DEEP SEA BENTHOS, CONTRASTING ECOSYSTEMS

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Contents

Summary

The exploration of the deep-sea benthos started in the late 1860's, following the first transatlantic telegraphic cable-laying operation. During some 70 years (1872-1952), numerous cruises concentrated on zoological studies of deep-sea benthos, invertebrates and fish, starting with the H.M.S. *Challenger* circumnavigation and ending with the deep-sea trenches exploration performed by the *Galathea* (1950-52). During the second half of the 20th century, ecological studies dominated deep-sea research, together with some physiological results (respiration, growth rate, metabolic processes). Several technological improvements, such as deep-sea photography, bathyscaphs and deep-sea submarines, use of acoustics for positioning and moorings, radically changed the efficiency of the oceanographic cruises. As a result, the paradigm of a miserable deep-sea benthos adapted to low temperatures, high pressures and permanent darkness, scarcely fueled by micro- and megaparticles falling from the ocean surface layer was developed up to the late 1970's.

At this time, the discovery of the bacterial and animal communities linked with hydrothermal vents and those associated with cold seeps completely changed the scientific knowledge. Chemolithotrophic bacteria living as endosymbionts within specialized tissues of their hosts (different invertebrates) are able to oxydize various reduced molecules, such as H_2S and CH_4. Important physiological and biochemical results have been obtained on the chemosynthetic production.

The world scientific community involved in deep-sea benthos research is no more than one thousand scientists. This low figure is due to the technological needs, the high logistic costs and the lack of economic objectives. Since a few years, oil and gas exploration below 1,000 meters has given a new impulse to environmental research on the deep-sea floor.

1. Introduction: The Exploration of the Depths

The fact that scientific progress is strongly linked with technological developments is now considered as a banality. Thus, the scientific study of the depths of the oceans, which started during the second half of the 19th century, was made possible due to the technological results of the first telegraphic cable-laying between Ireland and Newfoundland (1858-1866). Reciprocally, oceanographers contributed to the operations through the study of Foraminifera shells collected in small sediment cores.

Some twenty years earlier, the marine zoologist E. Forbes, analyzing the results of several dredgings performed in the Aegean Sea from two to 230 fathoms depth, recorded a strong decrease of the number of individuals and species with depth. Forbes had no hesitation to extrapolate these data, and propounded a provocative concept, the so-called theory of the « azoic zone ». This incorrect statement was a consequence of the inadequate collecting dredge used by Forbes and the impoverished nature of the benthic marine fauna in the eastern Mediterranean. However, it was this statement that prompted many deep sea cruises up to the Danish *Galathea* (1950-1952). On the other hand, Forbes was not aware of previous findings of deep-sea organisms, such as an accidental dredging of *Asterophyton* at 800 fathoms in 1818 by J. Ross, or the catch of various species of crustacean and fish described at the same period by A. Risso from 800 to 1,000 meters in the north-western Mediterranean off Nice. A few years before Forbes's death, the norwegian marine zoologist M. Forbes published a list of 19 species living at depths greater than 300 fathoms, including the first «living fossil relict» (panchronic species), a stalked crinoid *Rhizocrinus lofotensis* belonging to the Cretaceous family Apiocrinidae. The hypothesis that deep sea might shelter other living fossils, such as ammonites and belemnites, was strongly supported by J. Huxley, following the ideas of evolution presented in Ch. Darwin's *Origin of species*.

2. In the Reign of Zoology

Following the successfull cable-laying through the north Atlantic, several trial cruises were organized between 1868 and 1870 by the Royal Society with ships from the Navy. The *Lightning* found negative temperatures north to 60°N and positive ones south to 50°N, which suggests that a submarine ridge separates the north Atlantic from the Norwegian Sea, and collected large sea pens (*Bathyptilum carpenteri*) at 650 fathoms

(1,190 meters). Then, the *Porcupine* successfully dredged in the Gulf of Biscay to 2,435 fathoms (4,456 meters) and found a rich animal life. The collection of

These remarkable issues decided the Royal Society to organize a circumnavigation over the world ocean, on board HMS *Challenger*. The *Challenger* sailed on December 7, 1872 from Sheerness, and returned on May 26, 1876, after three and a half years. During that cruise, HMS *Challenger* traversed a distance of 68,890 nautical miles, and at intervals as uniform as possible, established 362 observing stations. The results of the *Challenger* expedition were published between 1885 and 1895; a total of 37 volumes deal with botany (including phytoplankton, 2 vols), deep-sea deposits (including the first description of the manganese nodules, 1 vol.), physics and chemistry (2 vols) and zoology (32 vols). The « challenge » was fully achieved.

