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C. Wyville Thomson, J. Murray, and the "Challenger" Expedition

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INTRODUCTION

On the occasion of the first centenary of the "Challenger" expedition a brief review is offered of this famous scientific voyage which marked the beginning of modern oceanography. A brief biography of C. Wyville Thomson is presented, which includes details of his ocean studies that formed the prelude to the round-the-world voyage. Bibliographical notes are also given about John Murray, the renowned geologist of the expedition.

Several historians of science claim that modern oceanography really came into being with the "Challenger" expedition. This epoch-making scientific voyage began in 1872, a century ago this year. This anniversary is ample reason to dedicate a brief review to this expedition and the two most eminent researchers among its scientific staff.

C. WYVILLE THOMSON

Charles Wyville Thomson was born on March 5, 1830, at his ancestral country home of Bonsyde, in the neighbourhood of Edinburgh, near the shores of the Firth of Forth. When he was sixteen, he matriculated as a medical student at the University of Edinburgh. However, at that time his main interests already were zoology, botany and geology, and he was often found out in the fields and along the shores instead of attending lectures and studying textbooks. Three years later, he gave up his medical studies because of health, and definitely turned to biology and geology. In 1850, he left the university without a degree, but with such a well-known ability and reputation that only one year later, he was appointed Lecturer in Botany at the University of Aberdeen. In 1853, he filled the post of Professor of Natural History at Queen's College, Cork; one year later, he took the chair of Professor of Geology in Belfast and in 1860, he became Professor of Zoology and Botany in the same college.

While at Belfast, Wyville Thomson studied several groups of living and extinct invertebrate animals, such as coelenterates, polyzoans, cirripedes and trilobites. Studies of fossil crinoids evoked his interest in the only recent members of that group in the British seas, the rosy feather stars. In 1862, he completed a study on the embryogeny of *Antedon rosaceus*, which was published in the *Philosophical Transactions of the Royal*

Society for 1865. While he was working with W.B. Carpenter on the later development of *Antedon*, he heard that Michael Sars, in Norway, had discovered a remarkable new crinoid genus. This led to his first oceanographic expeditions, the "Lightning" (1869) and the "Porcupine" (1869, 1870). The results of these new, successful investigations increased his fame. In 1869, he was elected to the Fellowship of the Royal Society and in 1870, he was appointed Professor of Natural History at the University of Edinburgh. Both Carpenter and Wyville Thomson saw, in the success of the earlier expeditions, sufficient basis for a proposal to the Royal Society and British government for organization of a grand-scale expedition to the great oceans. This led to the famous "Challenger" expedition, 1872–1876. Wyville Thomson was appointed director of the civilian scientific staff on board and, as John Murray, the geologist of the expedition, reported later, he was the most enthusiastic member of the team. At first, when the dredge came up from great depths, everyone crowded around it to see what had been fished up. But gradually the crowd became smaller and it appeared that even naturalists could get weary of deep-sea dredging. However, Wyville Thomson never missed the arrival of the net at the surface.

On the return of the expedition, he was appointed director of the commission to supervise the distribution and investigation of the material collected during the voyage, and to publish the results. Indeed, the best men from several countries were invited. The necessary administrative work took so much of Wyville Thomson's time that he himself was unable to also take a very active part in original research.

In 1876, Wyville Thomson was knighted and awarded a gold medal of the Royal Society. In 1877, he published the first half of a general review of the work of the expedition under the title *Voyage of the "Challenger" – The Atlantic.* It was intended that this two-volume publication would be followed by a similar publication about the Pacific, but this was never prepared. In 1880, he arranged for the "Knight Errant" expedition to the Faroe Channel, which was conducted by Captain Tizard and John Murray. Wyville Thomson had to remain in the Outer Hebrides, where he gave general directions for the four traverses of the Faroe Channel. Because of his declining health, he could not take a more active part in the expedition. In 1881, he resigned as director of the "Challenger" Expedition Commission and was succeeded by John Murray. On March 10, 1882, Charles Wyville Thomson died at Bonsyde.

