THE ORIGIN OF MARINE GEOLOGY

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INTRODUCTION

In our time, there is a growing interest in the history of science. This may be an indication that science is reaching adulthood. It has taken an established and recognized position. Although still strongly striving towards further advances in a near future, science has now learned that only when seen against the background of its history its present position can be understood and its future prospects be assessed.

What is true for science in general also holds for the marine geo-sciences. The following pages show a few major lines along which oceanography and, more particularly, the marine geo-sciences have developed. In the selection of subjects and examples, a review of this length necessarily has to be somewhat arbitrary. Moreover, it ends at a stage where the full scope of the marine geo-sciences actually just began. However, if a discussion of developments during the last three-quarters of a century would have also been included, at least an equal amount of pages extra would have been required and the selection would have been even more arbitrary. Nevertheless, it is hoped that this paper will help a little in the understanding of how the scientific disciplines to which this journal is devoted were born.

PRE-CLASSICAL TIMES

Hebrews

The Hebrews were never a maritime nation. This is reflected in the Bible, which contains no very definite notions about the sea. The waters of the sea represented for them a dangerous and ominous power; in the Creation, these were separated from the dry land, it is true, but they still continuously threatened that dry land (cf. Job 38 : 5; Psalms 46 : 3, 93 : 3, 104 : 6). There are indications that the ancient Jews had similar general ideas about the distribution of land and water as the Greeks at the

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time of Homer (cf. Job 26 : 10; Psalms 139 : 9; Proverbs 8 : 27). From the expression in Genesis 1 : 9 "Let the waters under the heaven be gathered together into one place" and the passage in the apocryphal book IV Esdras 6 : 42 "Upon the third day thou didst command that the waters should be gathered in the seventh part of the earth, six parts hast thou dried up and kept them", it has been interpreted that the ancient Jews believed that only one-seventh of the earth's surface was covered by the oceans. This was done, e.g., by Columbus, when he tried to prove that the Atlantic was not of any great extent.

Egyptians

The Egyptians, like the Hebrews, appear to have been antipathetic to everything connected with the sea. Maritime commerce was almost unknown to them, and their history contains no indications that they made any important discoveries related to the oceans. The ships they employed, for example in the famous southward voyage ordered by Pharaoh Necho II which resulted in the first circumnavigation of Africa, appear to have been manned by Phoenician sailors.

Phoenicians

In contrast to the Hebrews and Egyptians, the old Phoenicians, Carthaginians and Greeks had many explorers and navigators among them, who generally sailed the seas for commercial purposes. Although they developed their activities mainly in the Mediterranean area, some of their voyages reached much farther, to the western parts of the Indian Ocean and the eastern parts of the Atlantic Ocean.

The Phoenicians sailed the seas long before the Greeks had emerged from a state of barbarism. They are supposed to have come from the coasts of the Erythraean Sea (Indian Ocean), but had already settled all over the Mediterranean area before the oldest Greek and Hebrew scriptures were written. In the Atlantic Ocean, outside the Pillars of Heracles, they recognized an ocean with high tides similar to the Erythraean Sea. They sailed the Atlantic along the west coasts of Africa and Europe, to and from Gades and other settlements outside the Pillars of Heracles. They discovered the Canary Islands and were acquainted with floating gulfweed. It is not certain whether they reached the Sargasso Sea proper, as the gulf weed is frequently driven to east of the westernmost Azores; it is possible that the Phoenicians met the gulf weed somewhere in the Atlantic. Northward from the Pillars of Heracles, the Phoenicians discovered the Cassiterides, which may have been either the Scilly Isles or the islands in Vigo Bay, on the northwest coast of Spain. They went there in search of tin, of which they kept a monopoly by concealing its source from rival nations. Going still further northward, the Phoenicians reached Britain. East of the classical world, they sailed around the southern part of Arabia into the Persian Gulf and along the east coast of Africa. Commerce in pearls was undoubtedly a major stimulus for ravel in that part of the world.

CLASSICAL TIMES

Carthaginians

The Carthaginians followed in the tracks of their Phoenician ancestors, the Tyrians, as commercial sailors. Unfortunately, as with the Phoenicians, all their historical monuments have been destroyed. It is likely that the Carthaginians really discovered the Sargasso Sea off the African west coast. From the Greek translation of the *Periplus* of Hanno, we know that this Carthaginian admiral sailed as far south as the mouth of the Gambia in about 500 B.C. Another Carthaginian sailor, Himilco, undertook a voyage of discovery in the Atlantic Ocean northwest of Europe at about the same time.

Greeks

In Greek mythology, Oceanus is the son of Uranus (sky) and Ge (earth), the husband of Tethys, and the father of the Oceanids and River gods. In the writings of Homer, we find a reasonable idea of the conception held by the Greeks of his time concerning land and sea. In his works, the earth is represented as a large disk with slightly elevated

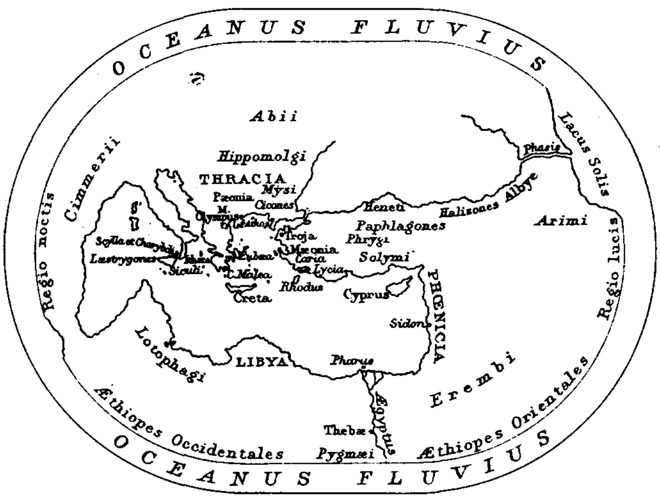

Fig.1. The world, according to Homer (about 1000 B.C.). (All illustrations in this paper are after J. Murray, 1895, *Rept. Sci. Results Voyage H.M.S. "Challenger"*, 50.)

edges; in the centre of the disk are the Aegean Sea and its archipelagoes. Oceanus is the river which encircles the whole world, beginning at the Pillars of Heracles, bordering the Elysian fields and Hades, and having its sources in the west where the sun sets.

The oldest story about Greek navigation is the legendary voyage of the Argonauts; however, this was probably a Phoenician rather than a Greek undertaking, in search of gold. Towards the end of the eighth century B.C., the Greeks began to build larger ships, which enabled them to undertake more distant voyages with less danger. According to Thucydides, the Corinthians were the first to build triremes, and the Samians learned the use of them from the Corinthians as early as 700 B.C.

Early in the sixth century B.C., the Greeks developed newer, less mythological views about the ocean. A century later, Herodotus (484–408 B.C.) abandoned speculative theories and gave further attention to the observation of facts. Although the Greeks should be considered the founders of scientific oceanography, they likely did not undertake oceanic voyages of discovery before the fourth century B.C., and in a way, these voyages were the prelude of oceanographic researches. In this connection, the naval enterprices of the Phocaeans need to be mentioned in particular. Phocaea, the most northerly of the Ionian cities in Asia Minor pioneered the exploration and colonization of the western Mediterranean. From their settlement of Massilia (Marseilles), the Phocaeans undertook such expeditions as that to the North Sea, under Pytheas, and that to the African west coast, under Euthymenes.

In the fourth century B.C., Aristotle also made important contributions to the knowledge of the sea, both as a naturalist and as a thinker. In his work *Meteorologica*, Aristotle mentions that currents flow from the Palus Maeotis (Sea of Azov) into the Pontus Euxinus (Black Sea) and from here into the Aegean. The cause of these movements was sought by him in the inequalities of depth in these seas. He thought that the Maeotis was being filled up and that it ultimately would become land. In the same work of Aristotle, we also find the first generalized, though inexact bathymetrical picture of the Internal Sea (Mediterranean). He records that the Pontus has parts, called whirlpools, wich are so deep that the lead never reached the bottom. With the exception of these deep places, the depth of the Internal Sea was believed to increase towards the west. The Pontus was supposed to be deeper than the Maeotis, the Aegean deeper than the Pontus, and the Tyrrhenian and Sardinian Seas deeper than the Aegean.

The Ptolemies, successors of Alexander the Great in Egypt, strongly promoted science in the third century B.C. Many learned men of the Alexandrian school published scientific work. Of these, the great influence of geodetical, astronomical and geographical studies of Eratosthenes (276–196 B.C.) should particularly be mentioned, because these prepared the way for the work of Hipparchus (?190–125 B.C.), whose name is especially associated with the introduction of projections in the tracing of charts and maps.

