ITEM 6. History

Manganese precipitation in the deep oceans has probably been a widespread natural process since at least the Ediacaran period (~635 to ~548 million years ago) which is probably when the deep-oceans first oxidized (Fike et al. 2006). The current crop of nodules found on the seabed within the Clarion Clipperton Zone (CCZ) are constrained by the age of the Pacific Ocean crust itself and published dating indicates that they are probably no more than several million years old (e.g. Chang et al, 2005).

Even in terms of human history the discovery of polymetallic nodules is a relatively recent event, i.e. about 140 years ago (see below). However, since then and especially in the last 50 years, an immense amount of effort has gone into their exploration, attempted exploitation and not least, regulation. Review of the history of this work in the CCZ provides context to the mineral resource and environmental and engineering issues, and also provides context to the current administrative regime.

This history can be considered in four periods:

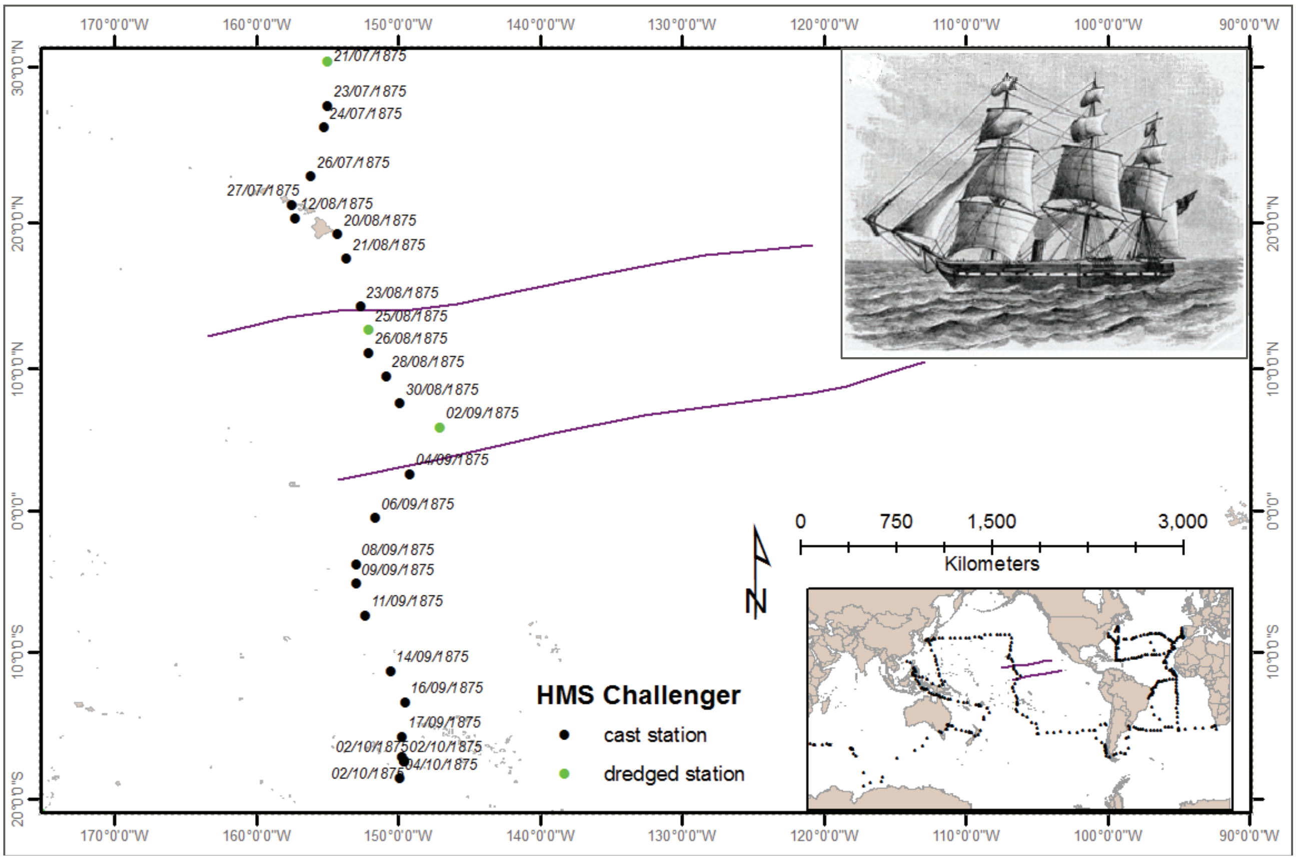
1 The discovery of the Clarion Clipperton Zone (1875-1969)
2 The International Decade of Ocean Exploration (1970-1981)
3 The Reciprocating States Regime and the Pioneer Investors (1982-1995)
4 The International Seabed Authority (1996 to present day)

6.1 1875 – 1969: Discovery of the Clarion Clipperton Zone

6.1.1 First Samples

Polymetallic nodules were first reported in the Arctic Kara Sea (Ingri, 1985) and then by the British HMS Challenger expedition, in February 1873, in the Atlantic Ocean off the Canary Islands (Murray and Renard, 1891). Fossil nodules had already been found in the Alps by C.W. von Giimbel in 1861 (Jenkyns, 1977).

Figure 6.1 Path of the HMS Challenger



Location data from Natural History Museum UK, (2014); vessel picture from Charles Morgan

Although the HMS Challenger was primarily sail driven, new technology in the form of a steam engine enabled her crew to winch up nodule samples at 50 of the 343 seabed sample stations surveyed by the ship. Two of these sample stations are in what was later to be called the CCZ (Murray and Renard, 1891; Figure 6.1). The expedition resulted in numerous oceanographic discoveries including the widespread nature of nodule deposits on the deep-ocean floor. Confirmation of the extent of nodules in the Pacific was made by a contemporary of Murray and Renard, Alexander Agassiz (Mero, 1965) who made several expeditions aboard the US Fish Commission's USS Albatross around the turn of the century, including one through the central pacific to the Marquesas.

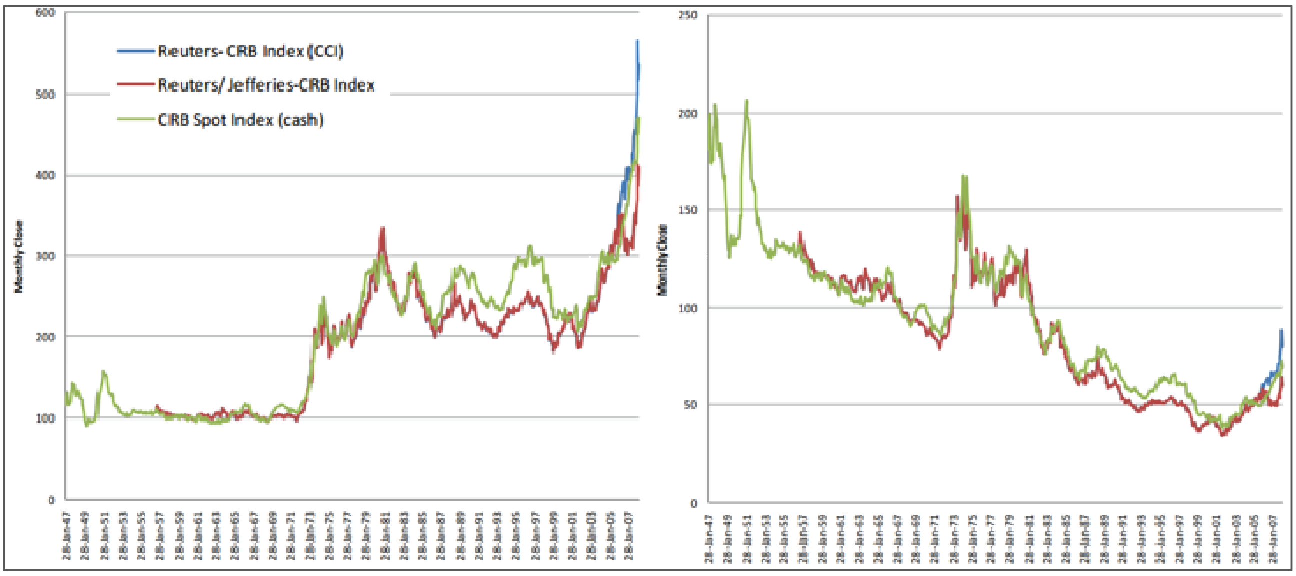
At this time nodules were only seen as items of scientific curiosity.

6.1.2 Commercial Recognition

After the Second World War a Swedish expedition reportedly recovered nodules (United Nations, 1979), and interest in exploring seabed nodules started to increase again in the 1950s (as reflected in the publication rate on the subject; Meylan et al, 1976), with people like John Mero (Mero, 1965) promoting their potential with some success. Early exploration efforts and discussion were spread around the planet, but based on less than 100 samples collected from the CCZ, Mero predicted the occurrence of many millions of tons of deposits with nickel and copper concentrations each greater than 1% as well as significant manganese and cobalt (Mero 1965).

Promotion of nodules as a possible mineral reserve was aided in no small way by increasing prices of metals and other commodities (Figure 6.2), with a noticeable step change in the early 1970s.

Figure 6.2 Post WWII Evolution in Nominal (L) and Real (R) Commodity Prices



Source: UNDP (2008); Monthly close value is an index developed by the Commodity Research Bureau with 1967 set at 100

Two of the early explorers in the 1960s were the USSR and the US companies Kennecott Exploration Inc and Deepsea Ventures. All started exploring in areas other than the CCZ, and it was only in the late 1960s and early 1970s that it became apparent that the CCZ had the best nodule fields in the world in terms of both grade and abundance (McKelvey et al, 1979). By the late 1960s and early 1970s, these explorers had been joined by others. Their efforts are detailed in subsequent sections.

6.1.3 USSR

Source Andreev (pers comm. March 2016), unless referenced otherwise.

The USSR started an integrated marine research programme in 1949, led by the USSR Academy of Sciences. Regular expeditions commenced with the R/V Vitiaz and later the R/V Dmitri Mendeleyev, starting with at least three cruises to the Indian Ocean (Bezrukov and Andrushchenko, 1972; Bezrukov, 1962, 1963) then in the southwest Pacific (e.g. Skornyakova et al. 1990), including the Penrhyn Basin near the Cook Islands, and then in the central Pacific (Bezrukov, 1969).

Over twenty years, some seventeen Soviet expeditions included at least some research on nodules.

By the late 1960s the focus of Soviet exploration shifted to the Clarion Clipperton Zone when Vitiaz cruises number 43 (1968) and 48 (1970) focused on the Clarion Clipperton fracture zone. Hundreds of samples and thousands of photos were taken along with seafloor bathymetry mapping. Some mineral inventory estimates were also made (Skornyakova and Andrushchenko, 1964).

As early as 1963-1964 the research institutes "Gipronickel" and "CNIIČermet" examined the possibility of processing nodules. Technological tests carried out by those institutions demonstrated quite high extraction of manganese, nickel, cobalt and copper.

6.1.4 Kennecott

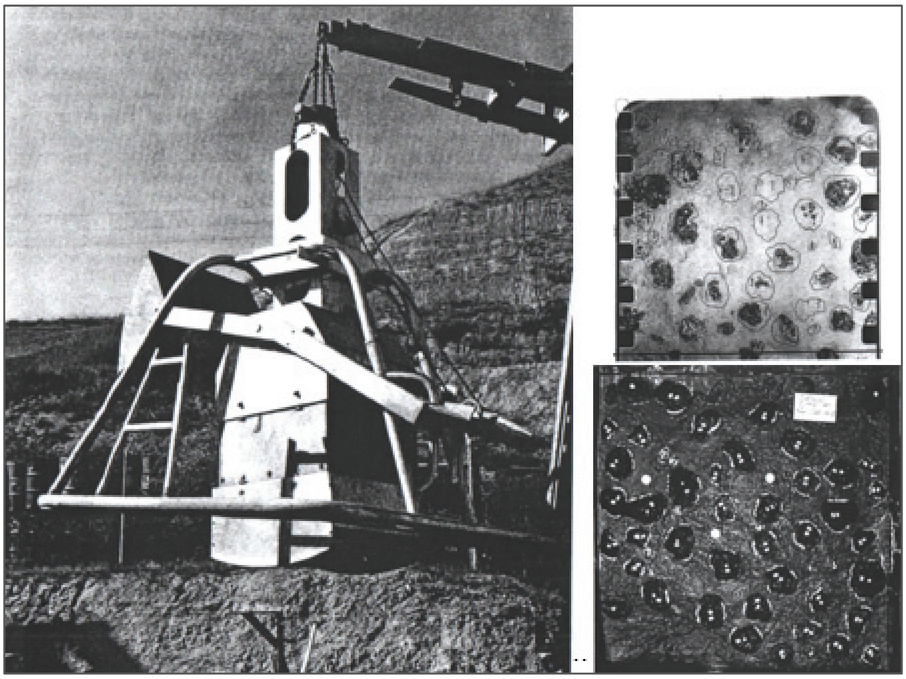
Source Dave Felix and John Halkyard (pers comm. 2015), unless referenced otherwise.

Kennecott Copper Corporation became interested in manganese nodules in part based on the publications of Dr. John Mero (e.g. Mero, 1965) and work being done at Scripps Institution of Oceanography in the 1960s. Through their subsidiary Bear Creek Mining, Kennecott's first exploration cruise dates back as early as 1962, when 10 tons of nodules were dredged from a site west of Baja California. For the next few years the group relied on technical associations with oceanographic research cruises (Killing, 1983) but Kennecott followed up with two more of their own cruises in 1967. That year, newly designed free fall grabs were used for the first time during the "Clarion" cruise, while the "Confidence" cruise investigated a portion of the CCZ with 143 sample stations, bottom photos and dredge hauls.

The subsequent "Aries" cruise in 1968 was a three month effort in the eastern and central tropical Pacific which resulted in delineation of what they called the Albatross Deposit (today covered in part by the USA 1 and 4 licenses; Figure 6.8).

In 1969, Kennecott Exploration Inc (KEI) was formed and between 1970 and 1974 KEI conducted another seven cruises, with progressively more detailed sampling and survey work including dredging for bulk samples (up to 197 tons of nodules and 400 cubic ft of sediment in 1972; Isaacs, 1973). In 1970, on the Crux Cruise, KEI discovered what they called the Frigate Bird deposit in the eastern CCZ (Figure 6.8).

Figure 6.3 Rinek-Bouma type spade or box-corer (L) and matching sea-bottom (TR) and sample-top (BR) photos.



Source: Felix (1980)

Not all the Kennecott cruises were to the CCZ. The 1969 Aquila Cruise was to the Marquesas and Tuamotu Islands in the south Pacific while the 1970 Crux Cruise included the Peru Basin.

Many exploration techniques and nodule deposit characterization methods were developed and used successfully, but these were never publicly released. Some of the techniques developed at this stage are still used today (e.g. large diameter box-coring and photographic analysis (Felix, 1980; Figure 6.3).

6.1.5 Deepsea Ventures Inc

Deepsea Ventures' first effort started with the Newport News Shipbuilding and Drydock Company, which then and now, is one of the largest shipbuilding companies in the US. Their first cruises were in the mid-1960s in both the Atlantic (Blake Plateau off Florida) and Pacific (ISA, 2004). They were supported by US academic efforts (e.g. Fuerstenau et al, 1973) which focussed on the geochemistry of nodules and their metallurgical processing.

In the summer of 1970 the company conducted successful collector and air-lift trials at a depth of 762 m on the low metal grade nodule deposits of the Blake Plateau (Kaufman and Latimer, 1971; Lecourt and Williams, 1971; Geminder and Lecourt, 1972; United Nations, 1979). Deep Sea Ventures equipped the Deep Sea Miner, a 6,750 t freighter, with a 25 m derrick and a 6 m by 9 m central pool (the space from which the subsea devices are deployed). The nodules were raised by airlift, a system previously tested in a 250 m mine shaft (ISA, 2004). The towed collector sled was fitted with a series of tines to exclude material above a certain cut-off size and thereby reduce the chance of pipe string clogging. Material passing the first set of tines was channelled to the suction point by a second set of more closely spaced tines. The first nodules arrived aboard the mining vessel on July 30, 1970. Pumping rates between 10 and 60 tons/hour were successfully achieved during this pre-production mining trial (EC, 1997).