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 collected from the Lofoten fjords, from waters deeper than 300 fathoms (ca. 550 m). 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 worthwhile to organize a more general investigation of the deeper parts of the Atlantic Ocean 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", which Wyville Thomson described as perhaps the very oldest paddle-steamer in Her Majesty's Navy (*The Depths of the Sea*, p.57); it was scarcely seaworthy. Nevertheless, they obtained important results during a six-week cruise off the coast of Scotland. Dredgings and temperature measurements were made at dephts down to 1,300 m. Later researches, inspired by their observations, led in 1880 to the discovery of sills between Scotland and Iceland, which became known as the Wyville Thomson Ridge. In recognition of the initial results obtained by Wyville Thomson and his colleagues aboard the "Lightning", in 1869 and 1870 a better ship, the "Porcupine", was equipped for them by the Admiralty.

In successive voyages, the Atlantic was investigated from the Faroe Islands in the north, down to south of Gibraltar. This revealed that the ocean is a vast region with mountains and valleys, warm and cold streams, light and oxygen, and everywhere abundant life. Large zoological collections were secured. 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. Thus, Wyville Thomson discovered *Holtenia* and other new deep-sea hexactinellid sponges, about which he reported in the *Philosophical Transactions of the Royal Society* for 1874, and which threw new light on the ventriculites of the Chalk. He also caught the first living representative of the flexible sea urchins which were previously known only through fossils from the Chalk (see *Phil. Trans. Royal Soc.* for 1874).

THE AZOIC ZONE REJECTED

At the time Wyville Thomson started his oceanographical studies, there was the view advocated by Edward Forbes that life in the sea ended at a depth of about 300 fathoms (549 m). Forbes had reached this conclusion from observations in the Mediterranean; he did not know then that this sea is of exceptional character in some respects.

During his early years in Belfast, Wyville Thomson had developed a doubt as to the correctness of Forbes' view. In 1860, a cable was lifted from the floor of the Mediterranean to be repaired. It came from a depth of more than 1,000 fathoms (1,829 m). Nevertheless, Professor Fleeming Jenkin found several animals attached to the cable, including a deep-sea coral. Wyville Thomson's visit to Sars, in 1866, provided him with further indications that life also occurs below a depth of 300 fathoms. During the "Lightning" expedition, he dredged down to 600 fathoms. On the "Porcupine" expedition, he got sixteen successful hauls from depths greater than a thousand fathoms, the deepest of which reached 2,435 fathoms (4,453 m). In all cases, life was found to be abundant, and Forbes' views on the azoic zone were definitely proven to be wrong.

THE FIRST GENERAL TEXTBOOK OF OCEANOGRAPHY

A good review of the results of the "Lightning" and "Porcupine" expeditions is given in Wyville Thomson's book *The Depths of the Sea* (1872). Although the book emphasizes descriptions of the expedition and its marine zoological results, it also discusses in the final chapters subjects in the fields of physical and chemical oceanography, such as deep-sea temperatures, the Gulf Stream, and sea-water chemistry. This may be considered the first general textbook of oceanography. Since it was published about the time of departure of the "Challenger" expedition, it also gives a good picture of the state of oceanographic knowledge just before the epoch-making event.

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 four-masted spar-deck corvette of 2,306 ton displacement, with auxiliary engines, 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 followed the following route: Gibraltar – Canary Islands – Antilles – Halifax – Bermuda Islands – Azores – Cape Verde Islands – along the Atlantic coast of Africa – east coast of South America – across the Atlantic coast of Africa – east coast of South America – across the Atlantic again – over Tristan da Cunha to Cape Town (October–December 1873) – Marion and Crozet Islands – Kerguelen – down to the Antarctic region (66°40′ south in February, 1874) – Australia – New Zealand – New Guinea – Philippines – Hong Kong – New Guinea – Admiralty Islands – Yokohama – Sandwich Islands – Valparaiso – Strait of Magelhães (January, 1876) – Montevideo – Cape Verde Islands – Sheerness (May, 1876). During this three-and-a-half year expedition, a distance of about 69,000 miles was covered, and 370 deep-sea soundings, 255 temperature measurements, 111 dredgings and 129 trawlings were made. To us, the number of deep-sea stations may appear to be low, but we should remember that it took about a day to dredge and trawl at any considerable depth.