Straton of Lampsacus, who was for some time the teacher of Ptolemy II Philadelphus in Alexandria, and from about 287–269 B.C. was the president of the school in Athens, believed that the Pontus Euxinus and the Mediterranean had earlier formed one closed sea with a much higher water level than they had in his time. The presence of marine shells and of salt deposits far in the interior of Libya was stated as evidence in favour of this conception. The Straits of the Bosporus, the Hellespont, and Gibraltar were believed to have been formed when the former sea burst its

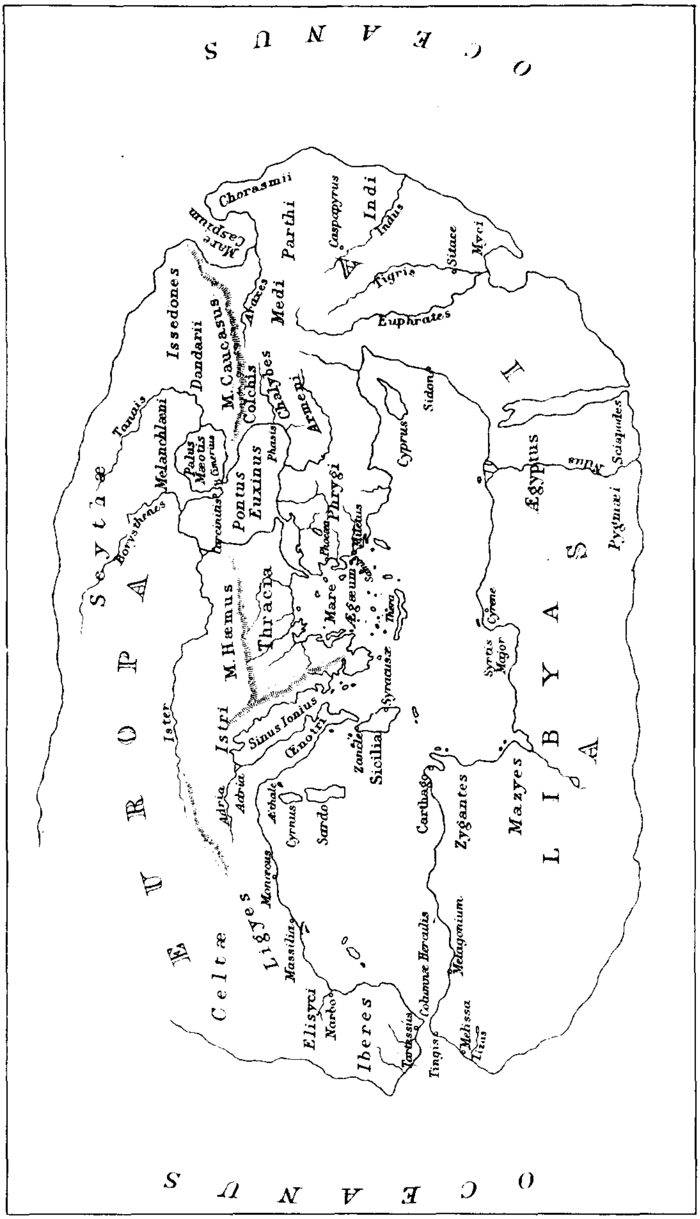

Fig.2. The world, according to Hecataeus (about 500 B.C.).

barriers. In this respect, Straton recorded the occurrence of a submarine bank in the Strait of Gibraltar, uniting Europe and Africa. Modern science has definitely proved that such a bank exists, but at such a depth that it is hardly probable that it could have been found by ancient soundings. It would, therefore, be interesting to know how Straton obtained this knowledge.

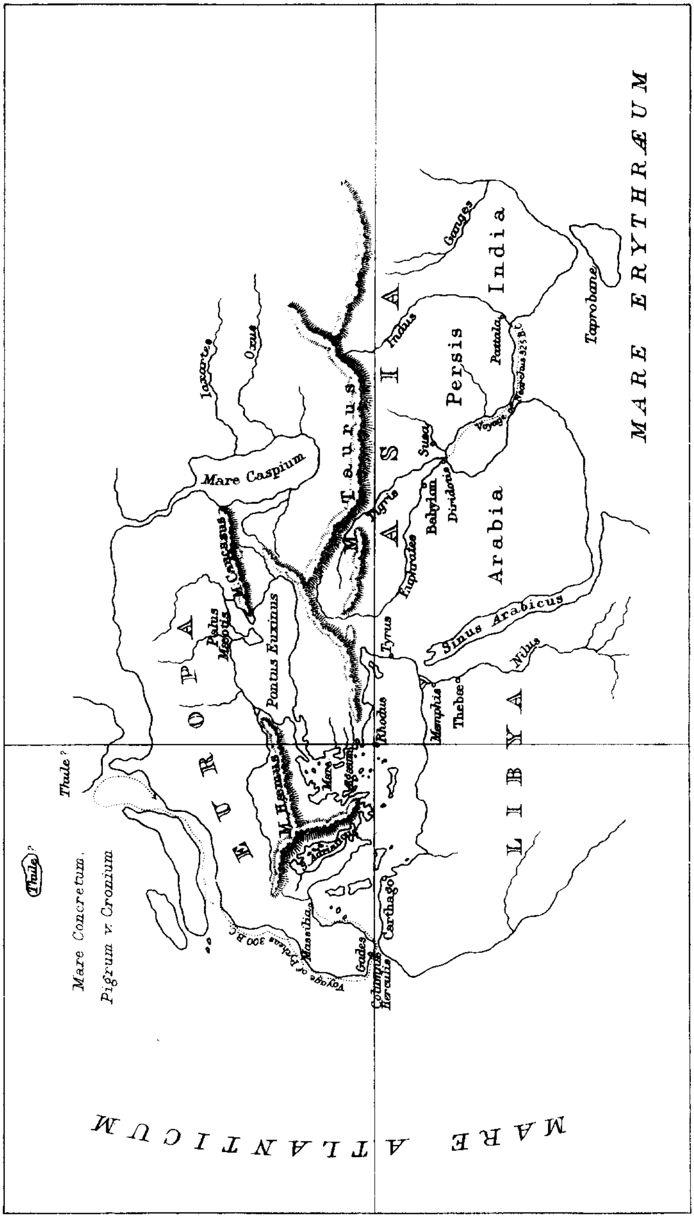

Fig.3. The world, according to Dicaearchus (about 300 B.C.).

Romans

Although the Romans extended their empire over most of the world they knew, they made few oceanographic discoveries. They were essentially a warlike and practical people. Scientific advances made in their times were often due to people of non-Roman descent, though generally possessing Roman citizenship.

Polybius (?203–ca. 120 B.C.), the Greek historian of Rome wrote about marine sedimentation and pointed out that rivers debouching into the Palus Maeotis (Sea of Azov) carry into this sea considerable quantities of sediment; he estimated the time it would take the fluviatile alluvium to fill up both the Palus Maeotis and the Pontus Euxinus (Black Sea) (Polybius, iv. 39–42). However, the rate of sedimentation is much slower than he supposed. Polybius reported that in his time, the greater part of the Sea of Azov was only 5–7 fathoms deep; about the same depths can still be found on modern hydrographic charts of that sea.

From these Roman times, another mystery around ancient bathymetry needs to be reported. Posidonius (also often called Rhodius because of his stay on the island of Rhodus), a Stoic philosopher (135–51 B.C.), stated that he measured the depth of the sea in the vicinity of Sardinia down to 1,000 fathoms. Unfortunately, there is no mention of how he did his measuring; however, this is the first record of a deep-sea depth determination and fifteen centuries passed before the second known deep-sea sounding was noted down by Magelhães.

Posidonius also left the first record about the appearance of a new volcanic island, one in the Lipari group. The movements of the land caused by earthquakes and volcanic eruptions showed him that the surface of the earth might be modified under the influence of these forces. This led him to believe that the Atlantis of Plato might not be pure fiction.

Also in Roman times, the Greek geographer Strabo (ca. 64 B.C.–at least 21 A.D.) wrote a comprehensive work about the physiography of land and sea. In the view of Strabo, all things on the crust of the earth are in a continual state of change.

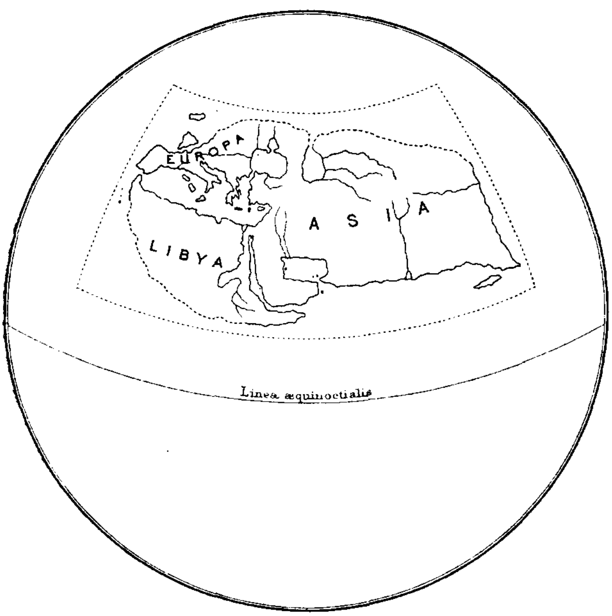

Fig.4. The world, according to Strabo (18 A.D.).