German groups also started working with Deepsea Ventures in 1970 (Backer and Fellerer, 1986) and were more formally involved when Deepsea Ventures went on to form the OMA consortium in the mid-1970s. OMA by then had changed focus to their claim area covering the higher grade nodules in the central CCZ.

6.1.6 Codifying International Rights

In the late 1940s, the newly formed United Nations started debating rights in national and international waters. Historically individuals, groups and countries had accessed the seas freely, occasionally conflicting over access and exploitation of its resources (WOR, 2010). At its first session in 1949, the International Law Commission started looking at how to codify these areas and assign rights (United Nations, 2009). By 1958 the discussions had expanded to include consideration “not only of the legal but also of the technical, biological, economic and political aspects of the problem, and to embody the results of its work in one or more conventions or other appropriate instruments.” This became the mandate for the First United Nations Law of the Sea Conference (United Nations, 2009; Guntrip, 2003).

Eighty-six states participated and four separate conventions were adopted: Convention on the Territorial Sea and the Contiguous Zone entered into force on 10 September 1964; the Convention on the High Seas entered into force on 30 September 1962; the Convention on Fishing and Conservation of the Living Resources of the High Seas entered into force on 20 March 1966; and the Convention on the Continental Shelf entered into force on 10 June 1964.

In 1967 the Secretary-General of the UN included a supplementary item in the agenda of the 22nd session of the General Assembly outlining the need to establish a regime to govern the deep-seabed (Guntrip, 2003). The proposal suggested both an international treaty and an international agency to regulate activities on the deep-seabed. Then in 1969 the Moratorium Resolution was adopted which created a moratorium on deep-seabed mining until an international regime had been established.

In March 1968, Lyndon B. Johnson, President of the United States proclaimed "an historic and unprecedented adventure — an International Decade of Ocean Exploration for the 1970s." In December 1968 the United Nations General Assembly endorsed "the concept of an international decade of ocean exploration to be undertaken within the framework of a long-term programme of research and exploration."

6.1.7 Summary Table: Discovery of the CCZ

A chronological summary of the history of discovery and exploration of the CCZ up to 1970 is summarised in the following table. References are elsewhere in the text above:

Table 6.1 Chronological summary of the Discovery of the CCZ

YEARS	History of the Discovery & Exploration of Polymetallic Nodules	History of the Law of the Sea and International Seabed Authority
1868	Seafloor polymetallic nodules first discovered in the Kara Sea by the Sofia.	-
1875	Dredging by the Challenger between Valparaiso and Tahiti discover “most interesting” manganese nodules.	-
1900	Alexander Agassiz finds nodules in samples taken from the Eastern Pacific Ocean	-
1950s	John Mero starts convincing industrialists of the economic interest of nodules and leading to exploration in the central Pacific Ocean	UN starts debating and drafting conventions regarding rights in national and international waters, including economic rights.
1958	-	First United Nations Conference on the Law of the Sea. Four separate conventions were adopted by the Conference involving territorial waters, high seas, fishing and conservation and continental shelves, and most of these took several years to come into effect.
1960s	Interest in the exploration and potential exploitation of the nodules grows Mero publishes his landmark “The Mineral Resources of the Sea” (Mero, 1965) The first nodule focused exploration cruises take place by the Soviets, Kennecott and Deepsea Ventures.	Second United Nations Conference on the Law of the Sea. The UN proposes an international treaty and an international agency to manage deep seabed rights, and places a moratorium on mining until the regime is established. Proclamation of the forthcoming International Decade of Ocean Exploration in early 1968, with later endorsement by the UN.

6.2 1970 – 1981: The International Decade of Ocean Exploration

As interest grew through the 1960s, more and more commercial and government funded organizations started exploring the oceans, especially within the CCZ.

The International Decade of Ocean Exploration (IDOE) was an international, collaborative programme to improve the use of the ocean and its resources for the benefit of mankind. It nominally spanned 1970 to 1980 (DOMES, 1981). By 1975 IDOE counted 46 nations as members, including cold world adversaries, the USA and USSR. The US participation was coordinated by their National Science Foundation. Programmes managed by IDOE were mostly scientific in nature including a large environmental research component. While CCZ nodules were high on the agenda, subjects ranged from plate tectonics to Antarctic research and included programmes to test some of the earliest hypotheses that active massive sulphide vent sites might exist at oceanic ridges. IDOE was charged to “Improve worldwide data exchange through modernizing and standardizing national and international marine data collection, processing, and distribution.” While the IDOE did build and manage a centralised data depository, it is not clear how much international cooperation was established.

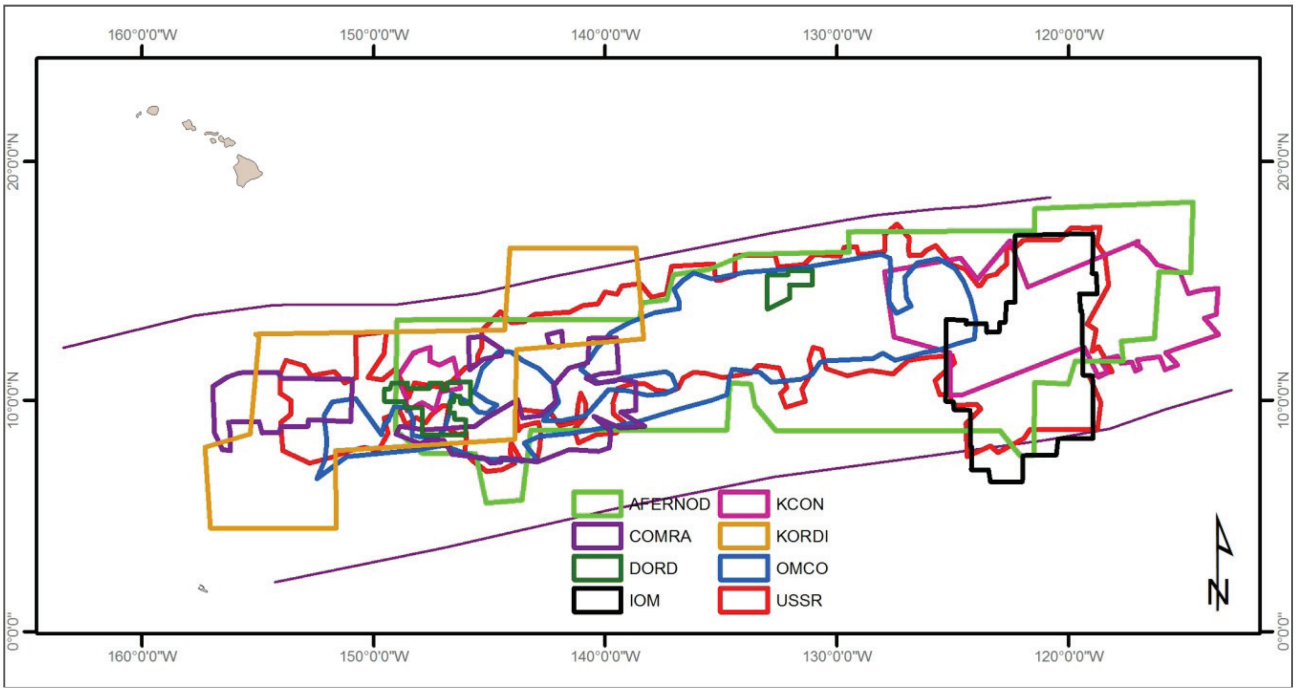
The United Nations was keenly aware of the significance of exploiting resources under international jurisdiction and debated how this resource should be managed. On 12 December 1970, the General Assembly of the United Nations adopted 2749 (XXV) “Declaration of Principles Governing the Sea-Bed and the Ocean Floor, and the Subsoil Thereof, beyond the Limits of National Jurisdiction” (United Nations, 1970). This followed negotiations which took place in a specially established Seabed Committee. This document declares the bed and ocean floor, beyond the limits of national jurisdiction, to be the common heritage of mankind (Guntrip, 2003).

Figure 6.4 United Nations Conference on the Law of the Sea III: Geneva Session (3rd), 1975

Source: http://archives.law.virginia.edu/records/mss/82-6/digital/9556

The UN’s efforts eventually led to development of the Third United Nations Convention on the Law of the Sea, but with a regulatory regime not yet in place, this period of the International Decade of Ocean Exploration is characterized by totally independent and usually overlapping areas of exploration as shown in Figure 6.5.

Figure 6.5 Examples of the overlapping exploration areas of some of the first explorers

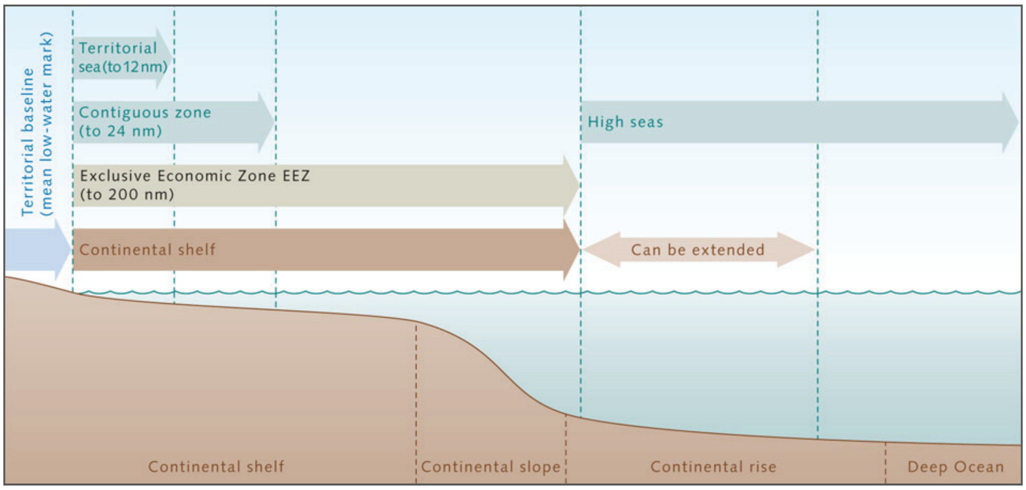


Sources: ISA, (2010), Menot et al (2010), Jeong et al (1994)

Ultimately the United Nations Convention on the Law of the Sea (UNCLOS or Law of the Sea) deals with a range of issues (United Nations, 1994):

- Setting limits (territorial waters, exclusive economic zones (EEZs), continental shelf jurisdiction, archipelagic waters etc (Figure 6.6));
- Marine navigation through straits;
- Deep-seabed mining (such as the polymetallic nodules of the CCZ) in Part XI - The Area;
- Protection of the marine environment;
- Provision for scientific research, and
- Settlement of disputes.

Figure 6.6 Limits covered by UNCLOS



Source: WOR (2010)

6.2.1 USSR

Source Andreev (pers com March, 2016), unless referenced otherwise.

During this period Soviet studies of the ocean floor continued from their efforts in the 1960s. From 1976 the USSR Academy of Sciences was joined by State scientific-production enterprises “Sevmorgeologiya” (St.-Petersburg) and “Yuzhmorgeologiya” (Gelendzhik), subordinated to the Ministry of Geology of the USSR.

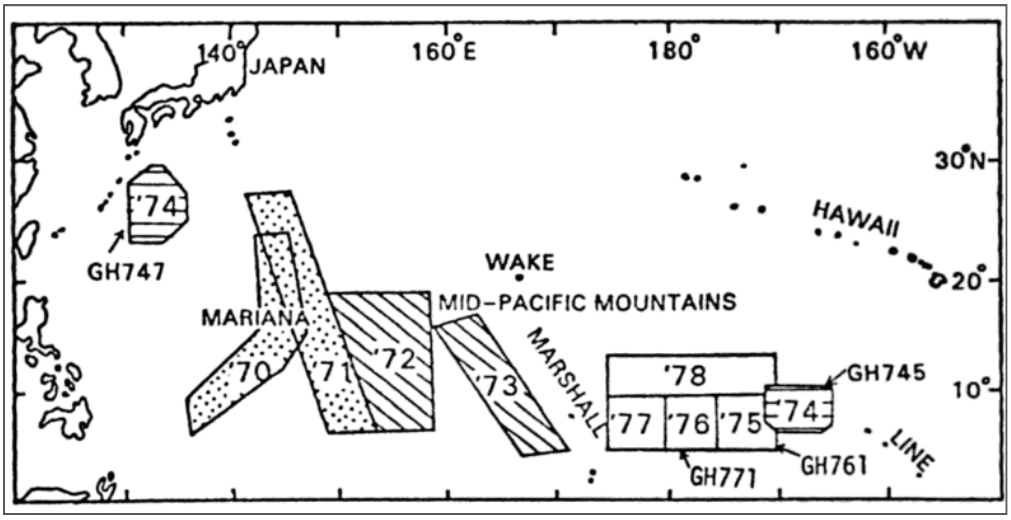
Publications from this period include monographs (Bezrukov, 1976, 1979; Volkov 1979) and numerous magazine articles (e.g. Bazylevskaya, 1973, Skornyakova et al. 1981).

Evaluation at the time of the nodule fields in terms of industrial development was encouraging. Also encouraging was the imminent conclusion of the Third United Nations Convention on the Law of the Sea, which promised a fundamental international legal instrument dealing with exploitation. These factors helped facilitate a separate Soviet programme focused on the Clarion Clipperton Zone.

6.2.2 Early Japanese Efforts

Japanese companies were easily the most prolific participants in nodule exploration and development in the 1970s, usually through large consortia such as DOMA and DORD (UNOETO, 1979). Japanese government efforts started in 1974 using their newly commissioned research vessel the Hakurei-Maru which was given two main projects: "Marine geological investigations on continental shelves and shores around Japan" and "Investigations on deep-sea manganese nodule deposits" which focused mostly in the Central Pacific Basin (Figure 6.7). These efforts concluded in 1984.

Figure 6.7 Areas researched by the Geological Survey of Japan in the 1970s



Source: UNOETO, 1979

6.2.3 Kennecott Consortium (KCON)

Kennecott continued their exploration in the early 1970s attracted by the large informal resource estimates for nickel and other metals. Kennecott also commissioned preliminary feasibility studies of mining by Lockheed Missiles and Space Company and Global Marine Development, Inc., starting in the late 1960s. Kennecott's corporate processing research centre in Lexington Massachusetts was charged with developing a metallurgical process for nodules with the Kennecott Computing Center in Salt Lake City being made responsible for resource estimates.

As the scale of the needed investment and level of required offshore expertise became apparent, Kennecott reached out and sought partners to share the risk. The KCON consortium was formed in 1974 based on the petroleum industry model of an operator (Kennecott Copper Corp) responsible for execution of work and supporting partners. The partners were Kennecott (50%), Rio Tinto Zinc (20%), Noranda (10%), Consolidated Gold Fields (10%) and Mitsubishi (10%) (Killing, 1983). Subsequently Rio Tinto Zinc sold half their shares to BP Petroleum Development Ltd. The Consortium was led by a Committee of Representatives (COR), which approved plans and budgets, and a Technical Advisory Committee (TAC) of technical experts from each partner which helped prepare the plans and review progress. Several engineers from the partner organizations were seconded to the KCON laboratories, principally the Ocean Mining Laboratory in San Diego, California.