Immediately after the return of HMS *Challenger*, several countries from Europe and north America organized oceanographic cruises, mainly devoted to deep sea zoology. A. Agassiz in the US on board the *Blake* and *Albatross*, the Netherlands with the *Siboga* expedition in the Indonesian Sea, the French expeditions of *Talisman* and *Travailleur* in the Gulf of Biscay and the western Mediterranean, the Norwegian north Atlantic deep sea expedition, the cruises of Prince Albert the Ist of Monaco on board *Hirondelle I* and *II* and *Princesse-Alice I* and *II*, the Danish *Ingolf* and *Dana I* and *II* expeditions, etc.; all these oceanographic cruises increased our knowledge of deep sea benthos, including demersal fishes due to the intruduction of deep sea trawls (A. Agassiz) and baited traps (Prince Albert the Ist of Monaco). The results of these expeditions consisted mainly in descriptions of animals, together with colour plates drawn on board on fresh material.

During the first forty years of the 20th century, some important cruises took place: the series of cruises led by J. Schmidt which resulted in the discovery of the spawning ground of the European eel in the Sargasso Sea and the migration of the leptocephali, the German *Meteor* cruises in the southern Atlantic for physical oceanography, etc.

After the second world war, the Scandinavian countries joined their efforts to solve the intriguing question of the limit of life in the deep ocean. A first expedition of the Swedish *Albatross* in 1947-48 enabled to design the new deep sea winches, gears and methods needed to successfully work at depths around 10 kilometers. Then, A. Bruun on board the Danish *Galathea* performed the deepest trawling operation in the Marianna trench in July 1952 around 10,000 meters depth: the trawl came in with several invertebrates, sea anemonies, bivalves, crustaceans, holothurians and the microbiologist C. Zo Bell discovered barophilic bacteria living in the sediments. The Forbes's theory of an « azoic zone » was definetely thrown up: bacteria and benthic animals can survive in the deepest parts of the ocean. The strong decrease in densities and biomasses with depth is linked with the poor energy transfer from the surface to the depths. The *Galathea* results enabled A. Bruun to propose the concept of a hadal fauna peculiar to deep sea trenches, a concept which was simultaneously suggested by L. Zenkevitch from *Vitiaz* cruises; the question of the origine and age of the hadal fauna was extensively debated before a consensus on the youthness of this fauna compared to abyssal fauna was agreed upon. As far as zoology is concerned, the *Galathea* collected several remarkable animals, such as the first specimens of Monoplacophora (*Neopilina galatheae*), a typical example of living fossil. The *Galathea* expedition also marks the end of the purely zoological approach of deep sea benthos: an important article by T. Wolff entitled « Animal life in a single abyssal trawling » is probably the first ecological study on deep-sea benthos.

3. New Technologies

Since the second world war, several technological progresses have radically modified the biological research in the deep sea. Before that time, the oceanographers worked from surface ships in a totally blind manner, and had to imagine the deep-sea floor and its fauna from small biased samples taken by grabs, dredges, corers and trawls. Within a short period of time, underwater photography, bathyscaphs and second generation of deep sea submersibles, remotely operated vehicles, completely changed their capabilities.

3.1. Underwater Photography

Deep sea underwater photography technique has been developed by H. Edgerton in the mid 50's, given the progress in steel processing and efficient joints manufacturing. Originally, the camera and its flash were operated automatically from a vertical cable, by the contact of a weight on the bottom. The same equipment can also be fitted on a kind of sled, the so-called troika, which was successfully used on the pillow lavae of the mid-Atlantic ridge on board *Calypso* as early as 1955.

Following the fast development of acoustics for military purposes during the second world war, precision echo-sounding recorders have been developed since the 1960's. Acoustic pingers at the same frequency as the depth recorder enable to continuously estimate the distance of the gear (dredge, trawl, deep sea camera, etc.) to the bottom. Acoustic releases made possible mooring of equipments (baited traps, cameras, current meters, etc.) on the sea floor for months and even years. These equipments strongly increased the success of deep sea sampling.

3.2. Bathysphere and Bathyscaphs

In the early 30's, the zoologist W. Beebe and the engineer O. Barton designed and built the bathysphere, fitted with three port-holes and hanging from a surface ship with a strong supporting cable. The bathysphere made several tens of dives between 1930 and 1934 in Bermudas waters (off Nonsuch Island), and went to 908 meters; a few sketches of deep sea pelagic fishes were published, but could never be identified.