The present relief of the surface of the earth is due to these modifications. The distribution of land and sea has therefore not always been the same. Earthquakes and volcanic eruptions make the land move. Movements of the ocean floor are produced even more easily as the crustal material there is as if it were made plastic by the water. With rises of the bed of the ocean, dry land is invaded by the waters; these oceanic waters retire when the ocean floor descends. Oceanic islands are considered to be of volcanic origin. The greater islands closer to land are supposed to have once formed part of the continents, but were detached by dislocations. Even the continents themselves are regarded as being subject to oscillations and might have been raised from the bottoms of the various seas. He also believed that there is a relief on the sea floor with valleys and mountains similar to that on dry land.

Strabo also paid attention to erosion and sedimentation. He states that running water can produce profound modifications on the surface of the land, depending upon the nature of the country through which the streams and rivers flow. Torrents coming down from mountains have a great erosive power, and the same holds for rivers flowing over soft or sandy ground. Both spread out over plains and great quantities of alluvial matter are transported by them to the sea. He noted that material brought in suspension to the sea is not transported to great distances in this sea, but is soon arrested by the movements of the sea. Therefore, sedimentation of sandy materials takes place mainly near the coast, where modifications of the surface of the earth are thus greatest, with the result that one can easily get an exaggerated impression of the rate at which the bed of the ocean is being filled up. Strabo strongly rejected the view of writers who argued that the sediment brought to the Pontus Euxinus by rivers could have any considerable effect in filling up that sea and causing it to overflow.

Several statements concerning geological phenomena are found in the works of Ovid. In book XV of the *Metamorphoses*, Pythagoras is presented giving an account of many facts and processes of nature, such as the elevation and depression of great land areas and the great changes which these movements bring about, erosion caused by flowing water, and other subjects. However, Ovid lived about 43 B.C.–?17 A.D., and Pythagoras five centuries earlier. The latter left no works and even in Aristotle's days, he was already obscured by legend. Several passages in Ovid's poem suggest that he was giving the then-current conception of Pythagoras' teachings rather than an actual survey of knowledge which the Greek philosopher could have possessed.

Seneca had good notions about the erosive action of water. In his *Naturales Quaestiones* (dated about 63 A.D.), he stated that all rocks, including even the hardest, are penetrated by water. Due to a presence of a gas (spiritus) in this water, it is continually active in dissolving and disintegrating the rocks and transporting their components, often to far from their place of origin. The water also has considerable mechanical effects on the rocks. Not even the hardest rock can resist the destructive action of a repeated dripping of water, and such action is much more pronounced when the forces in play are those of streams, currents, and the waves of the sea. Water attacks and destroys rocks everywhere, with chemical erosion often preceding the mechanical effects. Streams and rivers always pick up demolition material from

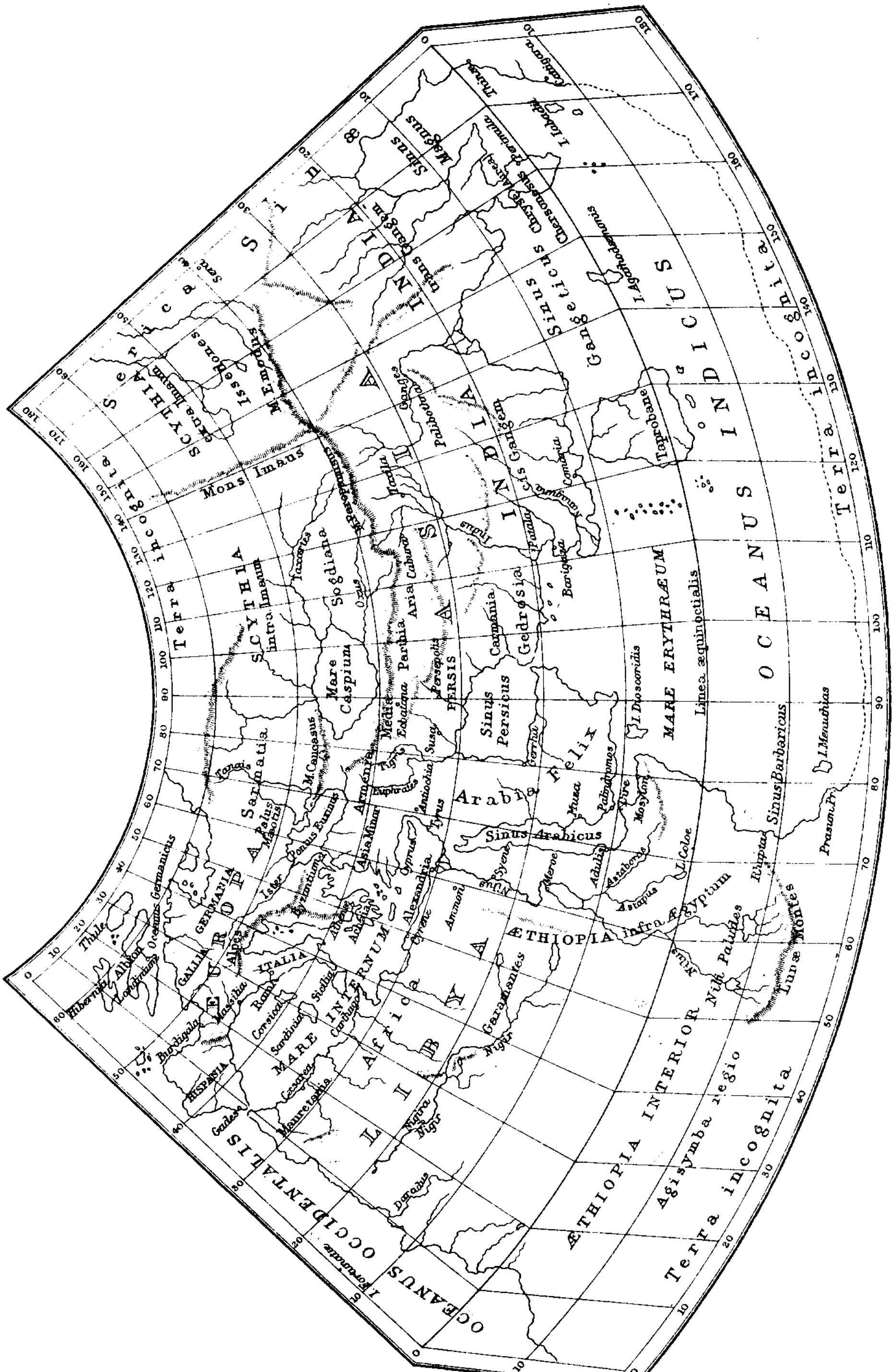

Fig.5. The world, according to Ptolemy (about 150 A.D.).

their beds, especially during floods. Sea waves exert even more erosive action than running water; this is well demonstrated by cliffs which are broken and smashed into ruins along several sea coasts. A large part of the material carried by rivers is transported into the sea. Part of it is deposited at the mouth of the rivers, thus forming deltas. The smaller mineral particles are often brought to great distances from the shore before they are deposited on the sea floor. Tides and currents are mentioned among other factors which contribute to the pattern of marine sedimentation.

Oceanographic observations in classical times more or less reached an end with the Hellenistic astronomer and geographer, Claude Ptolemy, who lived in Alexandria in the second century A.D. His famous map (Fig.5) shows the Oceanus indicus as an enclosed sea bounded by Africa, southern Asia, land extending from Sinae southward, and a Terra incognita in the south. The historical influence of Ptolemy is well demonstrated by the fact that this interpretation of the Indian Ocean was held until the second half of the eighteenth century.

MIDDLE AGES

After the fall of the Roman empire (fifth century), little was added to our knowledge of the sea for the next twelve centuries. In the west, there was initially a great retrogression from the advanced ideas of the Greek geographers and naturalists. In the sixth century

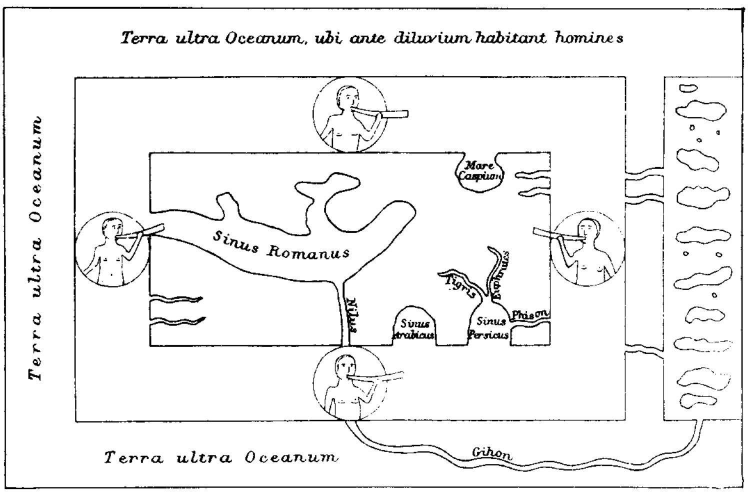

Fig.6. World map of Cosmas Indicopleustes (sixth century). Cosmas held the earth to be not a sphere, but a quadrilateral plane 400 journeys, or stations, of 30 miles each in length and half that distance in breadth. The earth is surrounded by the ocean and beyond this ocean is a second earth which everywhere reaches to the walls of heaven. Man was created at the eastern side of this transmarine earth, where Paradise was also located. When our ancestors were driven out of Paradise, they went westward (see top part of map), and with the deluge, Noah and his sons were carried in the ark to the land which we now inhabit. The four rivers of Paradise are conveyed by subterranean channels to our present land.

