beds; for when the sea is lifted up, it will overflow, and when it is lowered, it will subside to its former level" (*Geography*, i. 3. 5). The stratum composing the sea bed, by virtue of its humidity, was thought by Strabo to be particularly susceptible to the wind, which would bring about these changes in position.

How are we to evaluate the popularity of these alternative hypotheses in antiquity? Presumably, since there is no mention of any other adherents to them, they posed little serious threat to Herodotus. Plutarch, living a century after Strabo wrote his *Geography*, seems fully committed to the alluvial deposition theory. And Diodorus Siculus, an older contemporary of Strabo in the second half of the 1st century B.C., when relating what historians teach concerning Egypt, only mentions the standard account of the alluvial deposition theory—one in which *all* of Egypt was a gift of the Nile (Diodorus, iii. 3. 2-3).

Clearly, belief in the former marine transgressions was prompted by the occurrence inland of artifacts normally associated with the sea. Their distance from the shore was often quite great. Xanthus saw bivalves "far from the sea, in Armenia, Matiene, and Lower Phrygia . . . and therefore was persuaded that these plains were once sea" (Strabo, *Geography*, i. 3. 4). Eratosthenes, as a prelude to praising the explanations of Xanthus and Strato, poses the question "how does it come about that large quantities of mussel-shells, oyster-shells, and scallop-shells, and also salt marshes are found in many places in the interior at a distance of two thousand or three thousand stadia from the sea" as, for example, he says adducing more evidence in favor of one of Strato's specific examples, "in the neighbourhood of the temple of Ammon and along the road, three thousand stadia in length, that leads to it?" (Strabo, *Geography*, i. 3. 4).

Shells were not the only evidence used in support of the theory of marine transgression. In the early 5th century B.C., Xanthus had noted the presence of salt lakes in support of his contention; a little later Herodotus reported that so much salt was exuded from the soil that the bases of the pyramids were being injured; about the temple of Ammon Eratosthenes noticed many beds of salt and jets of salt water; and in Egypt Plutarch observed "all the springs and wells, of which there are many, have a saline and brackish water, as if some stale dregs of the ancient sea had collected there" (*Moralia*, 367B). Even the shores of Lake Moeris—a lake near Ammon and thus considered once part of the sea—commented Strato, looked more like sea beaches (Strabo, *Geography*, i. 3. 4; and xvii. 1. 35). In each case the evidence seemed to the writer yet further proof that the sea had penetrated far inland.

CONCLUSION

The "easiest" shells hypothesis is untenable when applied to the Greeks. In fact, it was only because these shells were not the "easiest" that the need was felt for an elaborate theory of marine transgression to account for their present position. The belief that the sea had once covered certain tracts of land was widely held by geographers and historians for over half a millenium in classical times. Such was its popularity that it eclipsed the — apparently sole — alternative explanation of fossils in antiquity, proposed by Aristotle's pupil, Theophrastus. According to this, fossil fish found in Heraclea and Paplagonia were either fish that had strayed in search of food and had become entombed in the rocks or — in a form resembling a theory advanced by Edward Lhwyd in the late 17th century — were generated from fish-spawn left in the rock. In addition to explaining such observations, the marine transgression theory could also account for other anomalies, particularly inland salt lakes and salt deposits. Herodotus postulated the growth of the land by silt deposition as the mechanism of the sea's retreat. Most later writers accepted this, and although some only conceded its limited application, many agreed with Herodotus that all of Egypt was alluvial. Certainly, striking evidence of continuing deltaic growth was found when historical records were consulted. This procedure was a consequence of the lack of distinction between historic and geologic time, so that although geographical changes were recognized as being of long duration (particularly by Aristotle), still they could be discovered using historical evidence. Likewise, the Persian poet and mathematician Omar Khayyām (died about 1123) was led to the belief that the sea had retreated from certain areas in Asia by a comparison of contemporary and early Persian charts, supported by the observation of inland salt lakes.

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REFERENCES

Aristotle, *Meteorologica*, translated by H. P. D. Lee, 1952: Cambridge, Mass., Harvard Univ. Press; London, Heinemann, Loeb Classical Library.