The next step was made by A. Piccard, who invented the bathyscaph; the cable is replaced by a float made of a liquid lighter than sea water, the kerosene; ballast made of small iron balls is secured by an electromagnetic field (positive safety: in case of electric failure, the ballast falls out of its silo and the bathyscaph comes back to the surface). From 1938 to 1975, several bathyscaphs were built by Belgium (*FNRS 2*), France (*FNRS 3*, *Archimède*), Italy (*Trieste*) and United States (*Trieste*, with a new sphere able to afford the highest pressures of the oceans). *Trieste* went once to 10,916 meters in the Mariana trench in 1960, and returned with some heavy damages on the sphere; *Trieste* was then limited to 1,500 meters. The *Archimède*, launched by the end of 1961, made several successfull dives between 8,000 to 9,560 meters depth. As a whole, a few hundreds of dives have been performed by these bathyscaphs, resulting in descriptions of sea floor, large invertebrates and fish living there and black and white pictures, but very few samples. *Archimède* succeeded with a sediment core containing a deep sea holothurian, *Myriotrochus bruuni*, at 9,500 meters depth in the Kurile-Kamchatka trench.

3.3. Deep Sea Submarines

In the early 60's, new technology based on syntactic material competed with the bathyscaphs. The first submarine that utilized that new buoyant stuff was the so-called 'diving saucer' or *Denise*, built by J.-Y. Cousteau's group in the late 50's; due to the ellipsoidal shape of the resistant habitation, *Denise* was limited to 300 meters depth. The second generation of deep sea submersibles (*Alvin* in the US, *Cyana* in France, *Shinkai 2000* in Japan) are much lighter than the bathyscaphs and can be carried on board their mother ship. Thanks to high pressure hydraulics, they are equiped with teleoperated arms and claws which enable them to collect samples.

They possess several cameras and videocameras, which strongly improve the interpretation of observation by the scientific team. The first light submersibles were able to dive up to 3,000 (*Cyana*) to 4,500 meters (*Alvin*). More recent ones, using titanium, are able to dive up to 6,000-6,500 meters (*Sea Cliff* in the US, *Nautile* in France, *Mir 1* and *2* in Russia, *Shinkai 6,500* in Japan). The best example of the efficiency of these new submarines is the discovery and revisit of small scale sites, such as the hydrothermal vents, cold seeps and whale falls: with very few exceptions, most of our knowledge of the distribution and function of the bacteria and fauna living in those sites has been obtained with deep-sea submarines coupled with acoustic positioning.

3.4. Remotely Operated Vehicles

Since some fifteen years, several Remotely Operated Vehicles (ROV) have been built for depths from 3,000 to 6,000 and even 10,000 meters.These ROV receive energy from their mother ship, and continuously send to the surface the image of the sea floor through optical fiber cables. They are able to make close up pictures and to collect samples. Apart security questions, their greatest advantage is probably the fact that they can operate 24 hours round and explore significant surfaces; their data are continuously available for all the scientific team on board the mother ship and recorded.

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Bibliography

Angel M.V. and Sibuet M. (1990). Deep-Sea Biology. *Progress in Oceanography* 24 (1-4): i-ix, 1-343. [This book contains a selection (28) of the 87 papers presented during the Fifth Deep-Sea Symposium, held at Brest, IFREMER, in June 1988. The general theme of the symposium was the biology and ecology of bathyal and abyssal environments, including for the first time hydrothermal and cold-seep communities].

Belyaev G.M. (1972). *Hadal bottom fauna of the world ocean*, vi+199pp. Academy of Sciences of the USSR, Institute of Oceanology, Izdatel'stevo 'Nauka', Moskva 1966, translated from Russian, Israel Programme for Scientific Translation, Jerusalem, 1972. [This translation is the single monography dealing with fauna that lives in the deep sea trenches below 6,000 meters. A revised version of the book has been published by the same author in 1989 title: 'World scale review of the hadal or ultra-abyssal fauna living in the sediments of deep sea trenches].

Childress J.J. (1988). Hydrothermal vents. A case study of the biology and chemistry of a deep-sea hydrothermal vent of the Galapagos rift. The Rose Garden in 1985. *Deep-Sea Research* 35 (10/11A): 1677-1849. [This special issue of *Deep -Sea Research* is devoted to long-term changes of a hydrothermal site discovered in 1979 and revisited en 1985 and later in 1988, the Rose Garden site, 2,470 meters depth on the Galapagos rift. The main megafaunal change is the shift from *Riftia pachyptila* in 1979 ot *Bathymodiolus* and *Calyptogena magnifica*].

Gage J.D. and Tyler P.A. (1991). Deep-Sea Biology: a natural history of organisms at the deep-sea floor, xvi+504pp. Cambridge University Press, Cambridge and New York, 1991. [This treatise provides a comprehensive account of the natural history of organisms inhabiting deep sea environments, together with methods to collect the diverse fauna and processes of feeding, respiration, reproduction, growth and dispersal. It is the first monography which consider ordinary deep sea floor as well as hydrothermal vents and cold seeps environments].