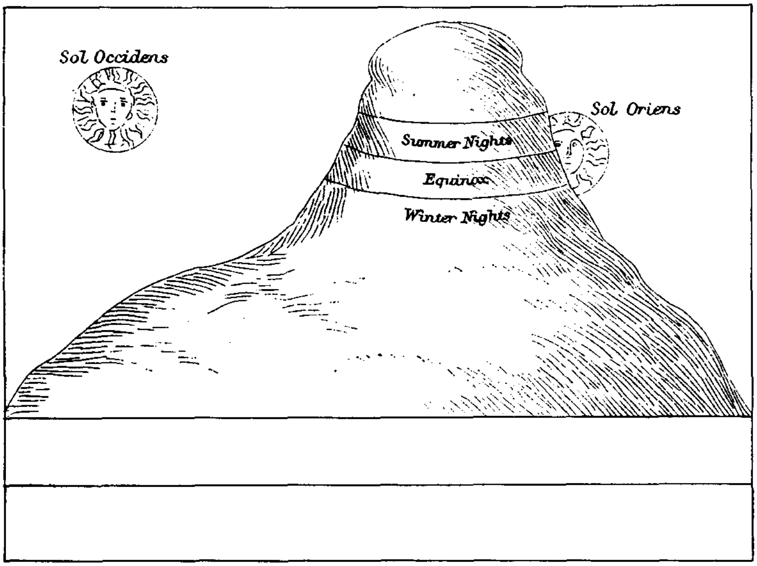

Fig.7. The conical mountain of Cosmas Indicopleustes, causing day and night and the seasons. The mountain was thought to rise from the hinterpart of the earth. When the sun reaches the mountain, night begins for the inhabitants of the earth. Seasons originate because the sun does not always make exactly the same revolution. When the sun follows the lowest line, nights are longer and it is winter; the sun passes the greater part of its course behind the mountain. When the sun ascends to the middle line, the equinox is caused and in summer, the sun reaches the uppermost line.

A.D., Cosmas, surnamed Indicopleustes, who was considered a great geographer in his time, taught that the earth is not a sphere but a quadrilateral plain; the firmament extends around the earth, the ocean and the stars, enclosing them hermetically in its crystal walls (Fig. 6, 7). Isidore of Seville, in the seventh century, developed the idea that the earth has the appearance of a wheel and, thus, gave rise to the "wheel maps" which can be found in several manuscripts from the Middle Ages (Fig.8).

Arabs

In the east, the Arabs sailed the Indian Ocean and introduced the mariner's compass, which they had found with the Chinese. Several accounts of Arabian voyages were collected by Abu Zaid around the year 851. Despite their frequent voyages in the Indian Ocean, many of the Arabs continued to hold the geographical ideas of Ptolemy about that ocean. However, some held more advanced views, such as Ibn-el-Fakīh, in the beginning of the ninth century, who wrote about the Great Sea extending from Maghrib to Kolzom (Suez) and to the Wak-wak Island of China (Japan). In the writings of Kazwini, we find early Arabian notions about the transport of sediments by rivers and the deposition of the coarser material in the river bed and of the finer material in the ocean. Mas'ūdī wrote about marine animals, and about the phenomena

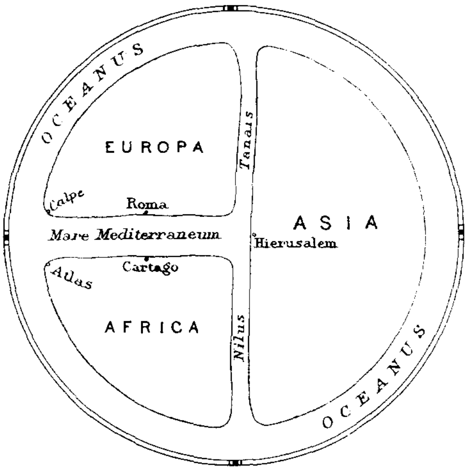

Fig.8. Example of a "wheel map"; maps such as this ornament several manuscripts from the Middle Ages. The idea that the earth has the appearance of a wheel was developed by Isidore of Sevilla (seventh century). He based this idea on the scriptural phrase, "the circle of the earth" and derived, by a false etymology, "rotundatus" from "rota", a wheel (Isidore, *Origines*, lib.XIV, cap.2,1: "Orbis a rotunditate circuli dictus, quia sicut rota est"). The representation of the earth as a wheel is similar to the Homeric idea of a disk surrounded by an ocean. The wheel maps divide the earth into two halves, an eastern half for Asia and a subdivided western half with Europe in the north and Africa in the south. The centre of the world is Jerusalem. Asia and Eurafrica are separated by the rivers Nile and Tanais (Don), and Europe and Africa by an unramified Mediterranean. This tripartite division ("Divisio trifaria") was supported by a text of St. Augustine, *De Civitate Dei*, xvi.17: "Unde videntur orbem dimidium duae tenere, Europa et Africa, alium vero dimidium sola Asia . . . Quapropter si in duas partes orbem dividas, Orientis et Occidentis, Asia erit in una, in altera vero Europa et Africa". This text is often found quoted by medieval cosmologists. (After J. Murray, 1895, *Rept. Sci. Results Voyage H.M.S. "Challenger"*, 50, Summary, p.30, pl.5.)

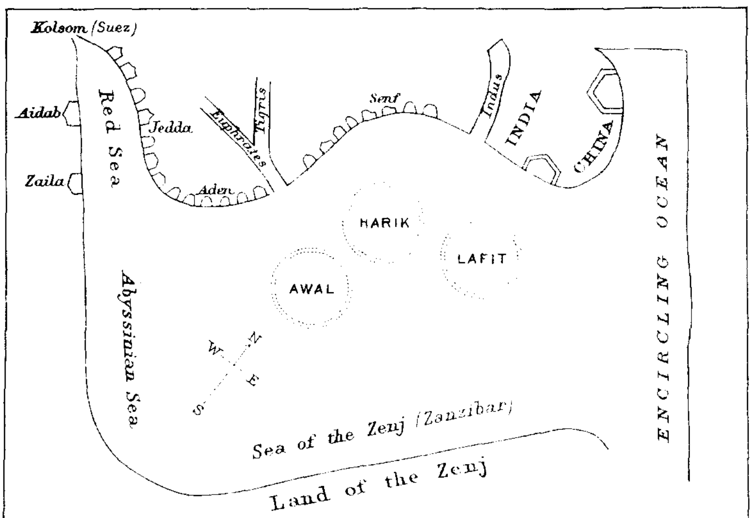

Fig.9. Map of the Indian Ocean (1173 A.D.).