Arrian, *Anabasis of Alexander*, translated by E. I. Robson, 1933: London, Heinemann; New York, Putnam, Loeb Classical Library, 2 v.

Bromehead, C. E. N., 1945, Geology in Embryo: Geol. Assoc. Proc., v. 56, p. 89-134.

Diodorus of Sicily, translated by C. H. Oldfather, 1935: Cambridge, Mass., Harvard Univ. Press; London, Heinemann, Loeb Classical Library, 10 v.

Gould, S. J., 1970, History versus prophecy—Discussion with J. W. Harrington: Am. Jour. Sci., v. 268, p. 187-189.

Harrington, J. W., 1967, The first, first principles of geology: Am. Jour. Sci., v. 265, p. 449-461.

———— 1969, The pre-natal roots of geology; a study in the history of ideas: Am. Jour. Sci., v. 267, p. 592-597.

Herodotus, *History*, translated by A. D. Godley, 1920: London, Heinemann; New York, Putnam, Loeb Classical Library, 4 v.

Hippolytus, *Philosophumena or the Refutation of all Heresies*, translated by F. Legge, 1921: London, Macmillan, 2 v.

Homer, *Iliad*, translated by A. T. Murray, 1960: Cambridge, Mass., Harvard Univ. Press; London, Heinemann, Loeb Classical Library, 2 v.

———— *Odyssey*, translated by G. H. Palmer, 1921: Cambridge, Mass., Riverside Press.

How, W. W., and Wells, J., 1928, A Commentary on Herodotus: Oxford, Clarendon Press, 2 v.

Hume, D., A Treatise on Human Nature, edited by T. H. Green and T. H. Grose, 1874: London, Longmans, Green, and Co, 2 v.

Kirk, G. S., and Raven, J. E., 1957, The Presocratic Philosophers: Cambridge Univ. Press, 487 p.

Krynine, P. D., 1960, On the antiquity of "sedimentation" and hydrology: Geol. Soc. America Bull., v. 71, p. 1721-1726.

Lyell, C., 1853, Principles of Geology, 9th ed.: New York, Appleton, 834 p.
Ovid, *Metamorphoses*, translated by F. J. Miller, 1916: London, Heinemann; New York, Putnam, Loeb Classical Library, 2 v.
Plutarch, *Moralia*, translated by F. C. Babbit, 1936: London, Heinemann; New York, Putnam, Loeb Classical Library, 14 v.
Popper, K. R., 1972a, Conjectures and Refutations, 4th ed.: London, Routledge and Kegan Paul, 431 p.
——— 1972b, Objective Knowledge: Oxford, Clarendon Press, 380 p.
Rudwick, M. J. S., 1972, The Meaning of Fossils: London, Macdonald; New York, Elsevier, 287 p.
Schvarcz, J., 1862, On the Failure of Geological Attempts in Greece prior to the Epoch of Alexander: London, Taylor and Francis, 75 p.
Steno, N., 1669, The Prodromus on Solids, *in* Steno—Geological Papers, edited by G. Scherz, translated by A. J. Pollock, 1969; Odense Univ. Press, 370 p.
Strabo, *Geography*, translated by H. L. Jones, 1949: Cambridge, Mass., Harvard Univ. Press; London, Heinemann, Loeb Classical Library, 8 v.
Thucydides, translated by C. F. Smith, 1930: London, Heinemann; New York, Putnam, Loeb Classical Library, 4 v.
Tozer, H. F., 1893, Selections from Strabo: Oxford, Clarendon Press, 376 p.
——— 1897, A History of Ancient Geography: Cambridge Univ. Press, 387 p.
Whewell, W., 1847, History of the Inductive Sciences, 2d ed.: London, John W. Parker, 3 v.
Woodward, J., 1723, An Essay Towards a Natural History of the Earth, 3d ed.: London, Bettesworth and Taylor, 304 p.
Von Zittel, K. A., 1901, History of Geology and Palaeontology, translated by M. M. Ogilvie-Gordon: London, Walter Scott; New York, Scribner, 562 p.