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. More general information can be found in the books by Spry, *Cruise of H.M.S. "Challenger"* (1876), Wyville Thomson, *Voyage of the "Challenger" – The Atlantic* (1877) and Mosely, *Notes by a Naturalist on the "Challenger"* (1877).

BIOLOGICAL RESULTS

The "Challenger" expedition again proved that marine life is possible at great depths, and that the enormous pressure, the utter darkness, and the differences in the chemical and physical conditions of the water and in the proportions of its contained gases depending upon such extreme conditions do not influence animal life to any great extent. Buchanan once convincingly demonstrated the enormous pressures at great depths. He lowered a hermetically sealed thick glass tube, wrapped in flannel and encased in a wide copper tube with perforated ends, to a depth of 2,000 fathoms. When hauled in, the copper tube was flattened and the glass tube inside the flannel was reduced to a fine snow-like powder. Wyville Thomson called this an "implosion", the converse of an explosion. It was explained that very delicate animals can live under these high pressures because their tissues are permeated by fluids under the same pressure; thus, the pressure is equal on the inside and outside. When animals, such as deep-sea fishes, are brought up suddenly from great depths, the release of pressure causes the eyes to burst out, forces off the scales and distorts other parts of their bodies.

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. Hjalmar Théel described an entirely new group of abyssal holothurians, the Elasipoda, with over fifty species distributed practically from pole to pole. Many pages in the "Challenger" reports are devoted to the crustacean phylum, in which almost a thousand new species were included, again mainly from abyssal depths and sometimes showing remarkable environmental modifications. In the Strait of Magelhães, at a depth of 245 fathoms (448 m), the remarkable hemichordate *Cephalodiscus* was caught for the first time. Also, many new abyssal tunicates were described. The "Challenger" expedition found that deep-sea fishes occur down to depths of at least 2,750 fathoms (5,030 m). 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. Moseley tells in his book that, 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 live off the Australian coast.

BATHYBIUS UNMASKED

In earlier deep-sea samples, biologists found a grey gelatinous material clinging to particles such as sand grains, mud, minute shells and shell fragments. This was interpreted, especially by German marine biologists, as being the remains of a primitive protoplasmic living slime. They felt that this slime covered the ocean bottom as a nutrient pabulum upon which the higher animals fed in the absence of plants. The famous British zoologist T.H. Huxley also received some of this slime, taken from mud samples collected during the laying of the first telegraph cable between England and America. In honour of Ernst Haeckel, he named it *Bathybius haeckelii.* Haeckel published a paper on this slime in the *Jenaische Zeitschrift* in 1870. He considered it a proof of the concept of a generatio spontanea. Haeckel enthousiastically wrote: "die Tatsache, dass ungeheure Massen von nacktem, lebendem Protoplasma die grösseren Meerestiefen in ganz überwiegender Quantität und unter ganz eigentümlichen Verhältnissen bedecken, regt zu so zahlreichen Reflexionen an, dass man darüber ein Buch schreiben könnte". The "Challenger" expedition revealed that a grandiose mistake had played a part. Buchanan showed that this *Bathybius* was nothing more than a sulphate of lime precipitated when a certain amount of strong alcohol was added to a certain volume of sea water.

HYDROGRAPHIC AND PHYSICAL 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 (8,184 m), not far from the Mariana Islands in the western Pacific north of the Equator. This showed that the great depths which were earlier believed to occur in the oceans had generally been exaggerated. 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 refined. While crossing the Atlantic, a depth sounding was made every 100 miles. Since the soundings had to be made with a 90 kg weight attached to a hemp cord, the procedure was very laborious. This explains the long distances between successive measurements. Nevertheless they led to a very important discovery: the centre of the Atlantic is half as deep as the large lateral troughs.

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 (183 m), 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 (10.3°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.

THE "KNIGHT ERRANT" AND "TRITON" EXPEDITIONS

During the "Lightning" and "Porcupine" expeditions, Carpenter and Wyville Thomson had discovered notable differences in water temperatures and animal life between the northeastern and southwestern part of the Faroe Channel between Cape Wrath and the Faroe Isles. Whereas the water down to a depth of 200 fathoms had about the same temperature-range in the whole channel, water at a depth of 250 fathoms in the northeast showed a temperature of about 34°F (1.1°C), compared to about 47°F (8.3°C) in the southwest. At a depth of 600 fathoms, this was about 30 and 42°F respectively (−1.1 and +5.6°C). In the "warm" area, 216 animal species were found; in the "cold" northeastern area, 217 species. However, of these, the two parts of the Faroe Channel had only 48 species in common.