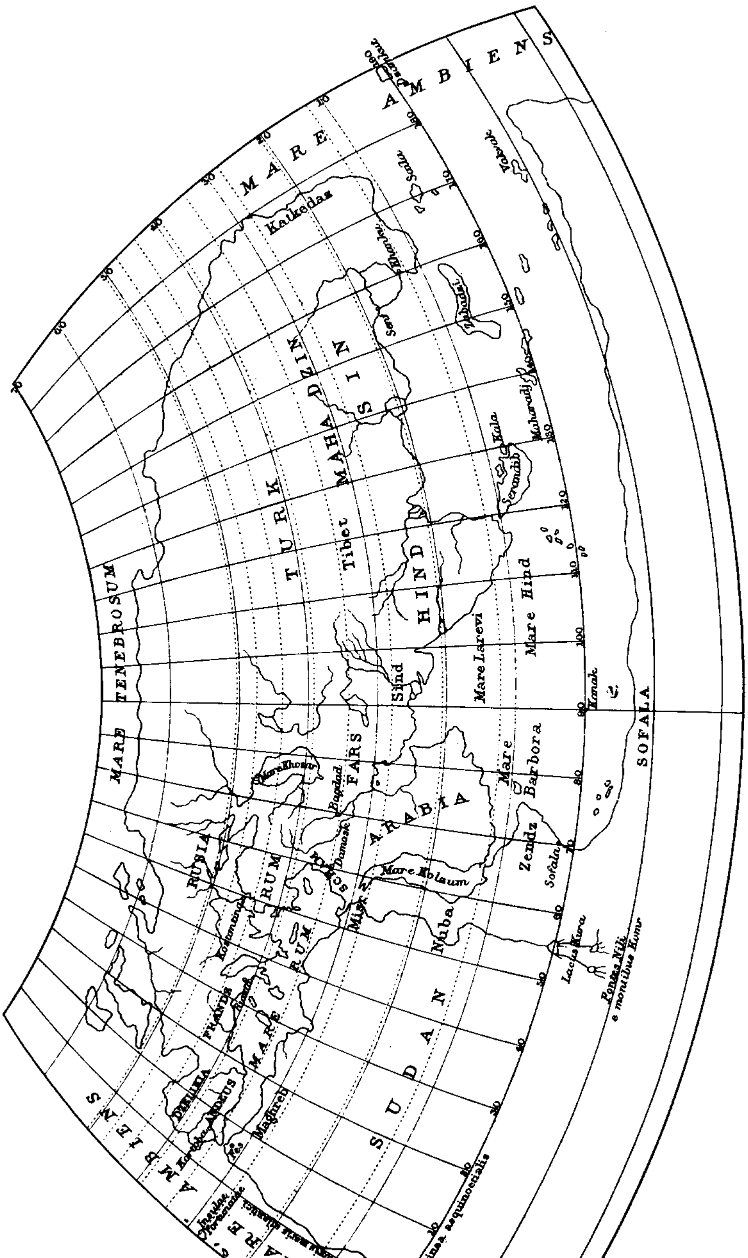

Fig.10. Quadrans habitabilis, according to Abu Rihan Birunensis (1030 A.D.).

of evaporation, formation of rain and the salinity of sea water. Although mixed in with several errors, he presented several very exact notions.

Norsemen

In the west, in the north Atlantic, the Norsemen were the dominant medieval explorers. Little is known about their various discoveries, but these should not be taken lightly as recent (1963) excavations in the north of Newfoundland have shown that the Vikings of Leif Eriksson indeed reached North America in about 1000 A.D., five centuries before Columbus. It is known that, in addition to Helluland (Newfoundland), Leif Eriksson and his companions also discovered the coasts of Markland (very likely Nova Scotia) and Vinland (very likely New England). It has even been alleged that for three centuries a transatlantic trade was carried on between Norway and a Norse colony in Vinland.

Late Middle Ages

In the thirteenth century, Roger Bacon (1214–1294) again promoted Aristotle's view that there is no great distance between Spain and India opposite the habitable world, and his arguments were copied by Petrus Alliacus in his popular book *Imago Mundi*, which belonged to the reading of Columbus.

Also in the thirteenth century, the famous compass charts made their appearance in Italy; these dealt mainly with the navigation of the Mediterranean. Since the ancients left no general or coast charts of that sea, these medieval maps mark important progress in knowledge about the geography of the Mediterranean.

THE PERIOD OF THE GREAT EXPLORATION VOYAGES (1453–1522)

The capture of Constantinople

The second main chapter in the history of oceanography is formed by the period of Renaissance and the great exploration voyages. The capture of Constantinople in 1453 led to a migration of learned Greeks to Italy, and this in its turn to a reappearance of Ptolemy's Geography. The clearly drawn maps of this work were a great improvement over the planispheric maps without graduation in use during the Middle Ages. The invention of the printing press also contributed greatly to make Ptolemy's maps and others based upon these widely known in western Europe.

The fall of Constantinople contributed also in another way to increasing knowledge in the west about the geography of the oceans. The victory of the Turks cut off the overland trade routes between Europe and Asia. Turkish pirates became a continuous threat to the merchant vessels of Christians and greatly imperiled the wealth which trade had brought to Venice, Genoa and western Europe. Therefore, the need to discover other ways to reach southeastern Asia increased.

Portuguese explorations

In 1420, the Portuguese prince Henry the Navigator had founded his famous maritime observatory at Sagres, close to Cape St. Vincent. There, several navigators were trained for the exploration of the Atlantic Ocean. Many expeditions were organized, and when Henry the Navigator died in 1460, about one third of the African west coast was known. About a quarter of a century later, in 1486, Bartholomew Diaz sailed around the Cape of Good Hope. Eleven years later, in 1497, Africa was circumnavigated for the first time since the legendary voyage of the Phoenician sailors twenty centuries earlier, and in this way, Vasco da Gama reached India.

In 1511, Albuquerque captured Malacca. This gave the Portuguese a new center of activity in the east, from where they sailed in all directions through the archipelagos of Indonesia and the Philippines and towards the coasts of China.

Spanish explorations

At that time, Spain also contributed greatly to an increasing knowledge of the sea, albeit often with the assistance of foreigners. Under the Spanish flag, Columbus rediscovered the American continent in 1492, the exploration of which was continued by Amerigo Vespucci. On September 25, 1513, from the summit of the Sierra Quarequa, Vasco Nuñez de Balboa beheld a boundless ocean at the west side of the Americas; this was the Pacific, and a period of search for a passage to that ocean was opened. Twenty years after the arrival of Columbus in the West Indies, Sebastian del Cano brought the first voyage around the world to an end. This voyage had commenced under Magelhães (Magelhan), who unfortunately lost his life in a fight with the natives of Mactan in the Philippines. Worth mentioning is that Magelhães made a first attempt to sound the depth of the open sea. He used the normal sounding line in use at that time for sounding shallow seas and, of course, was unable to reach the sea floor with it. This led him to the somewhat naive conclusion that he had reached the deepest part of the ocean.

In a period of only thirty years, 1492–1522, knowledge of the surface of the earth had increased to a considerable extent. An entire hemisphere had been added to the chart of the world, and the sphericity of the earth had become a demonstrated fact. However, thereafter the flow of new data again strongly diminished.

AN INTERIM PERIOD (1522–1768)

Compared to the great progress made in the preceding 30 years, advances in oceanographic knowledge during the next two and a half centuries was slow. In this period, however, is the dawn of marine geology.

Exploration voyages

Although Magelhães showed that southeastern Asia could be reached by sailing westward, this did not appear to be a promising trade route to that part of the world. Therefore, the idea of a northeast passage from Europe to Asia was developed. It seems likely that this plan was also derived from Ptolemy's map. Attempts to pass around Asia by the northeast were made by the Scandinavians, British and Dutch, but none of these were successful. Nevertheless, they provided much information on the geography of the northern seas.

Maps of the last quarter of the sixteenth century show that at that time great progress was made in determining the shape of the Americas, although the use of astronomical latitudes without longitudes still cause dseveral inaccuracies. The discovery of North America was completed by the discovery and exploration of the Hudson Strait and Bay by Hudson (1610) and Button (1612–1613) and of the Bering Sea and Strait by a Russian expedition under Bering (1728).

Several voyages were made to the Pacific. In the sixteenth century, some of these had already observed isolated parts of New Holland (Australia), and in 1642, Abel Tasman showed that this and also Van Diemensland (Tasmania) are surrounded by the ocean.

Between 1648 and 1764, the number of oceanic voyages was remarkably low. Except for the Bering expedition, hardly any important discoveries were made during these years.

Cartography

In the art of map making, five stages can be discerned. After the maps prepared in the fourteenth and fifteenth centuries by the maritime nations of the Mediterranean, in the sixteenth century, the Spaniards and Portuguese took the lead in map making. In about the middle of that century, the Germans took over that position, followed at the end of the sixteenth and in the seventeenth century by the Dutch and Flemish, and thereafter by the French. In 1514, Johann Werner presented the stereographic projection of the globe and, in 1569, Mercator's map on his increasing cylindrical projection was first published. The Dutch geographer, Abraham Ortelius (1527–1598), published the first atlas, under the title *Theatrum Orbis Terrarum* (1570, French edition 1598; an *Additamentum* was published in 1573).

Hydrographic signs, bathymetry

The first hydrographic signs are found on The Universal Chart, executed at Sevilla in 1527, and on a second similar chart dated 1529. They consist of crosses and dots to indicate reefs and other dangerous places. In later maps, dotted lines or masses of dots are introduced to mark sand banks and shallows. In 1728, the Dutchman Cruquius made a map of a river and applied the method of uniting points of equal depth by a contour line; after this, Philippe Buache was the first to use curves of equal level for a marine area. In 1737, he drew a map of the English Channel with isobathic curves, based upon soundings made every ten fathoms.

In 1752, Buache published an essay entitled *Essai de géographie physique, où l'on propose des vues générales sur l'espèce de charpente du globe, composée des chaînes de montagnes qui traversent les mers comme les terres; avec quelques considérations particulières sur les différents bassins de la mer et sur sa configuration intérieure (Hist. Acad. Sci.*, 1752, p.399). This title well demonstrates the value of recent publications having a summary in addition to a title. From the essay, it appears that Buache adopted the method of indicating the relief of the sea floor by means of isobathic curves with the intention of showing that certain elevations of the sea floor are related to the relief of the neighbouring land.