The exploration work described above ended up with two areas of interest for KCON (Figure 6.8):

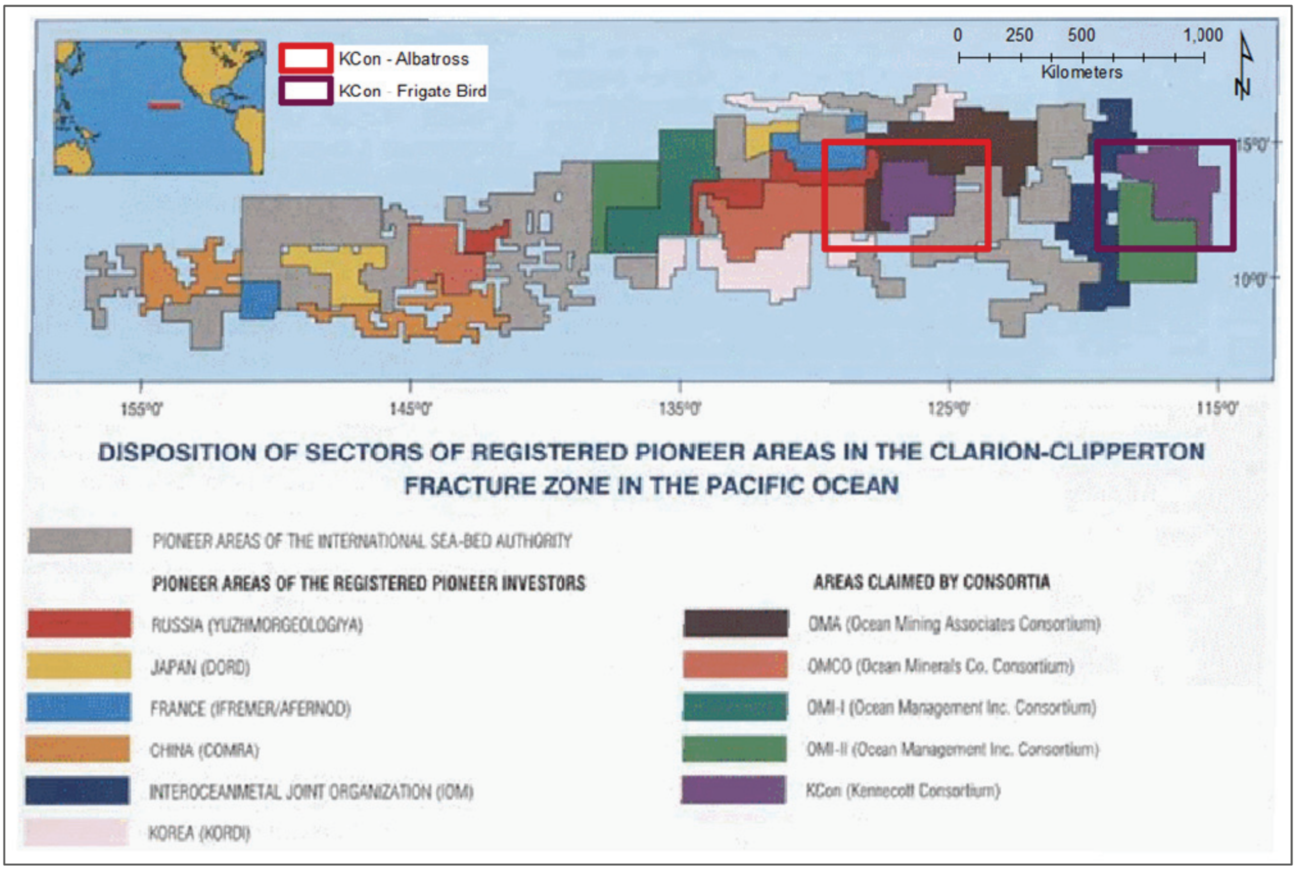
1. The Albatross area in the central part of the CCZ, which ultimately became the "USA4" license in 1984 (U.S. Department of Commerce) under the Reciprocating States Agreement (Figure 6.23 below);
2. The Frigate Bird area in the eastern part of the CCZ which ultimately became the "UK" License in the early 1980s.

This consortium developed many of the best exploration techniques used in the CCZ including large capacity box-coring and photographic survey (Felix, 1980). Ultimately KCON reached an unpublished "inferred reserve" for parts of their concessions (David Felix pers comm. 2015). This included definition of "mineable units" on the seafloor.

Once exploration was completed the consortium developed mining system designs, numerical models and tested various components of a commercial mining system (Halkyard 1980, 1982). The development work included a towed nodule pick-up system which was tested at approximately 1/5th scale (Figure 6.9, Morgan, 2011; Heine and Suh, 1978), a hydraulic and airlift system which was tested on land (Burns and Suhm, 1979; Doyle and Halkyard, 2007), and study of nodule attrition including several pump loop simulations, material handling and transportation (Halkyard, 1979).

Metallurgical development included pilot scale testing of the patented "Cuprion" atmospheric pressure ammoniacal leach process (Skarbo, 1975; Agarwal and Beecher, 1976; Agarwal et al, 1978). A 200 ton bulk sample of nodules collected in 1972 (Isaacs 1973) were intended for a large scale metallurgical pilot test. These nodules were stored in Safford, Arizona, however the samples were disposed of in the 1990s.

Figure 6.8 Kennecott priority areas of interest in the CCZ



Modified from Yamazaki (2008b)

A comprehensive cost estimate of a commercial mining venture was carried out by KCON between 1978 and 1980. The mining and processing research conducted by KCON in the 1970s was consolidated into a commercial system design and execution plan. This work was performed by Bechtel Corporation with support for the mining system provided by Global Marine Development, Inc. Two sites were selected for the land based processing plant: Southern California near Los Angeles and the West Coast of Mexico at Lazaro Cardenas, Michoacan, Mexico. Bechtel developed preliminary Cuprion plant designs and cost estimates for both sites. Extensive investigations were conducted into permitting requirements and options for tailings disposal. Lazaro Cardenas was under development as a deepwater port and an industrial hub to support Mexico’s industrialization plans. Meetings were held at a high level with Mexican officials who were encouraging KCON to consider a development at Lazaro Cardenas.

The cost estimate was based on a 3 Mtpa manganese nodule project producing about 88,000 lb per year of nickel and associated copper, cobalt and molybdenum. KCON never considered manganese a viable product. The overall conclusion of the KCON/Bechtel study was that at the time nodules could be cost competitive with new sources of nickel, but not with current sources (Dubs, 1983). Also, Kennecott and other industry representatives believed the then terms of the newly negotiated Law of the Sea Treaty would introduce unacceptable risk to the project.

KCON worked with government officials and other interested consortia in establishing a framework which would permit restructuring of Part XI of the Law of the Sea Treaty in a form acceptable to KCON and other active mining consortia. However, as time dragged on KCON progressively wound up their operations, stopping active exploration and closing their Ocean Mining Lab in La Jolla in 1981.

KCON applied for and received an exploration license for a segment of its exploration area under the US Deep Seabed Hard Minerals Resources Act in 1984 (USA-4; Figure 6.23). Although some ad hoc evaluation continued after this, in May 1993, KCON abandoned their license under the US Act. The consortium was dissolved. In June, 1993, Ocean Minerals Company (OMCO) submitted to NOAA an exploration license application from the former KCON license area USA-4. OMCO also acquired the exploration data for the KCON sites.

Figure 6.9 Towed KCON Test Collector

Source J. Halkyard pers comm 2015

6.2.4 Ocean Mining Associates (OMA)

Sources ISA (2004) and Tom Detweiler (pers comm. 2015).

The OMA consortium comprised Essex Minerals Company (US), Union Seas Inc (Belgium), Sun Ocean Ventures (US), with Deepsea Ventures Inc the consortium's service contractor.

Little is known about the exploration programme of Deepsea Ventures and OMA (e.g. Kaufman and Siapno, 1972; Figure 6.10).

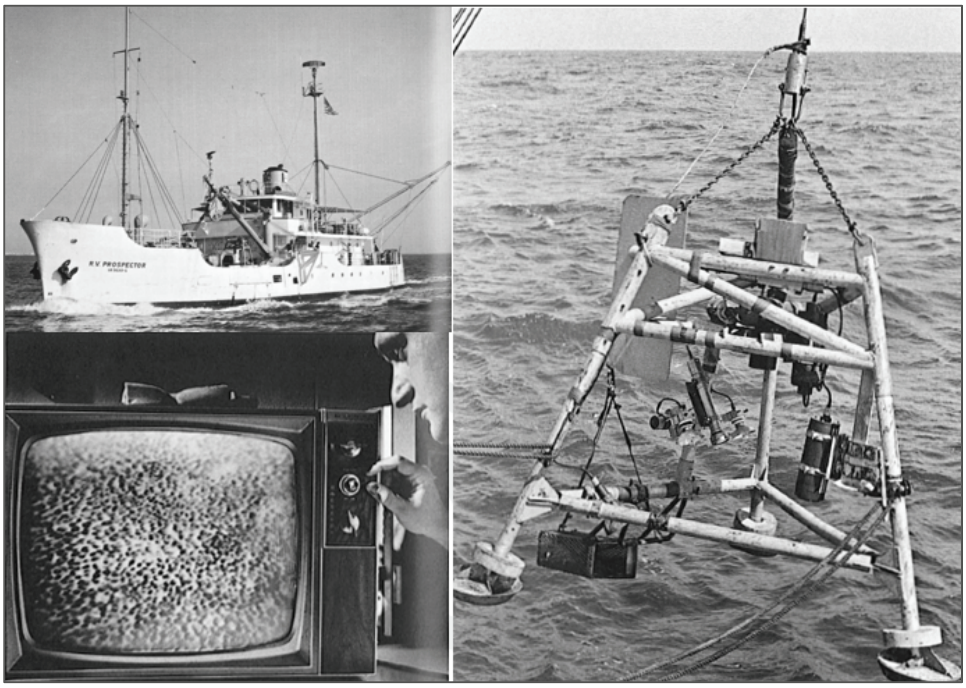
In 1976, six years after the Drake Plateau trials discussed above, OMA started a programme to trial mine nodules in the CCZ. OMA equipped the Wesser Ore, a 20,000 ton iron ore carrier, with a moon pool, a derrick and revolving thrusters (Figure 6.11). The ship had the two central holds converted for equipment and the moon pool, a forward hold set aside for general use and three holds combined into two for nodule storage. The ship's derrick was covered by a distinctive dome, whose purpose was mostly to keep proprietary technology hidden. The nodules were collected by a suction dredge towed on skis behind a rigid riser and were raised by airlift. The collector was at 1/5th scale except for the collector inlets which were at full design scale.

The ship, renamed Deepsea Miner II, conducted its first tests in 1977 at 1,900 km southwest of San Diego, California. The tests were suspended because the electric connectors along the pipe string were not completely waterproof. Early in 1978, two further trials encountered new difficulties when the dredge floundered in bottom sediment and a cyclone struck. The latter situation was dangerous as the riser could not be retrieved in time (it took well over 6 hours to recover), so the ship had to ride out the full fury of the storm (later voyages included an emergency explosive detachment system for the riser). Finally in October

1978, 550 tonnes of nodules were lifted in 18 hours, at a maximum capacity of 50 ton/h. The test was stopped after a blade broke in a suction pump.

Ultimately the nodules recovered were taken to Belgium (home of Union Seas Inc) and used for attrition testing in a three phase loop system.

Figure 6.10 Deepsea Ventures used the latest video technology in nodule exploration



Source: Kaufman and Siapno, 1972

Figure 6.11 Ocean Mining Associate's Deepsea Miner II

Source University of Virginia (2015)

6.2.5 AFERNOD

Unless referenced otherwise source is Ifremer (1994) or Menot et al. (2010).

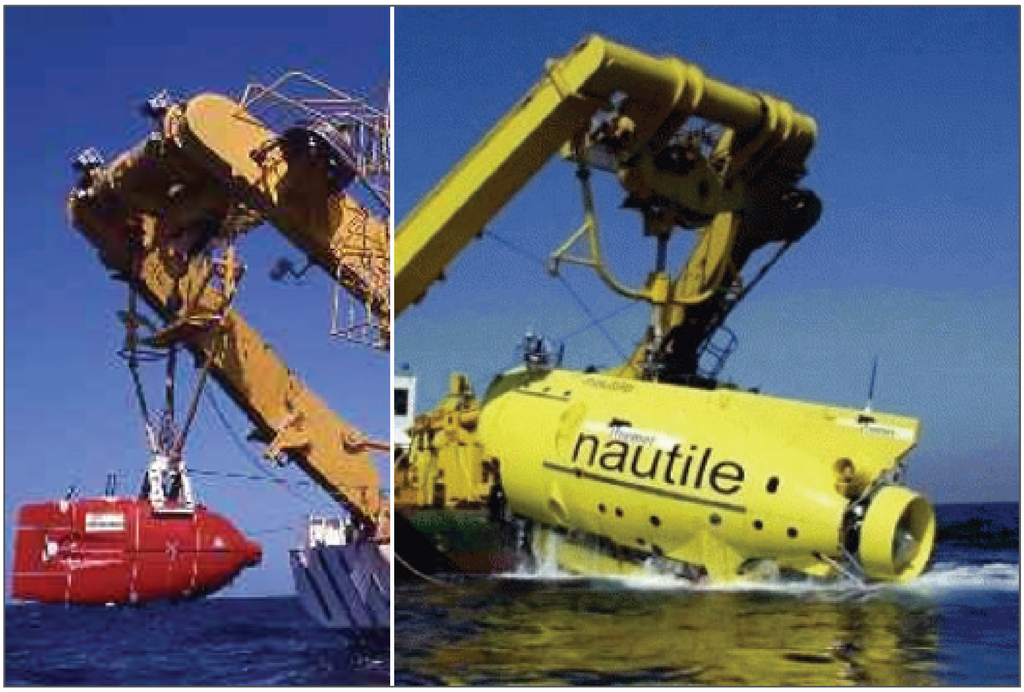
French interest in exploration and mining of Pacific nodules dates back to the mid-1960s but field work commenced in early 1970 when the Company "Société Le Nickel" (SLN) and the National Centre for the Exploitation of Oceans (CNEXO), which later became today's Ifremer (Institut Français de Recherche pour l'Exploitation de la Mer), began studying the nodule deposits, focusing near the Marquesas Island Group (French Polynesia).

In 1974, the Commissariat à l'Energie Atomique (CEA) and the Chantiers de France-Dunkerque, which in the meantime became Chantiers du Nord et de la Méditerranée (NORMED), formed a joint venture called Association Française d'Étude et de Recherche des Nodules Océaniques (AFERNOD). AFERNOD focused more on the CCZ.

In 1984 Ifremer and CEA (via their subsidiary TECHNICATOME) formed GEMONOD (which stands for Groupement pour la mise au point des MOyens nécéssaires à l'exploitation des NODules) which led the development programme of the technology of exploitation of nodules funded by the French government until 1988. Thereafter Ifremer resumed management of all aspects of the project.

AFERNOD used four research ships for most of their work during the 1970s, the Coriolis, the Noroit, the Suroit, and Jean Charcot. They also used one of the world's first AUVs, the Epaulard, and the manned submersible Nautile (Figure 6.12).

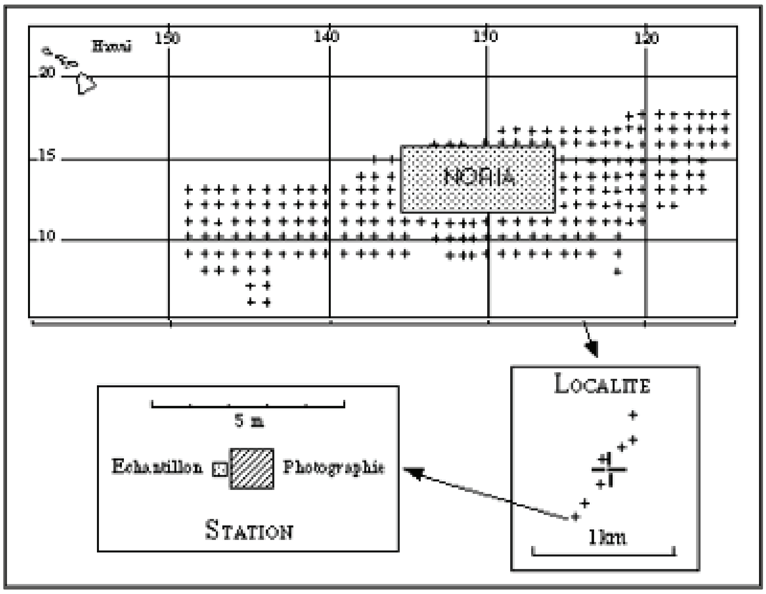
Figure 6.12 Early French AUV the Epaulard (L) and the manned submersible Nautile (R)



Sources: Ifremer (1994); Mer et Marine (2009)

Initial French efforts in French Polynesia between 1970 and 1974 employed some sixteen cruises over a massive area but with generally poor results compared to the emerging results from the CCZ (lower grades and erratic and often low abundances of nodules). Then between August 1975 and September 1976 the French explored the entire CCZ at a wide but systematic scale with nine cruises (called NIXO20 to 28). A wide range of technology was used in the exploration effort but from Figure 6.13 it appears that clusters of free fall grabs were typically used at each sample site.