The results of the "Challenger" expedition had indicated to Wyville Thomson that such remarkable differences in temperature and fauna were caused by the presence of submarine ridges. If this conclusion was correct, there should be such a ridge rising to within 200–300 fathoms of the surface between the "warm" and "cold" areas of the Faroe Channel. To test this hypothesis, Wyville Thomson induced the Admiralty to make an expedition to this region. This was the "Knight Errant" expedition, made in the summer of 1880. Murray, the scientist on board, actually discovered the ridge, which runs from the northwest of Scotland by the island of Rona to the southern end of the Faroe fishing banks. The ridge was called the "Wyville Thomson Ridge".

The "Triton" expedition was made to this same area in the summer of 1882, under Captain Tizard and Dr. Murray. This expedition laid emphasis on zoological investigations of the Arctic fauna in the northeast and the Atlantic fauna in the southwest of this area. Unfortunately, Wyville Thomson died earlier that same year and thus did not see his theory fully proven, that the faunal demarcation line corresponds to the submarine ridge that bears his name.

J. MURRAY

The name of John Murray has been mentioned several times in the previous pages. He was the geologist on board the "Challenger", the successor of Wyville Thomson as director of the "Challenger" Expedition Commission and the scientist of the "Knight

Errant" and "Triton" expeditions. Before briefly discussing the geological results of the "Challenger" expedition, it will be useful to first tell something more about this great oceanographer.

John Murray was born of Scottish descent in Coburg, Ontario, Canada, on March 3, 1841. He went to Scotland to study at the University of Edinburgh, where earlier Forbes and Wyville Thomson had also been students; he, also, studied medicine and science and left the university without taking a degree. Nevertheless, late in his life, none of his contemporaries held so many honorary degrees and titles, which had been awarded to him by universities and learned academies in both Europe and America.

After his passage from Canada to Britain, Murray went on his first sea voyage in 1868 in the function of surgeon. This was on board a Peterhead whaler to Spitzbergen, Jan Mayen and other parts of the Arctic region. This trip and the early deep-sea expeditions of Wyville Thomson stimulated his interest in sea research. When one of the scientists engaged for the "Challenger" expedition dropped out at the last moment, Wyville Thomson invited Murray to fill the vacant post. This determined the future course of his life.

Three subjects held the special interest of Murray during the "Challenger" expedition; the oceanic plankton, the marine sediments and the origin and formation of coral reefs and islands. In the reports which he sent to Britain during the voyage and which were published in the *Proceedings of the Royal Society*, we find the first classification of marine deposits and the first pictures of the remarkable deep-sea radiolarians which Haeckel later named Challengerida.

During the last years of Wyville Thomson's life, Murray took over more and more of the work on the "Challenger" collections and results, and in 1881, he officially succeeded Wyville Thomson as director of the "Challenger" Office. Under his directorate, the fifty thick quarto volumes of reports were completed. These included five volumes to which he contributed a very substantial part, among which is the monumental volume *Deep-Sea Deposits* (1891) and the two concluding volumes *Summary of Results* (1895). In these last two volumes, he presented views which were new and daring but which, in Murray's eyes, were supported by sufficient evidence to allow their publication. He admitted that he was sometimes wrong, but his slogan was that the man who never made a mistake never made anything else.

An example of a theory which Murray believed to be well supported by evidence from the "Challenger" expedition, but which turned out to be untenable, was the theory of "bipolarity". It was thought that identical organisms occur in the Arctic and Antarctic seas, representing the remains of an original marine fauna that had occurred world wide in an earlier phase of the Earth's history, but which had later disappeared except in the polar waters.

In 1884, Murray and Robert Irvine built a wooden house containing a chemical and a biological laboratory on a large canal barge. This was initially moored in a drowned sandstone quarry along the shores of the Firth of Forth, and later at the Millport biological station, Cumbrae Island. In this floating laboratory, Murray and Irvine carried out research on the chemical processes taking place in marine organisms secreting calcium carbonate, on the solution of calcium carbonate by the carbon dioxide present in sea water, and on the chemical changes that occur in submarine deposits.