In the first half of the fifteenth century, Cardinal Cusanus developed a sounding apparatus to substitute for the sounding line and lead. It consisted of two bodies, one lighter than water and the other heavier; the first one was self-detached when the heavier one touched the sea floor, and then it returned to the surface. The sea depth could be calculated from the time that elapsed between the letting down of the apparatus and the return of the float. Modifications of the Cusanus apparatus were developed about a century later by Puehler, in the early seventeenth century by the Neapolitan architect Alberti, and around the year 1667, by Hooke. The greatest difficulty with all these apparatuses was to exactly determine the moment when the float returned on the surface. Therefore, in 1671, Hooke presented a bathometer with several improvements. The most important of these was a hole in the center of the apparatus containing an axis with inclined blades and a clockwork, which acted as a marker and which was stopped as soon as the weight touched the sea floor.

In total, these bathometers have contributed little to knowledge about the sea depth. The soundings made in these centuries were done as usual with line and lead and in coastal and shallow waters.

Marine geology

The rediscovery of the nature of fossils was made independently by both Leonardo da Vinci (1452–1519) and the French potter, Bernard Palissy (1499–1589). The latter, entirely on the basis of his own observations, came to the conclusion that fossils are the remains of animals and plants that long ago had lived on the earth. Leonardo may have derived his conception from the classical Greek literature. He wrote that the great rivers carry the waste of the land into the ocean, that deposits thus formed have been successively covered by others of varying thickness, that shells were deposited together with these layers and thus are the remains of marine organisms, and that these fossiliferous deposits were uplifted at a later stage, such that the bottom of the sea could become the top of mountains.

Unfortunately, not everybody held such advanced ideas as Leonardo. In places where basalt was found rising up out of the sea, such as the famous Giant's Causeway in Northern Ireland, the six-sided columns identical in shape gave rise to the idea that basalt had crystallized out of sea water. This conception of basalt genesis is found, among others, in the work of J. F. Henkel, *Pyritologia oder Kieshistorie* (1725). One of the greatest teachers of geology and mineralogy who ever lived, Abraham Gottlob Werner (1749–1817), considered Henkel to be the "father of mineral chemistry" and the teaching of the Wernerian school kept the false idea of basalt genesis until early in the nineteenth century. M. P. Colonne went one step further; in the book *Histoire naturelle de l'Univers* (1734), he wrote that sand is also a crystallization product of the waters of the ocean. Adhering to the old idea of four elements (fire, air, earth, and water) he explained sand as being a kind of salt in which the element earth is dominant. Both salt and sand are produced by the sea, along its shores. Under the microscope, sand looks like glass, and glass is made by fusing sand and salt together. Sand is, in fact, a salt that is somewhat more earthy than ordinary salt. Linnaeus (1707–1778) also believed in the genesis of sand out of water. In his extensive work on the systematics of the mineral kingdom, he opened his treatment of the *Arenatae* by writing that the members of this siliceous group "are formed from the most minute drops of water which fall as rain from the upper air and grow together into bodies of a sand-like material." Elsewhere in the same work, we read, "All still-standing fluids in nature gradually crystallize into a fine sand-like material. Such crystalline material, when it is deposited from sea water, is called sand when it is thrown up on the sea shore and becomes dry."

Closer to reality are the views of L. F. Comte de Marsilli. In his *Histoire physique de la Mer* (traduit par H. Boerhaave, Amsterdam, 1725, p.14), he stated his belief that the sea was excavated at the time of the Creation out of the same stone which we see in the strata of the earth. The material which seamen bring up in their soundings, he wrote, is not representative of the true nature of the sea floor because the rocky bottom is generally concealed by slime, sand, sandy, earthy and calcareous concretions, and organic matter, which material is brought there by the action of water. In the illustrations to his work, he marked the parts where the stony rock is present at the surface of the sea floor, and those parts which are covered with sand or with sandy conglutinations. The parts covered with fine sand are always those exposed to the flow of rivers.

The first chapter of Genesis, together with the apparition of small volcanic islands may have led the Italian Antonio Lazarro Moro to his theory, published in 1740, about the geologic history of the earth's crust. He wrote that the earth was initially completely covered with water. On the third day of the Creation, the sea floor was raised, leading to mountains of primitive rocks devoid of fossils. At a later stage, lava, salt, sulphur, and bitumen were erupted from the interior of the earth, which accumulated on the sea floor and later were also upheaved. These substances made the sea water salty. In the sea, animal life developed. Rivers brought continental wastes into the sea. With the eruptions continuing, an alternation of sedimentary and eruptive rocks was deposited.

Baldassari, while studying the fossils in the Siennese territory, recognized certain regularities in the distribution of fossils, the natural position of corals and the perforation of rocks by lithophagous shells. In the works of Knoor and Walet (1755–1773), we find already a distinction between pelagic and shallow marine fossils. They believed that fossils to which no analogues had been found belonged to groups existing in the unexplored deep seas.

A distinct link was thus laid, in the eighteenth century, between the study of the oceans and the geology of ancient deposits.

Physical and chemical oceanography

Several investigators have paid attention to the phenomenon of tides. Several different explanations were put forward, until Kepler recognized the dependence of the tides on the attraction of all the heavenly bodies.

In the fifteenth century, the Portuguese had already discovered the Guinea current. More information about marine currents became available as sailors began to abandon coasting, the only navigation of Ancient Times and the Middle Ages. In 1643, Fournier gave a list of all twenty localities from where currents were known and, in 1665, Athanasius Kircher brought together on a map all information of his time on marine currents.

Marsilli was one of the first to determine sea water temperatures at various depths. He carried out his studies over a period of six months, January–June, in the Mediterranean between Cassis and Riou and at depths between 10–20 fathoms. In 1757, Cavendish made the first self-registering thermometer. Varenius, Marsilli, Boyle, and Halley are the most prominent students of the salinity of the sea, which Halley believed to be due to salt brought in solution to the sea by rivers.

THE PERIOD OF INDIVIDUAL OCEANOGRAPHY (1768–1868)

In 1768, James Cook left England for the Pacific Ocean. On board his ship the "Endeavour" were the astronomer Green and the naturalist Joseph Banks. This was the beginning of a new period of expeditions, which greatly extended knowledge of the world ocean. This period reached its culmination in the second quarter of the nineteenth century. At that time, Charles Darwin was on board the "Beagle" for five years, the American geologist Dana did his researches on board the "Porpoise", Hooker made a voyage with the "Erebus" to the South Pole Sea, and Thomas Huxley went with the British Navy vessel "Rattlesnake" to Australia. This list of names can be extended with those of several others. There was a real renaissance in the scientific investigation of the oceans.

Particularly the earlier voyages provided a storehouse of geographical data. Thus, Cook's expeditions changed the Pacific area from almost a blank on the world chart to a chart differing but little from the present one. He also demonstrated that New Zealand was not part of the great Austral land. Gradually, however, the most important new data brought home were in the fields of the natural sciences, particularly on the geographic and vertical distribution of marine life.

The shallow seas closer to home also attracted increasing attention. Of great importance was the introduction of the naturalist's dredge for the study of the sea floor. The first to work with this dredge was the Dane O. F. Müller in 1799. In France, the dredge was introduced by Henri Milne–Edwards in 1830; in Great Britain, by Edward Forbes at around 1832; and in Norway, by Michael Sars in 1835.

Much use was also made of the experience of navy and merchant marine officers, among others, in the compilation of wind and current charts. One of the main compilors of such charts was M. F. Maury, a U.S. Navy officer. He also was one of the promoters of the Brussels Maritime Conference of 1853, which recommended the adoption of uniform methods for the making of nautical and meteorological observations.

Despite the great number of investigators interested in the ocean, there was little coordination between them until well into the nineteenth century. Almost everyone worked along his own ideas, interests and procedures. It was the time of great individual oceanography.

In the following, a few of the developments of this period are mentioned, again mainly in the fields of the geo-sciences.

Marine ecology and paleoecology

In 1832, J. V. Audouin and Henri Milne–Edwards published a 406 pp. study *Recherches à l'histoire naturelle du littoral de la France*. This was certainly not the first treatise on marine life, but it nevertheless deserves to be mentioned here because it contains a short chapter "Application de cette étude à la géologie" (pp.237–239). They clearly realized that the time would come when geologists would make good use of the findings of marine biology in distinguishing fresh-water deposits from those laid down in a marine environment, and also in estimating the depth of formation of some marine sediments. Audouin and Milne – Edwards also noted that shell accumulations are not always found at the sites where the animals actually lived, but that shells may be transported from various places before finally being assembled at a site of deposition.

At the British side of the Channel, Edward Forbes carried out similar studies. He also drew attention to the application of such ecological studies to geology and may be considered as the founder of paleoecology in the English-speaking world.