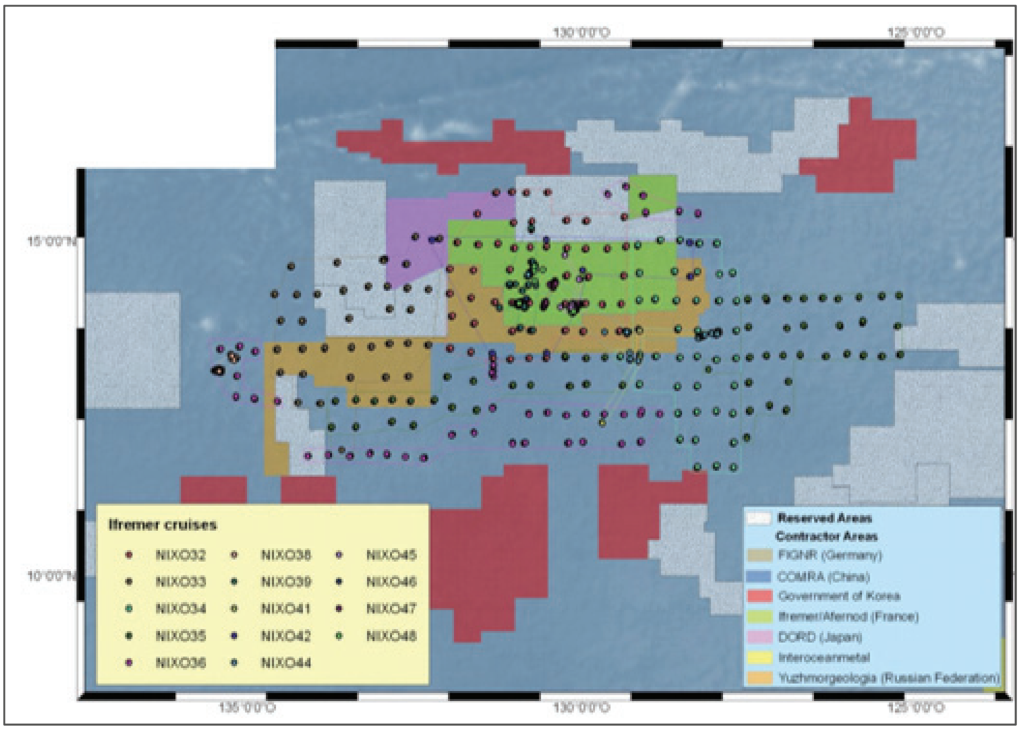
Figure 6.13 French exploration of the CCZ that led to NORIA



Analysis of exploration results of the area led to definition of two domains, with one having more continuous grade characteristics. For the next phase the AFERNOD selected an area with consistent grade and typically higher abundance, the 431,500 km^2 NORIA area (NOdules RIches et Abondants). The eastern parts of this area coincide with KCON's Albatross Area (Figure 6.14, Figure 6.8).

Work at NORIA between 1976 and 1977 started with several thousand kilometres each of sonar, magnetic and seismic survey. This was followed by six cruises of sampling and photographic survey.

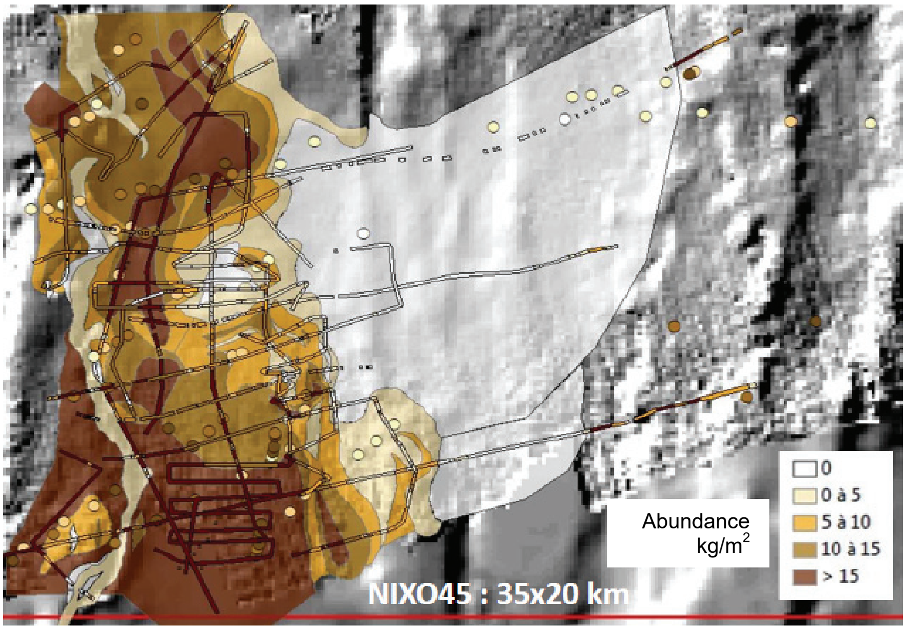
Figure 6.14 Samples in the NORIA Area



Source: Menot et al. (2010)

A "mining area" of 150,000 km^2 was then selected from the NORIA area for further work starting in 1979. This worked focused on mapping the seafloor topography and nodule abundance. The latest technologies such as multibeam echosounding and autonomous underwater vehicle survey (Figure 6.12; Figure 6.15) were brought to the problem as well as more detailed towed surveys.

Figure 6.15 Example of historical French seabed traverse mapping



Source: Fouquet et al. (2014)

6.2.6 Ocean Mining INC. (OMI)

Unless referenced otherwise the following is sourced from Brockett (pers comm. 2016) or Brockett et al. (2008).

The International Nickel Company (INCO) first became interested in deep-ocean mining for manganese nodules back in 1958, but it was not until late in 1971 that INCO opened its Ocean Mining Development office in Bellevue, WA. During those early years, INCO contracted with outside organizations (John Mero, Dames and Moore, and Deepsea Ventures) to assist with exploration activities including several survey cruises. INCO then explored in their own right with the M/V Growler.

A first generation mechanised self generating collector concept delivered by contractor Ocean Science Engineering in 1972, proved unworkable in trials in Discovery Bay, Puget Sound.

INCO made the decision to develop their collector systems in-house and set about designing what became internally known as the “Electro-Hydraulic” (EH) collector that was subsequently patented in 1976. INCO constructed a version of the EH collector designed to be tested on a cable and scheduled a deep-sea collector test in the CCZ in the early 1970s. Unfortunately the collector, its instrumentation system, and a 7600 metre electro-mechanical tow cable were lost during a shallow water test off the coast of Oahu, Hawaii. That loss triggered INCO’s decision to search for joint venture partners leading to the formation of OMI.

In 1975 the OMI consortium was created, led by INCO and including AMR of Germany, DOMCO of Japan and SEDCO of the USA.

AMR was given responsibility for the exploration programme within OMI and INCO was assigned responsibility for collector development (Brockett and Kollwentz, 1977). However, both AMR and DOMCO assisted with the design and construction of prototype test collectors. INCO excavated a land based collector test facility in Redmond, WA, and early in 1976 tested eight collectors developed by:

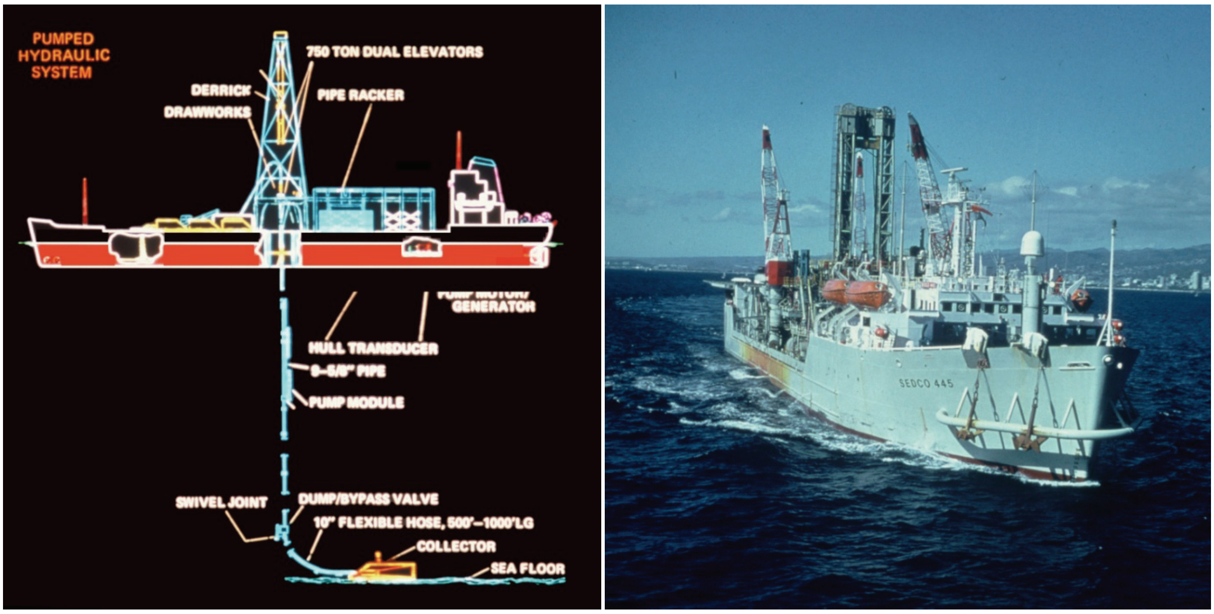
- INCO (2 passive designs and 2 hydraulic designs, with one clearly superior hydraulic design);
- AMR (2 rotating drum types and 1 more successful cutter blade scraper); and
- DOMCO (1 hydraulic design).

In 1976 the OMI collector team used the R/V *Valdivia* to conduct in-situ collector tests in the CCZ. Two collectors were chosen for a subsequent pilot mining test; the DOMCO hydraulic design and the AMR cutter blade scraper design. Two of the hydraulic collectors were constructed, one with a two metre wide active collection width and one with a three metre wide collection width.

The developmental mining system tested was configured around the SEDCO 445 drill ship which was a 445' vessel (Figure 6.16). A riser pipe assembled with 9-5/8" diameter oil field casing (Figure 6.18) extended from the gimbaled rig floor on the ship to within 50 metres of the seafloor. This gimbaled rig floor was important for safe and efficient operations and allowed the casing to be safely lowered and the collector deployed without damage. The addition of motion compensation equipment completed the list of requirements for creating the stable platform to carry out successful deep mining operations. The weight of the riser pipe, pumps, instrumentation and collector assembly was over 450 metric tons.

During the pilot mining testing, OMI tested both a hydraulic submersible pump (Figure 6.18) and an air injection lift system to raise the nodules from the seafloor to the surface. The interface between the seafloor collector and riser pipe was a structurally strengthened flexible hose to accommodate variations in seafloor bathometry. Above the flexible section of hose a deadweight was installed to control riser pipe lift-off during towing operations. Next in line was a dump valve to prevent nodule clogging in the riser pipe during mining shutdowns. There was also a vacuum relief valve in the lower assembly to prevent collapse of the flexible hose in the event the collector became jammed with nodules.

Figure 6.16 OMI Pilot Mining System Configuration and the SEDCO 445 off Honolulu



While the primary function of the collector was to gather the nodules from the seafloor, there were secondary functions; rejecting the oversized and undersized nodules, eliminating unwanted sediment, and introducing the nodules into the riser system. In addition to providing a conduit for lifting the nodules to the surface, the riser pipe was used to tow and navigate the seafloor collector through the mine site. Once on deck, an air, water and nodule separator directed the nodules to conveyors (Figure 6.19) for transporting the nodules to the ship holds and on deck storage containers. Any superfluous water and entrained sediment was returned to the ocean under supervision of NOAA environmental scientists associated with the DOMES project.

Three test cruises culminated a four year research and development programme by OMI to determine the technical feasibility and economic viability of deep-ocean mining at the time. This so called Pilot Mining Test (PMT) was conducted in more than 5,250 metres of water in the nodule rich belt located between the Clarion and Clipperton fracture zones roughly 1,000 nautical miles SE of Hawaii.

Figure 6.17 INCO electro-hydraulic collector test; DOMCO hydraulic collector launch & recovery test on the R/V Valdivia

Figure 6.18 Connection of riser to collector and in-line submersible pump

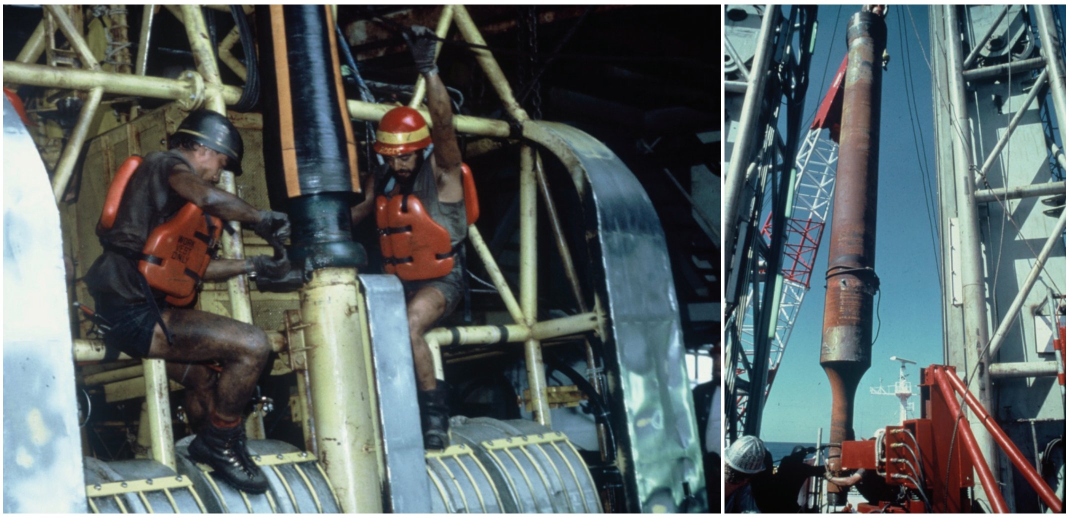
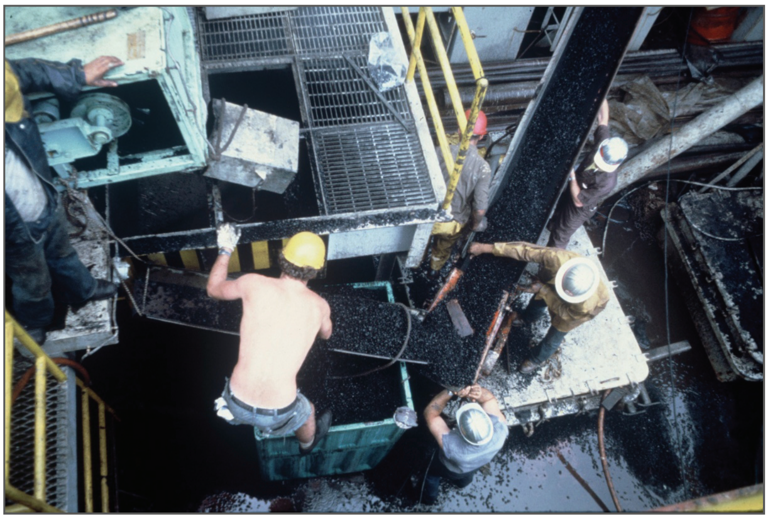


Figure 6.19 OMI Transport Conveyors Overflowing with Nodules



The OMI team, operating aboard the SEDCO 445 drill ship successfully recovered over 800 metric tonnes of nodules during these tests during the summer of 1978. The submersible pump system recovered approximately 650 tonnes of nodules while the air lift system recovered 150 tonnes. Nodule throughput varied dramatically throughout the tests with the rate exceeding 40 tonnes per hour at times causing the material handling systems and storage containers on the mining ship to overflow with nodules (Figure 6.19).