In the same years, Murray also used his little yacht "Medusa" for oceanographic investigations in the neighbourhood of land. In the years 1884–1892, it was actively engaged in the study of the physical and biological conditions in the fjord-like sea locks of western Scotland. From time to time, the vessel also penetrated fresh-water locks and, from 1897–1909, it was almost entirely used for a bathymetrical survey of the Scottish fresh-water locks. These appeared in part to have amazing depths of up to 180 fathoms, which is more than the depths in the open sea above the continental shelf.

The growing need for a general bathymetric chart of the oceans led to the setting up of a commission, which studied the question during the Seventh International Geographical Congress, held in Berlin in 1899, and which met again in Wiesbaden, in 1903. Murray was on of the nine members of this committee of experts.

Murray was the chief British delegate to the first International Conference on the Exploration of the Sea. This conference was held in Stockholm on June 15, 1899, in response to an invitation from King Oscar II of Sweden. This conference and similar conferences in Christiania (Oslo) in 1901 and in Copenhagen in 1902 led to the foundation of the Conseil Permanent International pour l'Exploration de la Mer.

The last voyage that Murray made was a very successful four-month cruise on board the Norwegian research steamer "Michael Sars", in the summer of 1910. The results of this were published by the Bergen Museum, and a general review of these can be found in the book *The Depth of the Oceans*, by John Murray and Johan Hjort, with contributions from several other investigators (published by Macmillan, 1912). In 1913, Murray published a general introduction to oceanography under the title *The Ocean: A General Account of the Science of the Sea* (Home University Library). In the next year (March 16, 1914), the great oceanographer was killed instantly in a motor accident.

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 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 south 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 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 North 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 Gent, 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 persuading the British government to annex this uninhabited volcanic island in the Indian Ocean, 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 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.

COLLABORATION WITH HJORT, CRUISE WITH THE "MICHAEL SARS"

In the summer of 1910, Sir John Murray made his last great scientific expedition, in collaboration with his friend, Dr. Johan Hjort. The investigating steamer used was the "Michael Sars" which, along with her crew and equipment, was lent to Murray for the North Atlantic cruise by the government of Norway. The steamer had been built ten years earlier by order of the Norwegian government for the specific purpose of being used in scientific oceanographic research.

Some of the methods and results of this cruise, as they are reviewed in the book *The Depths of the Ocean*, are worth mentioning. The biological data discussed include methods of plankton collecting, among which is the simultaneous towing of as many as ten large horizontal nets at various depths to collect pelagic organisms.

Another biological study conducted on this expedition concerned the characteristic colour of the fishes in various zones of depth, from the colourless or transparent forms abounding in the superficial layers, to the silvery and greyish fishes found at about 200 fathoms, and to the black and strongly-coloured invertebrates found from 500 fathoms downwards.

The "Michael Sars" expedition also provided evidence that fresh-water eels from northwestern Europe spawn as far away as south of the Azores and that their larvae are carried by currents back to the coasts of northwestern Europe.

Also very interesting is the description of the "mud-line". As a rule, terrigenous deposits become finer and finer at greater distances from the coast, until they reach this "mud-line" where the finest suspended particles are deposited. Murray placed this line at an average depth of 100 fathoms on the edge of the continental shelves or at the top of the continental slope facing the open ocean. Several investigators at that time and in following decades were greatly concerned with problems of the nutrition of marine organisms, and with the nature and amount of food available in oceanic areas. Murray considered the "mud-line" to be the greatest feeding ground of the ocean.

Murray presented careful estimations in the book for his theory that if all the elevations of the globe were to be filled into the depressions, the result would be a smooth sphere covered by an ocean 1,450 fathoms deep, the floor of which would be the "mean sphere level".

Dr. Helland-Hansen, the physicist on board the "Michael Sars", devised a new form of photometer and registered light as far down as 500 fathoms below the surface of the Sargasso Sea; he first showed that the red rays of light disappear first and that the ultraviolet rays penetrate most deeply.