Darwin and his coral reef theory

The most epoch-making expedition of this period, as far as the marine geo-sciences are concerned, was the voyage of the "Beagle" in the years 1831–1836. When Captain Fitzroy expressed his desire to take a naturalist on board, Charles Darwin offered his services and was accepted. For five years, he collected facts and impressions which, from the first day, he wrote in his diary. Even up until now this has remained a very readable work. In addition to descriptions of the areas visited and their flora, fauna and population, it contains many interesting marine biological contributions, such as the passages about the way of life of an *Octopus* already in the first chapter. Very important, even today, are his descriptions of many coral reefs and volcanic islands. The subject is especially dealt with in his book *The Structure and Distribution of Coral Reefs*, which appeared in 1842. In it, Darwin introduced the classification of reefs that is still in use, which includes fringing reefs, barrier reefs, and atolls. He also gave an explanation of the origin of these types of reefs, which because of its simplicity was generally accepted and even long did not meet with any opposition. Reef-forming organisms, Darwin stated, built a fringing reef along the coast. The land gradually drowned, but the building activity of the reef formers kept pace so that they remained growing in shallow water. The initial fringing reef, however, developed in this way into a barrier reef or atoll, depending upon the areal size of the drowning land.

Sounding and sounding leads

On board his vessel during his voyage to Baffin's Bay (1817–1818), John Ross had his blacksmith manufacture a sounding apparatus of his own invention, with which he made four historical deep-sea soundings down to the depths of 2,700, 3,900, 6,000 and 6,300 ft. He brought up much larger quantities of bottom sediment than he ever could have caught with the traditional sounding lead.

To ascertain the depth of the water in mid-ocean, James Clark Ross developed a new sounding line 3,600 fathoms long on board his ships during the "Erebus" and "Terror" expedition to the Antarctic (1839–1843). The first abyssal sounding, to a depth of 2,425 fathoms, was made with this new line in 1840. James Ross also introduced the procedure of noting the time each 100 fathom mark of his line left the reel. In the course of the expedition, he lengthened the line to over 4,000 fathoms, but even then, on two occasions, no bottom could be found.

Several other sounding apparatuses were proposed, the most important of which was the Brooke apparatus consisting of a detaching apparatus affixed to the lead of the sounding line on a principle comparable to that employed earlier by Cusanus, Puehler and Alberti without a line.

The eigth edition of Maury's *Explanations and Sailing Directions to Accompany the Wind and Current Charts* (1858–1859) contains a chart (pl.XI) showing the bathymetry of the Atlantic by means of four colour shades for depths within 1,000, 2,000, 3,000, and 4,000 fathoms.

In 1867, B. Pierce, Superintendent of the U.S. Coast Survey, ordered an epoch-making sounding and dredging programme off the Florida coasts. The ordinary sounding leads initially used were replaced in the course of the operation by sounding leads developed by Stellwagen and Sands. The Stellwagen apparatus had a conical iron cup screwed to the sounding lead. When the apparatus was drawn up, a leather lid firmly closed the cup. Sand's sounding lead had a side opening with a spring door which was forced open when the apparatus sank into the sea-bottom deposit, but which closed when it was drawn up. Both samplers brought up much more material than the Brooke apparatus. According to Count Pourtalès, leader of the Florida project, the number of samples of marine sediments collected by the U. S. Coast Survey amounted to 9,000 already by 1870, a very respectable number for that time.

Marine sediments

In marine geology, the belief that sand was chemically precipitated or crystallized out of sea water gradually gave way to the conviction that sand, pebbles and gravel are of clastic origin. In the early nineteenth century, this major misconception was left to the rear guard, along with ideas such as that pebbles found in places far from rivers and on mountains high above the rivers (and which we now know to be of glacial origin) must have fallen from heaven. Real progress of marine sedimentary geology now could start; this came about particularly after the thirties of that century.

Ehrenberg, in the middle of the nineteenth century, studied with enormous activity the microorganisms in samples of marine sediments and in ancient deposits. He reached the conclusion that sediments similar to those which play such an important part in the earth's crust are still being formed on the sea floor.

From microscopic examinations of sounding samples from the U.S. Coast Survey collected off the Atlantic coast of the U.S.A., J. W. Bailey showed, in 1851, that owing to an abundance of Foraminifera, the deeper deposits differ considerably from the shore deposits, in which mineral particles, especially quartz, predominate. He noted that these quartz grains are rounded and polished in samples from shallow water, but angular in samples from deeper water. In 1856, the same author published a report about the material collected by Brooke in the Sea of Kamchatka from depths between 900–2,700 fathoms. He found that mineral matter diminishes with increase in depth, whereas the percentage of organic remains increases with depth. In that same year, he also reported about samples taken from a long submarine ridge between Newfoundland and the British Islands. This ridge had received the name of Telegraph Plateau because a company was planning to lay a cable along it. Baily observed the presence of volcanic ash in the samples, but could not well explain its origin, in view of the great distance from active volcanoes. He also noted that calcareous organisms increase in abundance as the Gulf Stream is approached.

In the samples collected off the Florida coasts, Pourtalès (*Report of Superintendent of U. S. Coast Survey for 1869*, published in 1872) found two well-marked types of deposits: siliceous sediments, found in the course of the cold current, and calcareous sediments from the course of the warm current. The latter could again be distinguished in coral and foraminiferous deposits. Researches under Louis Agassiz in this area showed that reefs develop only close to the coast, and that from these down to a depth of 50–60 fathoms, there is a muddy bottom, and then down to 100 and occasionally 200 fathoms, there is a rocky plateau covered with a calcareous conglomerate with molluscs and corals. The foraminiferous deposit is found at moderate depths in the Florida Strait at points where the rocky bottom is hidden, and Pourtalès could follow it without interruption along the bed of the Gulf Stream.

Most of the knowledge about the lithology of the bottom of the North Atlantic was brought together in a book and folio atlas *Lithologie du Fond des Mers* by the Frenchman Delesse, published in 1871. The work also gives information about the sea-floor morphology and other data bearing upon the formation of marine sediments, such as currents, tides and prevailing wind directions.

Distribution of continents and oceans

In 1869, Louis Agassiz wrote that from what he had seen of deep-sea deposits, he was led to believe that none of the ancient deposits of marine origin found in the continents had been formed in very deep water. Assuming that this view was correct, he concluded that "the main outlines and circumscription of the continents and of the oceans must have been determined at the very beginning of the formation of inequalities upon the earth's surface, and remained essentially the same through all geological ages, varying only as to their relative height and depth, as well as to their respective extension." For the outlines of the continents, he took, on the average, the 200-fathom line.

THE PERIOD OF THE "CHALLENGER" EXPEDITION

The "Challenger" expedition is often recognized as the onset of modern scientific oceanography. The great promoter of this expedition was the British biologist C. Wyville Thomson. He was also director of the civilian scientific staff on board and, after the return of the expedition, was director of the commission to supervise the distribution and investigation of the material collected during the voyage, and to publish the results.

The "Lightning" and "Porcupine" expeditions

While Wyville Thomson was doing research work on crinoids, he heard about the discovery by Michael Sars of the crinoid genus *Rhizocrinus*. This genus appeared to be more related to the fossil Apiocrinidae than to living crinoids. In 1868, Wyville Thomson decided to go to Christiania (Oslo) to personally study this crinoid. There, he was amazed by the rare animals that Professor Sars' son, George Ossian

Sars, had colleced from the Lofoten fjords, from waters deeper than 300 fathoms. The collected specimens contained several animals which seemed to be related to animals known to him only as fossils. He felt that if so much important information could be brought up from the sea bottom, it would certainly be worth while to organize a more general investigation of the deeper parts of the Atlantic along the European coast. He and W. B. Carpenter managed to convince the British Admiralty that it was necessary for the progress of science that scientists have the disposal of a small ship. Thereafter, they were joined by a third zoologist, Gwyn Jeffreys. In 1868, these three were allowed to make a cruise with the "Lightning", and in 1869 and 1870, they were able to continue their researches on board the "Porcupine". In successive voyages, the Atlantic was investigated from the Faroer Islands in the north, down to south of Gibraltar. These showed that many of the animals living at great sea depths belong to previously unknown species or to taxa which were believed to be extinct.

The "Challenger" expedition

The good results obtained with the Atlantic expeditions persuaded the British government to react favourably when Carpenter and Wyville Thomson, through the Council of the Royal Society, made proposals for a much larger oceanographic expedition. The "Challenger", a spar-deck corvette of 2,306 ton displacement, was assigned to make the proposed voyage. Wyville Thomson was appointed director of the civilian scientific staff which, in addition to himself, comprised two other marine biologists, N. H. Moseley and R. von Willemoës-Suhm (who died during the voyage), a physico-chemist, J. Y. Buchanan, a geologist, J. Murray, and a draughtsman, J. J. Wild.

The expedition left Portsmouth in December, 1872, and returned to Sheerness in May, 1876, after having cruised all three great oceans.

The amount of new information collected by the "Challenger" expedition was considerable. Some preliminary results were reported during the voyage, but most of it had to be worked after the return of the expedition under the general guidance of Wyville Thomson as director of the "Challenger" Expedition Commission, and, after 1881, under John Murray. The last of the fifty quarto volumes of *Reports on the Scientific Results of the Voyage of H.M.S. "Challenger"* didn't appear until 1895.