Most of the 800 tonne sample was shipped to INCO's Port Colbourne research facility for process testing and development. There it was processed into Ni-Cu-Co matte which was distributed to the consortium partners for further evaluation.

Kollwentz (1990) discusses the challenges faced by OMI (and thus by the other commercial consortia) both leading up to, during, and most critically after the successful pilot mining trial. Issues relating to the project specifically revolved around management and related technology development (the nodule consortia were some of the earliest large complex joint ventures; Killing, 1983).

6.2.7 Ocean Minerals Company (OMCO)

Ocean Minerals Company comprised US and Dutch interests, namely: Ocean Systems of Lockheed Missiles and Space Company Inc., Amoco Minerals Co, Billiton International Metals BV and Boskalis Westminster (UNOETO, 1979).

In 1978, following the end of the infamous Project Azorian (CIA, 2012), OMCO rented the Glomar Explorer from the United States Government (Spickerman, 2012) to use as the pilot mining vessel. The Glomar Explorer (Figure 6.20) had been built to raise a sunken Russian submarine, but had used nodule mining as a cover story. The OMCO partners thus sought to leverage off much of the already completed engineering work.

OMCO conducted an extensive exploration campaign across the CCZ (Golder Associates, 2013) with a minimum of six cruises utilising the M/V Governor Ray between 1978 and 1981. Work included sampling (Spickerman, 2012), photography and video survey. Footage of some of the exploration work and subsequent pilot mining trials can be found at Periscope Film (2013).

The pilot mining vessel had dynamic positioning, a 33,000 ton displacement and a length of 180 m. It utilized a sophisticated system to deploy the pipe string and electric power conduits (ISA, 2004). Its large moon pool (61 x 22 m) facilitated the handling of a large collector and buffer. OMCO built a motorized collector outfitted with Archimedes screw-drives to crawl over soft sediment (Figure 6.20).

Initial experiments were at a depth of 1,800 m off California, but the first full tests were south of Hawaii at the end of 1978. These first tests were suspended because the doors of the moon pool refused to open. Finally in February 1979, the operation was carried out with more success. In addition, much data was assembled by the ship's advanced computer system. These operations succeeded in demonstrating that OMCO's basic approach to dredging and lifting worked (ISA, 2004).

Figure 6.20 OMCO Screw-drive collector and pilot mining vessel, the USNS Hughes Glomar Explorer

Sources: Spickerman (2012); Strauss (2014)

6.2.8 The CLB Group

In 1970 and 1972, the Continuous Line Bucket Group a syndicate of 30 companies (UNOETO, 1979; Ifremer 1994; ISA 2004) tested at sea a system invented by Commander Yoshio Masuda, a former Japanese marine officer (Masuda et al, 1971; Mero, 1978). Before sea trials, the system was subjected to a series of laboratory and shallow water at-sea tests in the late 1960s, with encouraging results.

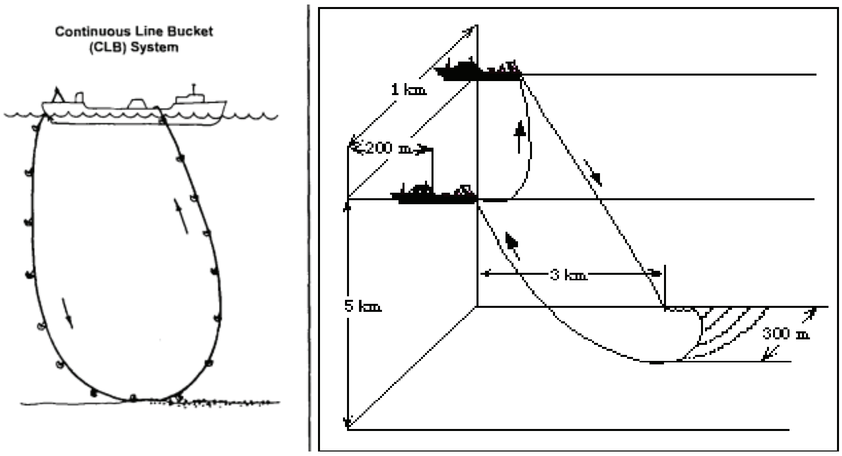
The Continuous Line Bucket (CLB) consisted of an 8 km cable on which buckets were attached at regular intervals. The buckets were launched from the bow of a former whaling ship, the Akurei Maru, and recovered at the stern. Some nodules were picked up, but the test has hampered by mechanical problems with the traction drives aboard the mining vessel, with the connectors used to attach buckets to the cable, and with tangling of the outgoing and the incoming bucket line legs. This resulted in the system being inoperative much of the time.

Bucket designs varied, but generally consisted of wire mesh, perforated steel boxes, or similar porous structure so as to allow sediment and other fine materials collected with the nodules to be largely rinsed off during the hoisting process. Some type of bucket closure mechanism was also thought to be desirable to prevent excessive loss of harvested nodules during retrieval.

The depth of bucket penetration into the sediment was believed to be controllable through a combination of adjusting mining ship speed and manoeuvrability, and use of angled teeth or sled-like runners on the buckets themselves.

Subsequently a French concept for utilising two surface ships to handle the incoming and outgoing CLB loops was considered. Using two ships would allow for further separation with less chance of entanglement. A new test was planned for 1975, but had to be cancelled for lack of funds.

Figure 6.21 The single vessel and two vessel continuous line bucket systems

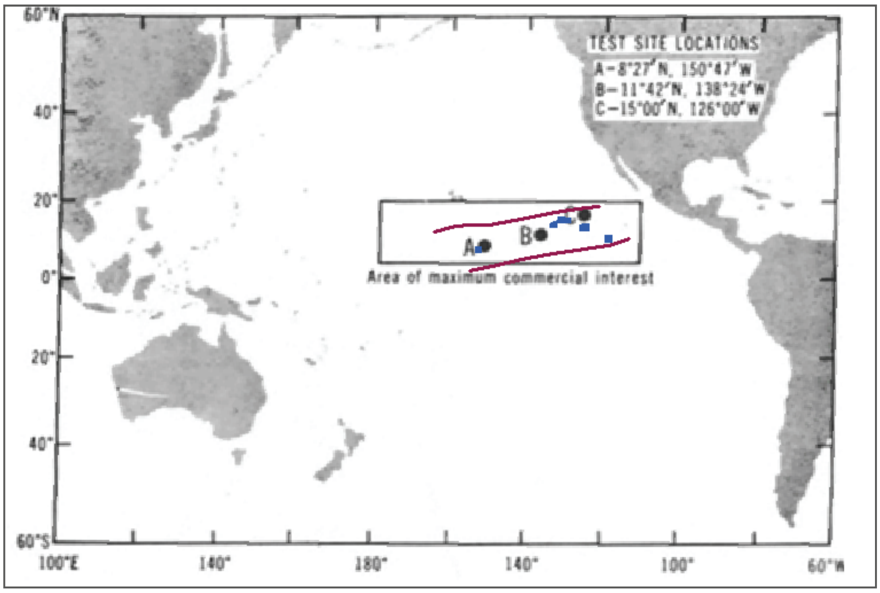


Sources: Thiel, 1991 and Ifremer 1994

6.2.9 DOMES

In order to meet requirements of national environmental legislation, the United States in 1975 initiated a comprehensive research programme called Deep Ocean Mining Environmental Study (DOMES; Bischoff and Piper 1979; DOMES, 1981; Thiel et al, 1997). The study was described as a Draft Programmatic Environmental Impact Statement, and characterised the environment in the CCZ region (which was included in a rectangular area called also the DOMES area) and the impacts of its potential mining.

Figure 6.22 DOMES baseline sites in the CCZ, within the DOMES area



Modified after Piper et al. 1979 with CCZ boundaries and TOML areas.

Phase I of the programme, called DOMES I, was undertaken by the National Oceanic and Atmospheric Administration (NOAA) of the US Department of Commerce to provide environmental baseline information on three representative mining sites (A, B, C) in the Pacific manganese nodule province. Each covered an area of approximately 200 km by 200 km and was chosen in consultation with industry and the scientific community.

The programme was run by NOAA’s Pacific Marine Environmental Laboratory with significant input from academia. Twelve cruises of NOAA's research vessel R/V Oceanographer were carried out from August 1975 through November 1976, totalling approximately 240 ship days at the three sites. Scientific disciplines represented were physical oceanography (studies of solar radiation and ocean currents), biological oceanography (studies of phytoplankton and benthic fauna), chemical oceanography (studies of nutrient chemistry and suspended matter), and marine geology (studies of sediment, nodules, acoustic stratigraphy).

DOMES II involved monitoring of the effects of the OMI and OMA pilot trials described above (e.g. Ozturgut et al, 1981). The OMI and OMA systems required discharge of return water from the lift system and this was monitored and characterised. Estimates of lift and collector impacts for a 5,000 dry metric tonne per day operation were also made.

Data review and reporting included assessment of required resources for mining and on-shore processing marketing and cost-resource-safety trade-off estimates.

DOMES was designed primarily as a data gathering effort and final data reports were submitted to NOAA by early 1978. Data collected concurrently by other workers was included with the DOMES data for completeness, with a book of key findings and data published in 1979 (Bischoff and Piper 1979). The final official Draft Programmatic Environmental Impact Statement was issued in 1981 (DOMES, 1981; Ozturgut et al, 1997). The conclusions of the study at the time were that for a commerical operation most issues were likely not of serious concern, but with key focus on:

1 Surface discharge from a typical riser lift system would have no long term impact and would be very small at the scale of the CCZ. A question remained on impact of particulate matter on fish larvae.

2 Impact from a typical seabed collector would be clearly adverse to benthic organisms at the site, but that on the scale of the CCZ impact would not be significant. Recolonisation rates were unknown. High rates of biodiversity and ecosystem function were addressed but not examined in depth and the inevitability of islands of undisturbed seafloor within the mine sites was pointed out.

3 Extent and impact of sediment plumes generated at the seafloor was still largely unknown and demanding of further investigation

The benthic impact experiments (BIE) discussed further below were then designed to specifically address the third point above (Ozturgut et al, 1997).

6.2.10 Summary Table: The International Decade of Ocean Exploration

A chronological summary of the International Decade of Ocean Exploration is summarised in Table 6.2.

Table 6.2 Chronological summary of the International Decade of Ocean Exploration

Years	History of the Discovery & Exploration of Polymetallic Nodules	History of the Law of the Sea and International Seabed Authority
1970/71	Trial nodule mining in by Deepsea Ventures in the Atlantic in 762 m of water. French exploration commences in the Marquesas.	General Assembly of the United Nations adopted 2749 (XXV). Declaration of Principles Governing the Sea-Bed and the Ocean Floor, and the Subsoil Thereof, beyond the Limits of National Jurisdiction.
1972/73	Continuous Line Bucket trial	Third United Nations Conference on the Law of the Sea. begins (concludes in 1982 after eleven sessions and several resumed sessions) IDOE count 46 nations as members
1974	KCON consortia formed AFERNOD starts work in the CCZ Geological Survey of Japan starts work in the central Pacific. OMI start pilot mining R&D programme.	Second session: (Caracas) of Third United Nations Conference on the Law of the Sea
1975	DOMES environmental baseline cruises commence (conclude 1976) French start focusing on NORIA area OMI consortia formed	Third Session (Geneve) of Third United Nations Conference on the Law of the Sea
1976	Yuzhmorgeologiya join the Russian nodule effort. OMA start pilot mining trials in the CCZ	Fourth session (New York, spring): of Third United Nations Conference on the Law of the Sea Fifth Session (New York, summer): of Third United Nations Conference on the Law of the Sea
1977	–	Sixth Session (New York): of Third United Nations Conference on the Law of the Sea
1978	OMI lift 800 wet tonnes of nodules using pumping and airlift. OMA lift 550wet tonnes of nodules using airlift. OMCO consortia formed and trials start at the end of the year. DOMES results published First Chinese nodule cruise to central Pacific	Seventh Session (New York, spring-Geneve, summer): of Third United Nations Conference on the Law of the Sea
1979	OMCO deploy and manoeuvre screw drive collector AFERNOD start detailed mining studies	The Eighth Session (New York, spring-Geneve, summer): of Third United Nations Conference on the Law of the Sea
1980	-	Ninth Session (New York, spring-Geneve, summer) of Third United Nations Conference on the Law of the Sea
1981	DOMES study published	Ninth Session (New York, spring-Geneve, summer) of Third United Nations Conference on the Law of the Sea
1982	-	Eleventh Session (New York, March and September) of Third United Nations Conference on the Law of the Sea

6.3 1982 – 1995: The Reciprocating States Regime and the Pioneer Investors

By 1980, the Third United Nations Conference on the Law of the Sea had been running for eight years and a successful outcome was far from certain (Churchill and Lowe, 1988). The process was drawn out by a need for consensus in the sessions as earlier attempts to use majority votes had proven unsatisfactory.

Even once most of the other sections of UNCLOS were accepted, there were deep divides over Part XI and Annexes III and IV, which dealt with The Area and deep-sea mining. There was an impasse between the nations (or their domiciled commercial groups) who had already invested hundreds of millions of dollars in exploration in the preceding decade and others (especially the Group of 77), some of whom were expecting to be carried through the entire process of development. Early drafts of Part XI were more complex and demanding, for example in the areas of Technology Transfer, Financial Terms and Production Policy (United Nations, 1998).

Nations such as the United States, Great Britain and West Germany found the proposed terms in Part XI unattractive, even if they accepted other parts of UNCLOS, and refused to sign (Reagan, 1983; Churchill and Lowe, 1988; Ranganathan, 2014).

Thus in the early 1980s legislative efforts to manage deep-sea mining (and specifically development of the CCZ nodules) split with:

- The United Nations establishing a specific Preparatory Commission (PrepCom; at the eleventh session) to look at defining principles and regulations to implement the 1982 Act and to encourage Pioneer Investors into the Area (this was often related to trying to get particular states to sign UNCLOS);
- Establishment of the Reciprocating States Regime (RSR). This directly involved USA, Japan, France, West Germany, United Kingdom and by distant association the USSR, China, and what became the IOM consortium. The RSR was either planned as a bridging system until UNCLOS could be sorted out, or was an alternative system altogether (Churchill and Lowe, 1988).

The UN was keen to close out UNCLOS and recognised the need to attract a group of Pioneer Investors on more attractive terms than originally envisaged (Resolution II). Many of the groups that had worked in the Area in the 1970s had the desire to register and protect past work with the hope that UNCLOS was imminent.