Jones M. L. (1985). Hydrothermal vents of the Eastern Pacific: an overview. *Bull. Biol. Soc. Washington*, n°6: 1-493. [This overview of our knowledge on hydrothermal vents communities is based on a symposium held in Philadelphia, december 1983. The 37 papers deal with geology and geochemistry of hydrothermal vents, the macrofauna (polychaets, tube worms, gasteropods and bivalves, crustaceans and fish), biochemistry and physiology, microbiology and ecology of hydrothermal vents and cold seeps].

Laubier L. and Monniot C. (1985). *Peuplements profonds du golfe de Gascogne*. Campagnes BIOGAS, 629pp. IFREMER publ., 1985. [This monography contains the results of a ten years research programme in the Gulf of Biscay, between 2,000 and 4,700 meters depth. 50 articles by various authors are devoted to the deep sea environment including organic particles fluxes, structure and dynamics of trophic and size faunal groups and zoological studies with description of new species].

Laubier L. (1988). Biologie et écologie des sources hydrothermales. *Oceanologica Acta* Vol. spécial n°8 (septembre 1988): 1-233. [This special volume of *Oceanologica Acta* contains the proceedings of an international symposium held in Paris in 1985 on hydrothermal vents communities. It also comprises a bibliographic list which extends the list published by Jones (1985)].

Menzies R. J., George R. Y. and Rowe G. T. (1973). *Abyssal environment and ecology of the world oceans*, xxiii+488 pp. John Wiley and Sons, New York, London, Sydney, Toronto.[This review presents a comprehensive history of deep sea zoology and ecology, together with more questionable data on faunal zones, origin of abyssal fauna and geological history of ocean basins].

Rona P. A., Boström K., Laubier L. and Smith K.L., Jr (1983). *Hydrothermal processes at sea floor spreading centers*, xiv+796pp. NATO Conference Series, Series IV, Marine Sciences, vol. 12. [This is the first monography on hydrothermal processes, based on a NATO Advanced Research Institute held in April 1982 at Cambridge University, UK. Topics include geological setting, hydrothermal convection, basalt sea-water interaction, Iceland and oceanic ridges, geochemical mass balances and cycles, ferromanganese deposits, hydrothermal mineralization including polymetallic sulfides and biological communities at hydrothermal vents].

Smith C. R., Mullineaux L. S. and Levin L. A. (1998). Deep-sea biodiversity: a compilation of recent advances in honor of Robert R. Hessler. Topical studies in oceanography. *Deep-Sea Research, part II*, 45

(1-3): 1-568. [This series of review papers in honor of R. R. Hessler deals with the deep-sea benthic biodiversity, including communities associated with hydrothermal vents, cold seeps and whale falls].

Van Dover C. L. (2000). *The ecology of deep-sea hydrothermal vents*, 424 pp. Princeton University Press, Princeton, New Jersey, USA. [A comprehensive and synthetic textbook written by a scientist who made more than 100 dives in different manned submersibles. Its main parts deal with the physical and chemical features of the hydrothermal environments, microbial ecology including symbioses between chemoautotrophic bacteria and invertebrates, physiological ecology of *Riftia* and bivalves, dynamics of transfers within comunities, evolution of vent taxa, relations with cognate environments and theories on origin of life and pre-biotic syntheses in vent habitats].

Biographical Sketch

Lucien Claude LAUBIER - French citizenship, born in Lille on September 22nd, 1936. Professor at the University of the Mediterranean, Director of the Oceanology Centre of Marseilles, since 1/10/1996.

Training: Licence in natural Sciences, Faculty of Sciences of Paris. Ph. D. submitted in December 1995, Faculty of Sciences of Paris, untitled «Le coralligène des Albères. Monographie biocénotique».

Positions: Laboratoire Arago, marine biology, Banyuls-sur-Mer, 1956-69, University of Paris. National Centre for Exploitation of the Sea (CNEXO), Centre Océanologique de Bretagne, 1970-78, headquarters of CNEXO then IFREMER in Paris, 1979-92. Scientific Counsellor, French permanent Representation to the European Union, 1992-96. Professor at the Institut Océanographique, 1984. Corresponding member of the french Académie des Sciences, 1980. Member of the french Académie de Marine, 1992.

Scientific studies: Researches on bionomy and ecology of coralligenous community from the Mediterranean. Morphology, biogeography and systematics of polychaetous annelids and parasitic Copepods on Invertebrates. Benthic ecological studies on the abyssal north Atlantic and adjacent Seas (Norwegian and Mediterranean Seas). Ecology of communities associated with hydrothermal vents and cold seeps. Marine pollution (several papers on the *Amoco Cadiz* oil spill). Marine aquaculture. 300 papers published. Three books, one of them (1985) on the hydrothermal communities.

Scuba diver. A dozen of dives between 300 and 3600 m depth in different deep-sea submarines.
Honors: Commandeur de l'Ordre National du Mérite, 2001. Chevalier de la Légion d'Honneur, 1992.