Some biological results

The "Challenger" expedition brought home an enormous number of new species. The majority of these belonged to either the abyssal benthos or the floating plankton. The term "benthos" was introduced by Haeckel, who studied the radiolarian material of the expedition and described more than four thousand species, most of which were new to science. P. H. Carpenter, son of Wyville Thomson's friend W. B. Carpenter, reported about the crinoids and showed that, instead of nearing extinction, the stalked crinoids are widely distributed and have shown hardly any decrease since the Mesozoic.

On the basis of his earlier expeditions, Wyville Thomson had hoped that living representatives of such Mesozoic groups as ammonites and belemnites could be found. Even to the last, every cuttle-fish which came up in the deep-sea net was squeezed to see if it had a belemnite's bone in its back, but this was all in vain. However, a "living fossil" was found in the mollusc group; this was *Trigonia*, a primitive lamellibranch genus known from Mesozoic deposits in Europe, and which still occurs alive off the Australian coast.

Hydrographic and physical oceanographical results

Progress in oceanography through the "Challenger" expedition was also considerable in fields other than marine zoology. Various little-known parts of the world were charted and surveyed. The exact position of many islands and rocks, whose locations had previously been uncertain, was determined. It was proven that on a magnetically suitable ship the variation of the compass can be determined with the same degree of accuracy as on land. Ocean currents were determined on the surface and at various depths.

For the first time, the depths and main contour lines of the Atlantic and Pacific Oceans were determined. The deepest sounding made by the expedition was 4,475 fathoms, not far from the Mariana Islands in the western Pacific north of the Equator. Of course, the contour lines that were obtained were very rough because of the small number of soundings made, but they did give the first reliable information which later was only extended and revised.

The 255 temperature measurements that were made gave an impression of the differences in temperature that occur at the surface and also showed that below a depth of about 100 fathoms, the temperature is independent of seasonal variations. Bottom temperatures were found to be constant over large areas, but differences were often found from one part of the ocean to another. The bottom temperature was found to be 32.7°F (0.4°C) in the southern Atlantic, 35°F (1.7°C) in the northern Pacific, 38.6°F (3.7°C) in the Arafura Sea, and as high as 50.5°F (12.8°C) in the Sulu Sea. These differences were explained as being caused by submarine ridges which separate the areas with different bottom temperatures and prevent a general spreading of the cold bottom waters from the poles. At no place did the bottom water show a temperature as low as the freezing point of salt water.

Reef studies

Soundings made during the "Challenger" expedition showed that there are many more submarine volcanoes than volcanoes which reveal themselves as oceanic islands. The surface of the submarine volcanoes may be covered by calcareous deposits which may help to build up a suitable platform for reef growth. Thus, no subsiding land would be required to lead to the formation of barrier reefs and atolls, such as was stated in Darwin's theory. In some cases, reef growth could even be accounted for along with elevation of land. This new theory was launched on April 5, 1880, when

Murray, the geologist of the expedition, read a paper about this before the Royal Society of Edinburgh. Initially, Murray's theory did not receive much attention, but this gradually changed. In the years 1896–1898, a committee of the British Association and the Royal Society investigated a selected atoll (that of Funafuti, which belongs to the Ellice Group in the southern Pacific) to find out which of the two rival theories was the most likely. A first expedition from Britain under Sollas was followed by two others from Australia under Edgeworth David. Borings were made to a maximum depth of over 1,100 ft. After the collected cores had been intensively microscopically investigated, supporters of both Darwin's and Murray's theories found that the results could be interpreted as supporting their views.

Origin of modern marine sedimentology

The "Challenger" expedition made principal additions to the oceanographic knowledge of the deposits now accumulating at various depths on the floor of the ocean. In a preliminary report sent home during the expedition, which was written by Murray from Valparaiso on December 9, 1875, and was published in the *Proceedings of the Royal Society* (Vol.24), we find the first classification of oceanic deposits into (*1*) shore deposits, (*2*) *Globigerina* ooze, (*3*) radiolarian ooze, (*4*) diatomaceous ooze, and (*5*) red and grey clays. Murray named deposits *2*, *3* and *4* after the nature of their chief constituents, and red clay after the alumina, iron and manganese it contains. Red clay contains comparatively few conspicuous organisms, but was sometimes found associated with great deposits of manganese nodules, ear bones of whales and gigantic shark's teeth, which apparently belonged to extinct species. *Globigerina* ooze occurs on the floor of moderately deep parts of the oceans (about 1,000–2,500 fathoms), where the water is temperate or warm, and is formed mainly of the shells of the Foraminifera which live in surface waters, the most abundant of which is *Globigerina bulloides*. The presence of this ooze was made known before the "Challenger" expedition by the soundings of cable-laying steamers in the northern Atlantic, described by Ehrenberg and Bailey (1853), and later by others, such as Wyville Thomson and Carpenter.

With the Abbé A. F. Renard of the Brussels Museum, later professor at Ghent, Murray accumulated material from all parts of the world and from all deep-sea exploring expeditions (about 12,000 items) for comparison with the "Challenger" sediment samples. Together, they produced the monumental *"Challenger" Report* 5, *Deep-Sea Deposits* (1891, 525 pp.). Murray classified all deposits into two main categories: (*1*) terrigenous, the gravels, sands and muds derived from adjacent land; and (*2*) pelagic, the deep-sea "oozes" far removed from land and largely made up of the calcareous and siliceous remains of organisms which once lived in the surface waters of the open ocean, and after death sank to the bottom.

The *"Challenger" Report* 5 first revealed to the scientific world the detailed nature and distribution of the various submarine deposits of the globe, and gave rational explanations for their process of formation and their relation to the rocks forming the crust of the earth.

In 1895, William Herdman, a younger collaborator of Murray and the first professor of oceanography at the University of Liverpool, proposed that a third category, named neritic, be added to include deposits found in shallow waters among terrigenous sands and muds but which are to a major degree not of terrigenous origin. Thus, the three primary divisions can be defined as follows: (*1*) terrigenous deposits formed chiefly of mineral particles derived from the waste of the land; (*2*) neritic deposits, largely of organic nature, of which the calcareous matter is derived from the shells and other hard parts of benthonic animals and plants; and (*3*) pelagic, or planktonic, deposits formed of the remains of free-floating animals and plants which lived in the sea over the deposit (except in the case of red clay).

Although later authors have proposed a variety of classifications, in which marine deposits are grouped according to several principles, the main elements in the Murray–Herdman classification have been retained in most of them.

Christmas Island

Among all the material that Murray collected for comparison with the rock samples that he himself had collected during the "Challenger" expedition, he found a piece of sediment from Christmas Island that appeared to be composed of a valuable phosphatic deposit. After overcoming several difficulties, he succeeded in convincing the British government to annex this uninhabited volcanic island in the Indian Ocean, south of Java, and to give a concession to exploit the deposits on that island to a company that he had formed. This turned out to be a great financial success in which the state also shared. Around 1910, Murray showed that the total amount the British treasury had received up until then, as a result of the exploitation of Christmas Island, was considerably more than the total cost of the "Challenger" expedition. Without that expedition, this income would never have been realized and the whole is a good example of how an expedition organized for purely scientific purposes can also lead to results of direct economic importance.

CONCLUDING REMARKS

It may seem to be somewhat arbitrary to end a review on the history of marine geology with the publication of the results of the "Challenger" expedition. Nevertheless, the author believes there is reason to do so. As stated, this expedition opened up a new stage in the development of this field. Even before the end of the nineteenth century, a few dozen further deep-sea expeditions were carried out, and a great many more followed in the twentieth century. Studies in shallow marine areas also vastly developed. If justice is to be done to all the work done since the "Challenger" expedition, the limits of a journal paper will have to be greatly surpassed. The foundations of the marine geo-sciences have been shown and readers of this journal can see for themselves the group of impressive constructions that have been raised upon these.

SUGGESTED READING

ADAMS, F. D., 1938. *The Birth and Development of the Geological Sciences.* Williams and Wilkins, Baltimore, 506 pp. Paperback reprint, 1954, Dover, New York, N.Y., 506 pp.

HERDMAN, W. A., 1923. *Founders of Oceanography and their Work. An Introduction to the Science of the Sea.* Edward Arnold, London, 340 pp.

ORTELIUS, A., 1570. *Theatrum Orbis Terrarum.* Aegidius Coppen Diesth, Antwerp, 278 pp. Complete reprint, 1964, Sequoia, Lausanne.

VON ZITTEL, R. A., 1901. *History of Geology and Palaeontology* (Translated by M. M. Ogilvie-Gordon). Walter Scott, London, 562 pp.

WALTHER, J., 1893–1894. *Einleitung in die Geologie als historische Wissenschaft. 1. Bionomie des Meeres. 2. Die Lebensweise der Meeresthiere.* Gustav Fischer, Jena, 531 pp.