PrepCom ran as follows (Li, 1994; Ranganathan, 2014):

- The Plenary oversaw the process and handled registrations of Pioneer Investors
- Special Commission 1 looked at possible impact of deep-sea mining on established land based industry
- Special Commission 2 looked at the function and training of the Enterprise (ISA’s own mining organ) including the prevailing economic conditions and profitability;
- Special Commission 3 looked at the Pioneer Investors proposed plans of work, contract terms (including financial), preservation of the marine environment and other accounting and workplace regulations.
- Special Commission 4 looked at the practical arrangements with regards to setting up the International Tribunal for the Law of the Sea

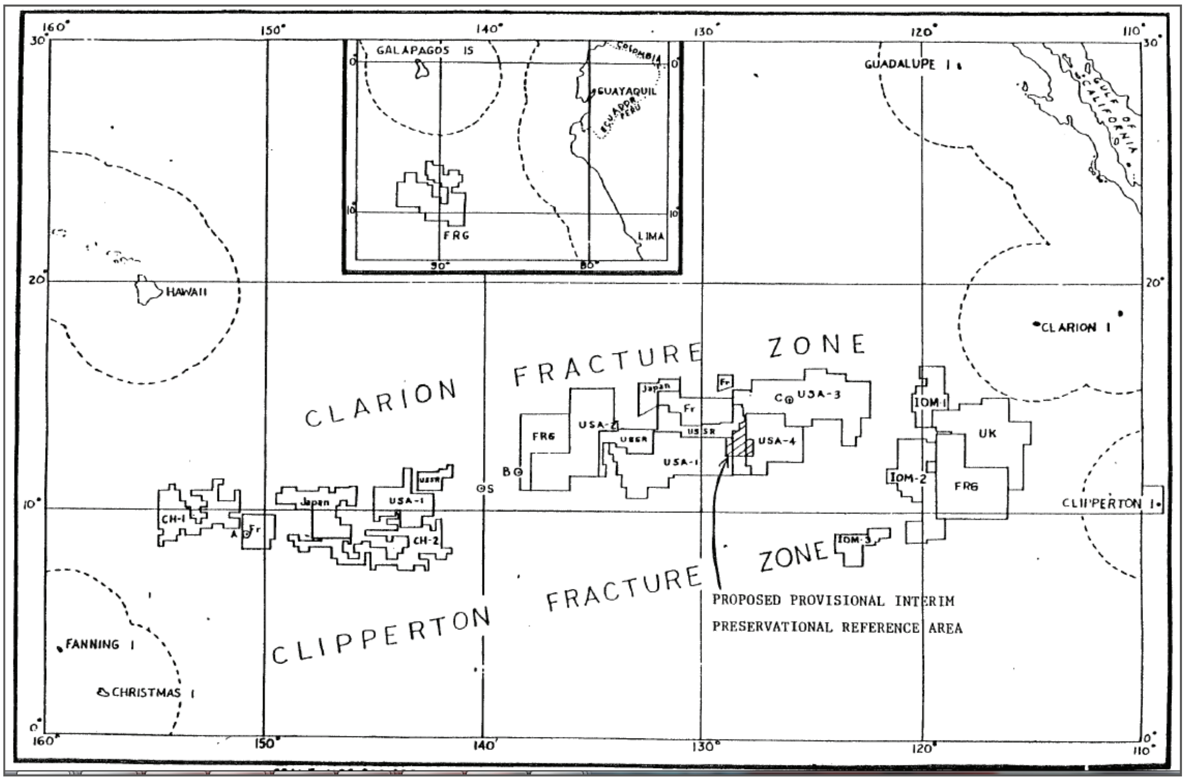
Suspicion existed between leading proponents of UNCLOS (such as the USSR) and proponents of the RSR (Ranganathan, 2014). After several initial attempts to progress discussions, the USSR and India registered first as Pioneer Investors in early 1984. With concerns about losing security of tenure, France and Japan followed suit in late 1984.

Issues with the applications, in part relating to overlapping areas, meant that most of these applications were resubmitted along with others in 1987 and 1988, after the Midnight Agreement (see below). In the meantime PrepCom worked on regulations, the RSR was progressed further and the nations concerned discussed the issues at the UN and in other forums.

The RSR worked by mutual co-operation whereby each participating state:

- Established domestic deep mining legislation of a broadly similar basis and
- Met and agreed that mineral rights granted under their respective domestic legislation would not overlap (Figure 6.23).

Figure 6.23 Operating Areas under the Reciprocating States Regime, circa 1993



Source: NOAA (1993)

The RSR worked well in terms of removing the issues of the overlapping work programmes (and subsequent claims) that characterised the previous decade (Figure 6.5). Numerous rounds of negotiation were required between the member states including the exchange of data. An "Interim Agreement" was signed between the United States, France, West Germany and the United Kingdom in 1982 and this was replaced in 1984 by an expanded "Provisional Understanding" that also included Japan, Belgium and Italy (Ranganathan, 2014). The USSR opposed the RSR at the UN, but participated in rationalising the overlapping areas (which was required by PrepCom as well), this crystallised through the Midnight Agreement and Exchange of Notes in 1987 in which the associated parties agreed to respect the existing rights of the others.

By 1993 there were 18 "operating areas" recognised by the US (Figure 6.23) with all but one in the CCZ. The four commercial consortia obtained seven of these blocks with:

- Two to KCON (1 called USA-4 issued by the US and 1 issued by the UK);
- Two to OMI (1 called USA-2 by the US and 1 by West Germany);
- One to OMA (called USA-3 or Delta-Gamma); and
- Two to OMCO (both called USA-1 (east and west) by the US).

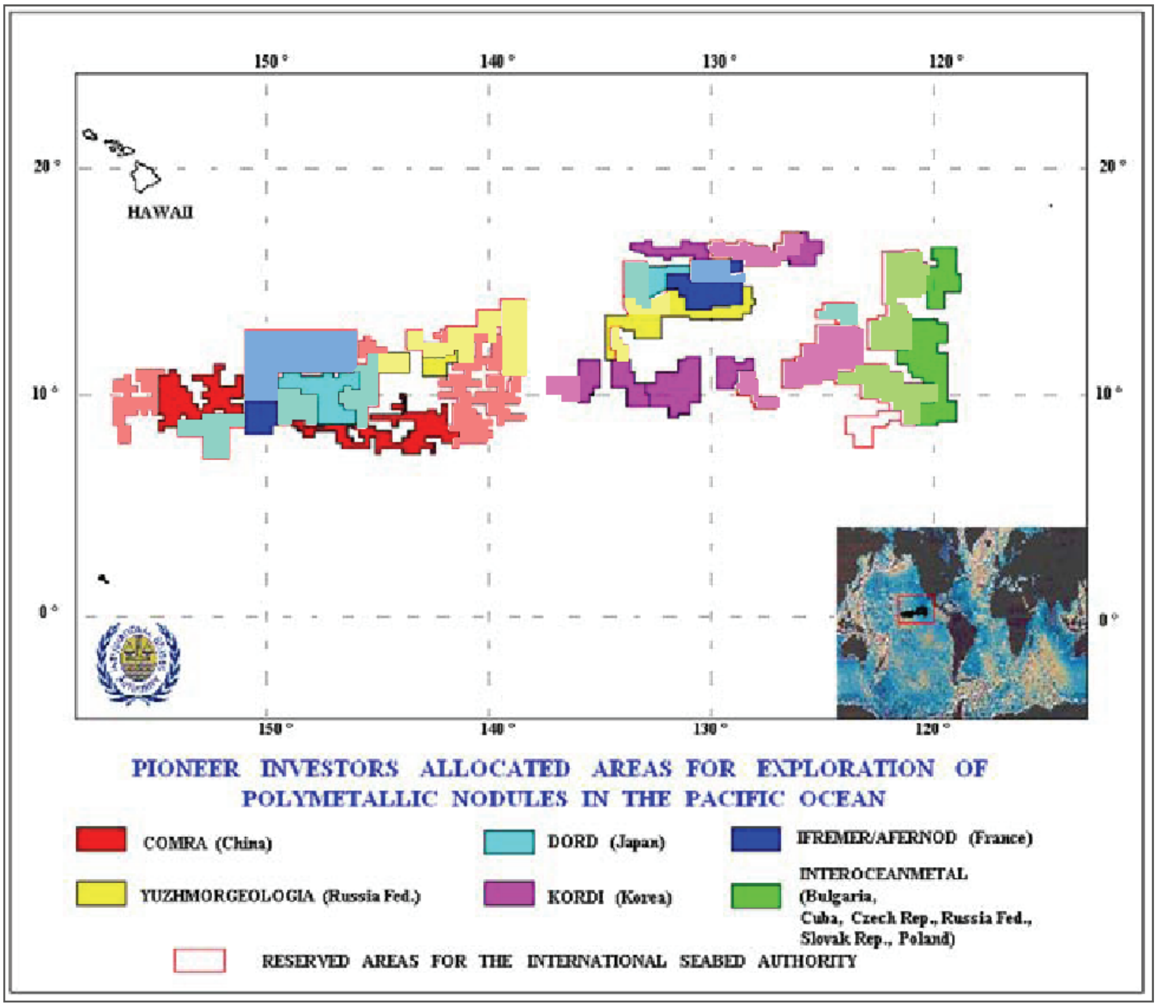
Most of these areas are now encompassed within the ISA contracts and returned areas (Figure 4.1). Today only three of these operating areas are still in force outside of UNCLOS, these being the USA-1 (two blocks) and USA-4 areas, all issued to Lockheed Martin under the US Deep Seabed Hard Minerals Act (NOAA, 2016). The deep-sea mining legislation developed by the other members of the Reciprocating States Regime is however still of value as domestic legislation is required in any event by Sponsoring States under UNCLOS.

Between 1989 and 1994 the commercial consortia started shutting down their nodule programmes and the UN Secretary General seriously tackled the idea of modifying Part XI (Ranganathan, 2014). This advanced through three rounds of progressively widening consultation with the signatory states. In 1994, revisions to Part XI (at this stage called "The Boat Paper") had progressed to point of widespread (if not complete) acceptance. The resulting Agreement on Implementation was included into UNCLOS and adopted as a binding international Convention. It mandated that key articles, including those on limitation of seabed production and mandatory technology transfer, would not be applied, that the United States, if it became a member, would be guaranteed a seat on the Council of the International Seabed Authority, and finally, that voting would be done in groups, with each group able to block decisions on substantive matters. The 1994 Agreement also established a Finance Committee that would originate the financial decisions of the Authority, to which the largest donors would automatically be members and in which decisions would be made by consensus. Ratification of UNCLOS by Guyana in 1994 provided impetus to resolution, as their signature reached the threshold number of signatures required for UNCLOS to enter into force.

Issuance of the Agreement of Implementation lead to a raft of ratifications from UNCLOS signatory states, but despite it being drafted largely in concession to the United States, the United States has not yet ratified UNCLOS, although it did provisionally sign the Agreement of Implementation.

By this time the registration of the seven Pioneer Investors was complete. This included the six shown in Figure 6.24 as well as India (with a contract in the Indian Ocean). The Pioneers received special terms including application fees at cost of administration (up to USD 250,000) and the right to apply for 150,000 km^2 in the first instance (returning a 150,000 km^2 area of equal value at that time; Figure 6.24), reducing to their preferred 75,000 km^2 over the next fifteen years.

Figure 6.24 Retained and returned (lighter shade) areas of the pioneer investors in the CCZ



Modified after ISA (2003) and Ifremer (1994)

6.3.1 Deep Ocean Resources Development

DORD has its origins in DOMA (Deep Ocean Minerals Association) a consortium of some 39 different Japanese companies that was formed as a public corporation in 1974 but with oversight by the Japanese Ministry of International Trade and Industry (MITI). The members of DOMA included companies in the fields of trading, shipping, ship building, steel making, mining and metallurgy, electrical systems and fishing. DOMA members were involved in the OMI and KCON consortia.

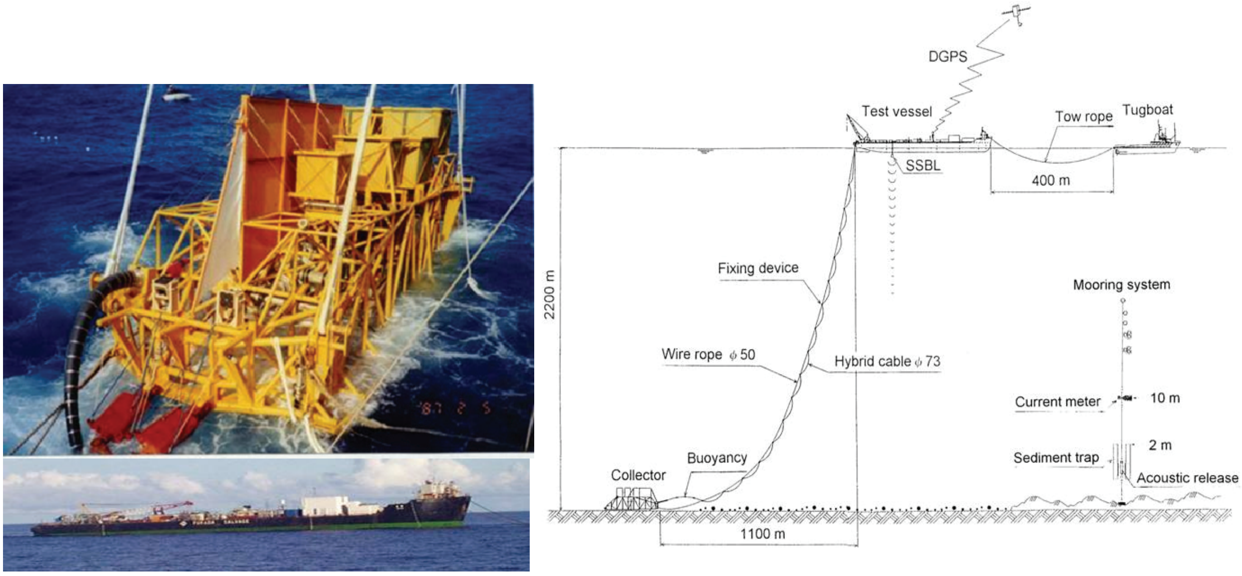
As the commercial consortium faded, DORD was established in 1982, specifically for the development of polymetallic nodules. However since the mid-1990s, it has been involved in other deep-sea mineral resource types and hydrocarbon research (DORD, 2013). DORD is 75.83% owned by Japan Oil, Gas and Metals National Corporation with the remainder distributed amongst some 43 commercial companies (DORD, 2013).

DORD began manganese nodule exploration activities in 1983, and was formally accepted as a Pioneer Investor in late 1987. DORD reports through the Japanese Agency of Industrial Science and Technology to MITI. Between 1981 and 1989 it spent some JPY20 B (~USD80 M at the time; Kajitani, 1990). Much of the research and development expenditure was on a mining system concept, models and simulations and pilot development by the Technology Research Association involving:

- Towed collector based on the OMI Asakawa design but incorporating a crusher;
- Lift system (either pumping or airlift);
- Flexible hose connection to collector that was key for helping managing heave and seafloor irregularities as well as landing and recovery operations; and
- Pumps and compressors and their efficiency.

In 1997, as part of the pilot programme of component testing, a trial was made using a towed collector without crushing or lifting (Figure 6.25). This was on a seamount southeast of Marcus Island (Minami-Tori-shima) at 2200 m and nodules were successfully collected (Yamazaki 2008, Yamazaki, 2011).

Figure 6.25 1997 Japanese collector, barge and trial schematic



Source: Yamazaki (2006)

In 1996, ahead of the seamount trial, DORD paused work in the CCZ, resuming only in 2008.

6.3.2 Chinese Entry and COMRA

Formal Chinese interest in deep-sea marine science and development is believed to date back to the mid-1970s with the leadership of Deng Xiaoping (Takeda Jun'ichi, 2014; Hoagland et al, 1992).

The first known marine surveys took place in 1978 (RV Xiang Yang Hong 05; COMRA, 2013a), 1983 and 1985 (RV Xiang Yang Hong 16 in the central Pacific; Hoagland et al, 1992; Glasby, 1986). Between late 1986 and 1987 a cruise to the CCZ covered 48,000 km^2.

Between 1991 and 2013, COMRA organized some 16 ocean expeditions to its area in the CCZ (COMRA, 2013b). Ultimately it delineated some 20 Gt of “mineral rich areas” (COMRA, 2013a), using in part an acoustic system called MFES (Multi-Frequency Exploration System; ISA, 2010).

In 2001, COMRA was involved with research institutes (including Hangsha Institute of Mining Research, Changsha Mining Research Institute, Shenyang Institute of Automation, Chinese Academy of Sciences, Second Institute of Oceanography, State Oceanic Administration, Harbin Engineering University) in pilot-miner trials in a test pool (2.8 m deep) and later in shallow water (~150 m deep; Li and Jue, 2005; COMRA 2013c). The tests included: trials of track and screw drive vehicles (Figure 6.26); determination of power requirements; ability to navigate obstacles; spud types for tracks; the ability to make turns; and the effect of sideloads. Tendency to accumulate mud is not specifically mentioned. Test work showed that the test tracked vehicle worked better than the test screw drive vehicle (Li and Jue, 2005) so a tracked vehicle was used as basis for the pilot vehicle.

Trials started June 2001 and in September the first successful production test were achieved with collection of 900 kilograms of synthetic nodules. At around the same time lifting tests were done using pumps and pipes in an old mine shaft (to 230 m).

Figure 6.26 Chinese pilot scale tracked and test screw-drive subsea vehicles

Source: Li and Jue (2005)

6.3.3 GEMONOD

AFERNOD continued working on the CCZ project for the French government until around 1984 when they were joined by GEMONOD (Groupement pour la mise au point des MOyens nécessaires à l’exploitation des NOdules), which focused on the mining and processing sides of the project (Ifremer, 1994).

Work at this time included provision of samples for metallurgical test work, more detailed seabed geotechnical work and accurate characterisation of the types of seabed obstacles. The geotechnical work included using the Nautile submersible to take shear vane readings on carefully selected sites during the 1988 NIXONAUT cruise (Cochonat et al., 1992; Figure 6.27, Figure 6.28; Figure 6.12).

Figure 6.27 Sub-bottom profiler sediment facies and related vane shear character

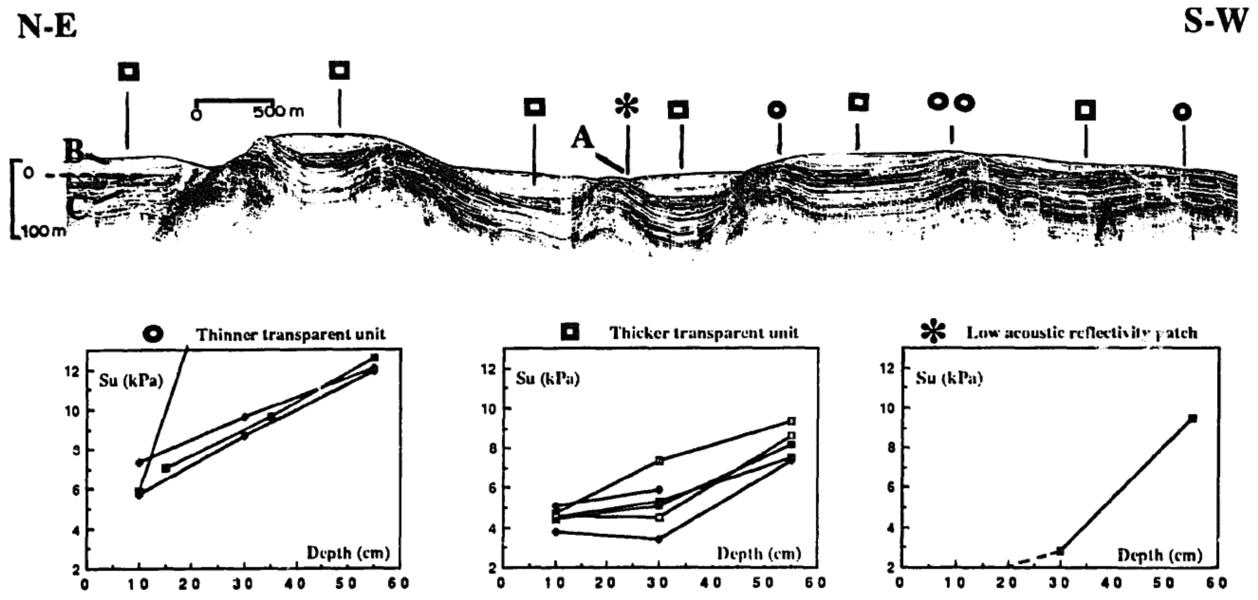
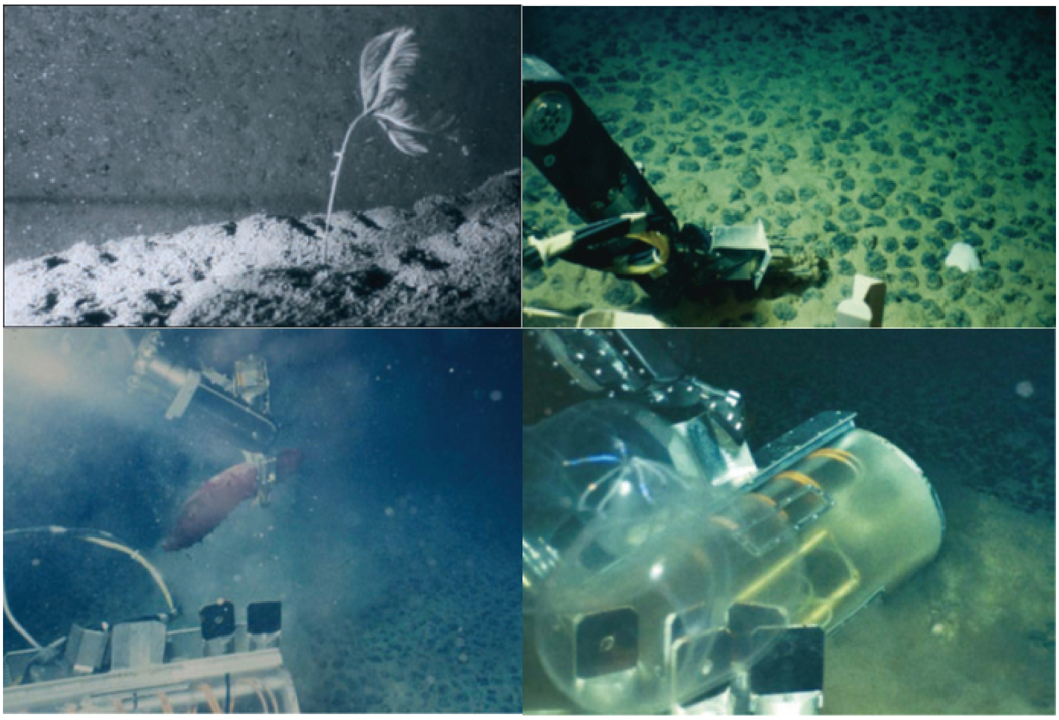


Fig. 5. Results of in situ vane shear measurements showing the three geotechnical facies distribution and the measurement stations in their morphological framework exhibited on a high resolution seismic profile. *A* = low acoustic reflectivity sonar facies; *B* = transparent unit; *C* = stratified unit; S_u = undrained shear strength (in situ vane shear strength in kPa).

Source: Cochonat et. al. (1992)

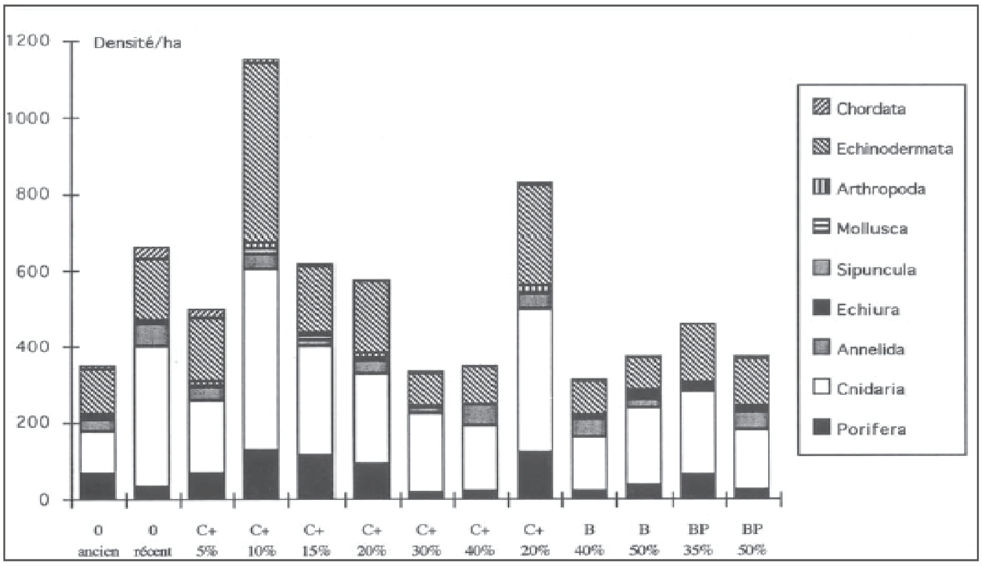
Much of the photographic and video data collected by Ifremer at this time was studied by biologists and is encapsulated in a detailed study on the megafauna (animals > 2 cm in size) of NIXO45 by Tilot (2006). This includes some of the first detailed photos of animals and landforms on the seafloor of the CCZ (Figure 6.28) and a quantitative analysis of the megafauna present (Figure 6.29).

Figure 6.28 Example photos from NIXO 45



Source: Tilot (2006); top left is a crinoid from the Epaulard, top right is an asteroid, bottom left a captured holothurian and bottom right a Pycnogonid parasitising a lobed Ctenophore in front of the vane shear device used by the Nautile

Figure 6.29 Faunal abundance by Ifremer nodule facies NIXO 45



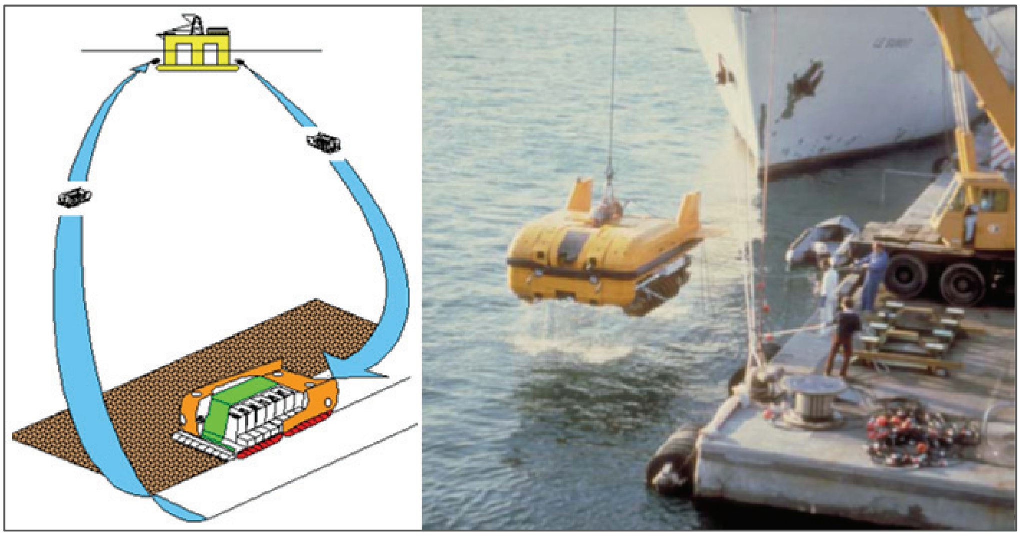
Source: Tilot (2006).

A 25 tonne metallurgical sample was collected from 49 dredge deployments. A trial mining site was also selected, called NIXO 45, and this area was surveyed and sampled in detail.

AFERNOD and then GEMONOD also considered a variety of possible mining systems during this period including one of the most exotic ever taken to testing phase.

Initially in the 1970's the continuous line bucket system (see above; Figure 6.21) was favoured (ISA, 2001b) but by the mid-late 1970s survey had discovered terrain obstacles on the ocean floor, such as blocks, steps, cliffs and potholes, convincing French engineers that an bottom collector independent of a surface vessel was needed.

Figure 6.30 AFERNOD autonomous Shuttle-Collectors concept and pilot model PLA-2 6000

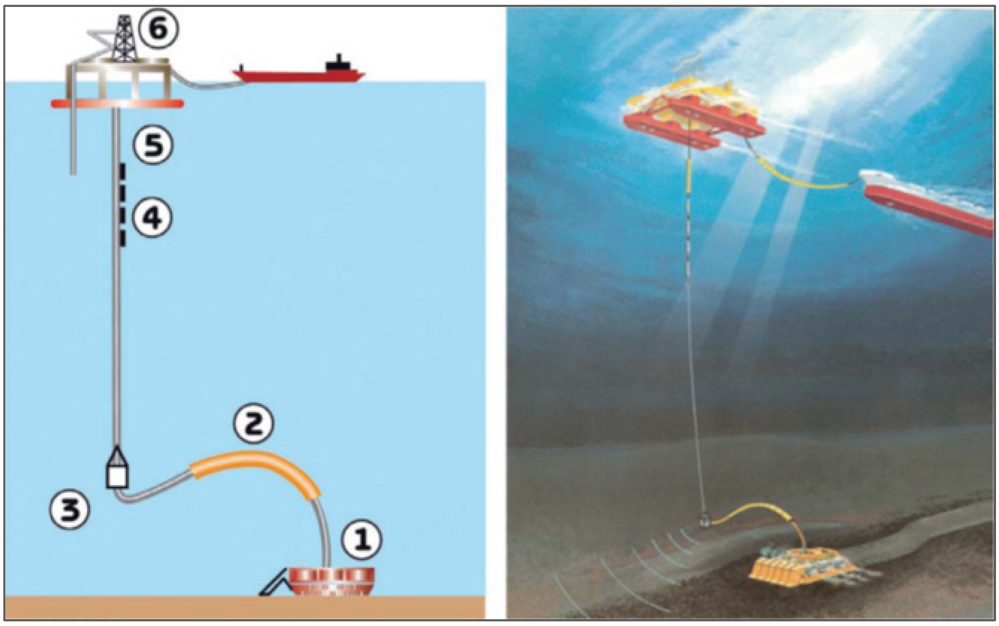


Sources: Ifremer 1994; Herrouin 2009; ISA 2001b.

In 1980 they worked on the concept of a free-shuttle mining system (Figure 6.30; Ifremer, 1994) consisting of a series of independent vehicles that would dive on their own to the ocean floor. Reaching the bottom, they would dump ballast to position themselves and would start to collect the nodules. They would crawl on Archimedean screws, adjusting their weight by the release of ballast. After loading 250 t of nodules, they would drop additional ballast and start their ascent to the surface. It was found during the feasibility study that the system would be too expensive, because the 1,200 t weight of the shuttles far exceeded their 250 t loading capacity. Nonetheless in 1985 a prototype pilot scaled vehicle (PLA-2 6000; Préleveur Libre

Autonome) was built and in late 1987 tested in the Mediterranean where it demonstrated flight, landing, seafloor movement, and return to surface (ISA, 2001b).

Figure 6.31 GEMONOD crawler and hydraulic lift system



Source: Herrouin 2009. (Crawler (1) hose (2) buffer (3) pumps (4) rigid pipe (5), semisubmersible platform (6))

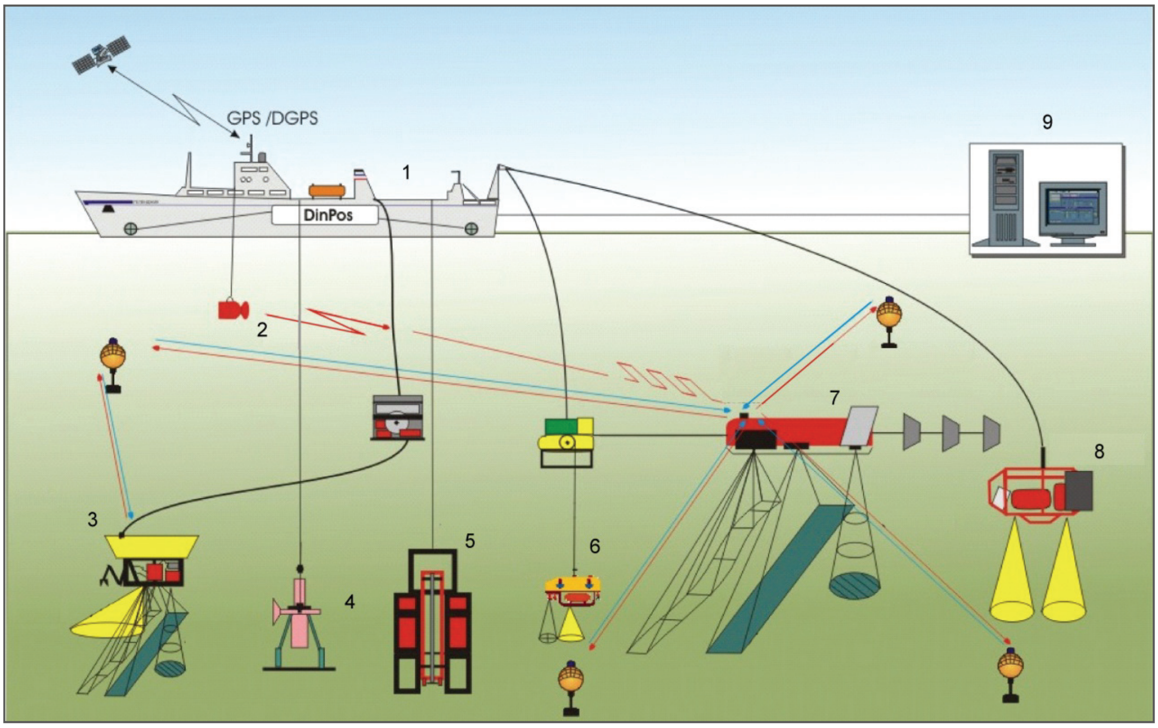
By the mid-1980s GEMONOD determined that hydraulic systems seemed to have the greatest potential (Ifremer 1994; Herrouin 2009; ISA 2001b, 2004). GEMONOD's system (Figure 6.31) consisted of: a semi-submersible surface platform; a 4,800 m rigid steel pipe string, and a flexible hose, 600 m long and with a 38 cm internal diameter, connecting the bottom of the pipe string to a dredge on the seabed. This hose would form an arc, allowing the dredge to deviate from the route followed by the surface platform so as to avoid obstacles. The self-propelled dredge would be 18 m long, 15 m wide and 5 m high, weighing 330 t for 78 t buoyancy. Crawling on the bottom, it would collect nodules and condition them for pumping through the flexible hose. Ore carriers would transport the nodules from mining ship to port, where the processing plant would be located.

GEMONOD also looked at mineral processing, both hydrometallurgical and pyrometallurgical options (Ifremer, 1994). This included a pilot processing plant for ammonia/acid leach circuits built in Fontenay-aux-Roses by CEA (ISA, 2001b), and smelting tests by MetalEurop.

6.3.4 USSR and Russia

Russian studies by the USSR Academy of Sciences increased markedly in number in the 1980s. New advances were in the study of the composition and structure of nodules, as well as local factors (e.g. Kazmin, 1984; Andreev, 1994). However, the most extensive research was carried out by the Ministry of Geology (through institutes such as Yuzhmorgeologiya) of the USSR. These studies included the Indian Ocean, but focused for the most part on the CCZ, and each year between 1982 and 1987 there were four or five marine expeditions (S. Andreev pers comm. 2016). Work included development of high quality towed sonar and photo platforms (e.g. MAK, MIR and Neptune that are still used today), as well as samplers and navigation systems. (e.g. ASMOD; Figure 6.32).

Figure 6.32 Deep-water instrumentation package for exploration designed by Yuzhmorgeologiya



Source: V. Yubko (pers comm 2016. Legend: 1 – RV; 2 – ASMOD underwater navigation; 3 – ROV; 4 – box corer; 5 – UGI geotechnical system; 6 – photo & video module; 7 – MAK high resolution geo-acoustic module; 8 – Neptune photo and video system; 9 – shipboard data acquisition and processing centre

During the 1980s and early 1990s the Soviet explorers examined of the order of 3 million km^2 area in the CCZ, with a network of stations at an average density of ~ 50 x 50 km. Studies included bathymetric, gravimetric and magnetometric observations, acoustic research, as well as bottom sampling. On the sections of the CCZ regarded as promising for the future development application, the station spacing was reduced to 25 x 25 km, and towed sonar and video-photography was added.

On May 16, 1988 the USSR formally became a Pioneer Investor through Yuzhmorgeologiya, and since then the Ministry of Geology effectively halted all nodule related work outside the CCZ. Up until 1997, YMG performed around 12,000 line km of deep-towed acoustic survey (typically side-scan and sub-bottom profiling) and 8,900 line-km of deep towed photo-television survey and collected about 1100 seafloor samples. The results of this work greatly clarified ideas about the structure of localized accumulations of the nodules.

In parallel with this work the Russians considerably intensified research and development into the extraction and processing of nodules. This included pilot testing of both pyrometallurgical and hydrometallurgical processing in 1989.

During 1988 and 1989 Yuzhmorgeologiya and Sevmorgeologiya also were closely involved in geological studies of the eastern part of the CCZ in order to prepare the applications created before the Interoceanmetal Joint Organization. This included results from some 11 research cruises.

Figure 6.33 Russian map of the CCZ circa 1990

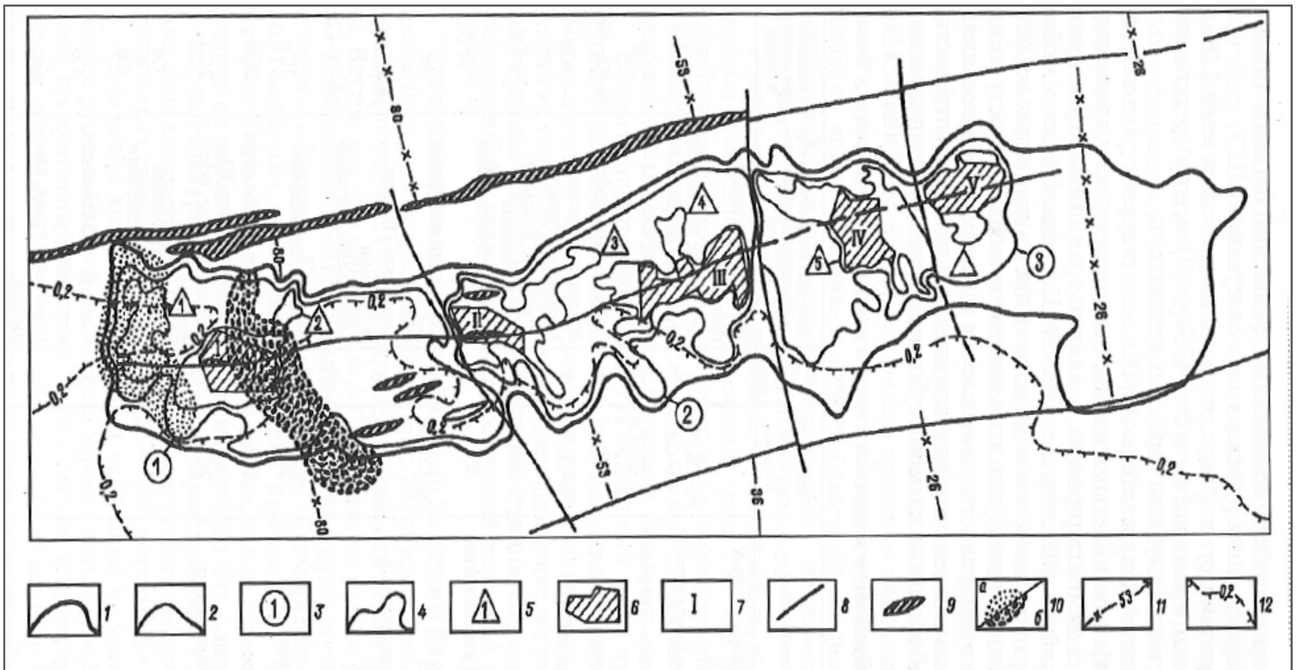


Рис. 29. Строение поля Кларион-Клиппертон (Тихий океан).
1 — контур поля; *2* — контур зоны; *3* — номер зоны (*1* — Западная, *2* — Центральная, *3* — Восточная); *4* — контур рудного района; *5* — номер рудного района (*1* — «Лаптев», *2* — «Купер», *3* — «Феодосия», *4* — «Севморгеология», *5* — «Южморгеология», *6* — «Дипси-Венчурс»); *6* — рудный узел; *7* — номер рудного узла; *8* — разлом; *9* — желоб; *10* — поднятия (*а* — вулканические, *б* — вулкано-тектонические); *11* — изохроны возраста океанического фундамента по магнитометрическим данным (млн. лет); *12* — изопахиты осадочного чехла (0,2 км).

Source: Andreev (1994) Field boundaries, 2 – zone boundaries, 3 –zone number (1-Zapadnaya/Western, 2-Centralny/Central, 3-Vostochny/Eastern), 4- mineralized/ore region boundaries, 5 – mineralized/ore regions called (1-Laptev, 2-Cuper, 3-Feodosiya, 4-Sevmorgeologiya, 5-Yuzhmorgeologiya, 6-Deep-Sea Ventures), 6-mineralized/ore camp/cluster, 7 – mineralized/ore camp/cluster number , 8 – structures/faults, 9 – trench, 10 – rises (a-volcanic, б-volcano-tectonic), 11 – age isochrones of the oceanic basement according to magnetic data (millions of years), 12 – sedimentary cover isopachs (0.2 km).

6.3.5 Interoceanmetal Joint Organisation

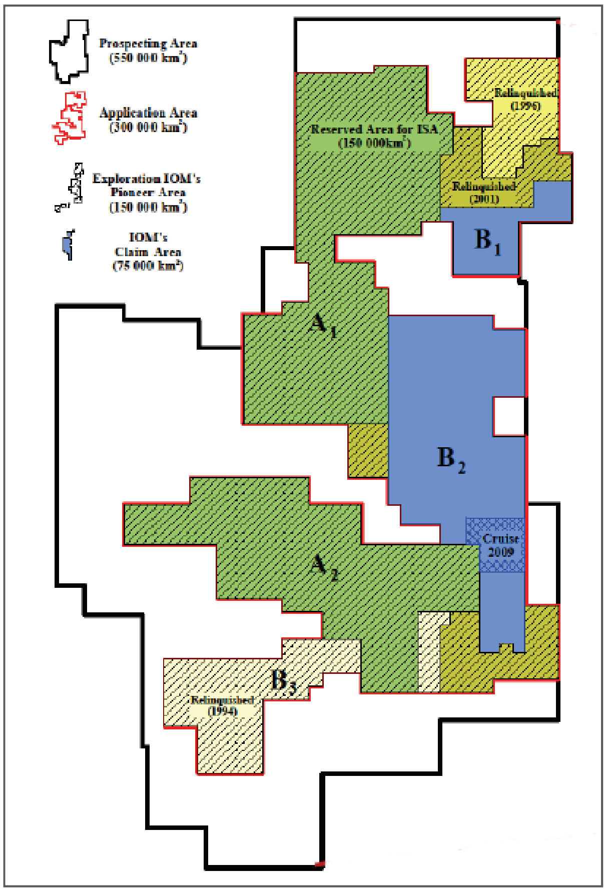
Interoceanmetal Joint Organization (IOM) was formed on 27 April 1987, based on an Intergovernmental Agreement and started operations in December that year (Kotlinski et al, 2008). In early 1991 IOM registered as a Pioneer Investor with PrepCom with their Certificate of Registration issued in July 1992. Present IOM member states are: Bulgaria, Cuba, Czech Republic, Poland, Russian Federation, and Slovakia. Past members included Vietnam and East Germany.

After its establishment, the IOM focused on regional geological and geophysical surveys within the CCZ in 1988 and 1989. After surveying 540,000 km^2 (including TOML Area E), IOM's claim with PrepCom concerned 300,000 km^2, all in the eastern part of the CCZ (Figure 6.34). Between 1987 and 2010 they were involved in some 20 research cruises (Stoyanova, 2010).

In the mid to late 90s IOM started research into mining (Figure 6.35, Figure 6.36) and minerals processing.

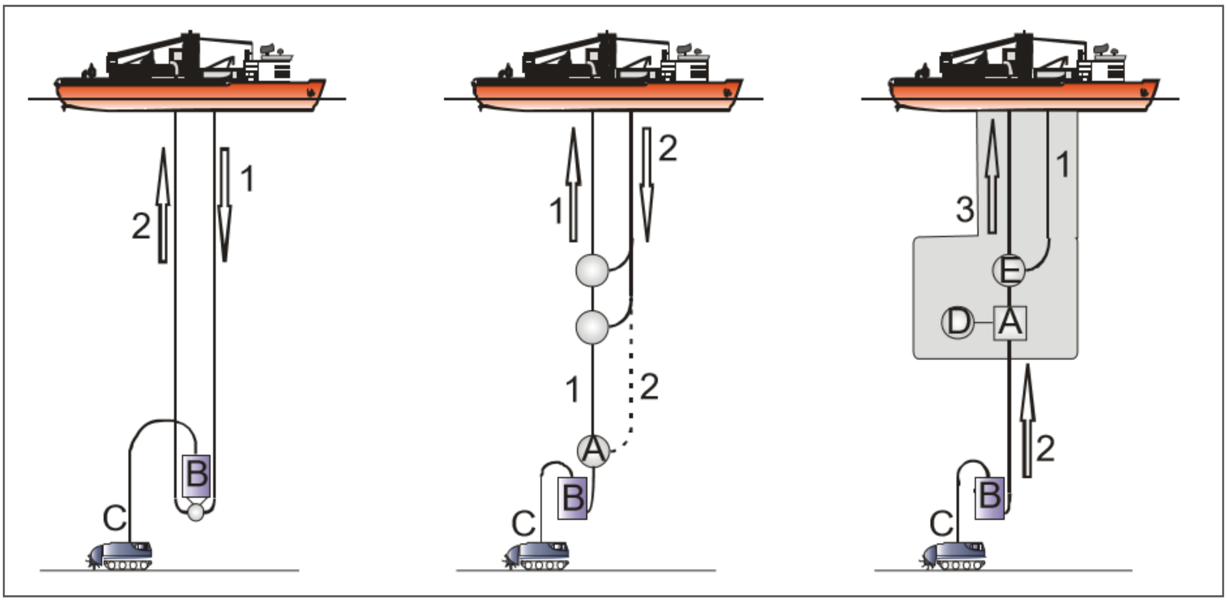
Concept design of a possible mining system included computer simulations of the effects of the marine environment on the mining system, movement of the mining vessel and nodule miner and effects of the movement on the transport rise pipe length paid out, and riser pipe deformation. The simulation showed that the riser pipe shape deformation depends mainly on mining vessel movement speed and can be controlled by horizontal forces applied at low speeds.

Figure 6.34 Progressive reduction in area for Pioneer Investor IOM



Source: Stoyanova (2010)

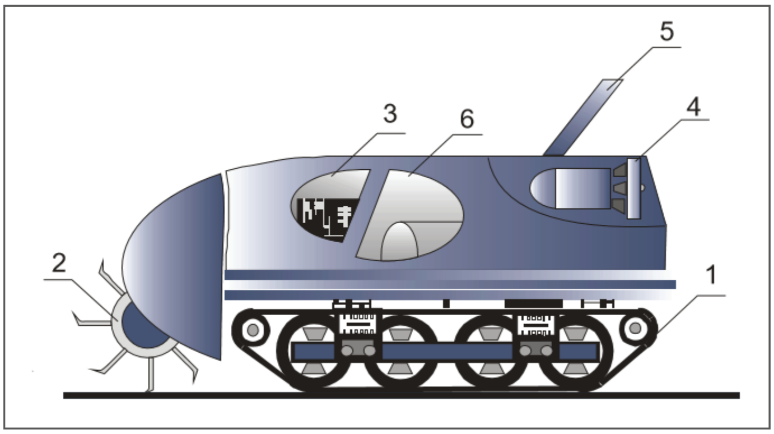
Figure 6.35 Alternative mining lift configurations studied by IOM



Source: Kotlinski et al. 2008; Components of hydraulic lifting mining subsystems. A – crusher, B – buffer, C – collector, D – discharge pump, E – lifting pump, 1, 2, 3 – progress mixture direction

Experiments were also done for nodules of different shapes and sizes for nodule and water velocity measurements at upward flow in the hydraulic laboratory at in the Department of Water Engineering and Hydrotransport of the Agricultural University of Wroclaw, Poland. The mixture phase velocity measurements were carried out with application of radioisotope-tagged natural and synthetic nodules. A volume concentration as high as 10% was used in a pipeline of 150 mm diameter, that could be considered for a trial or commercial system.

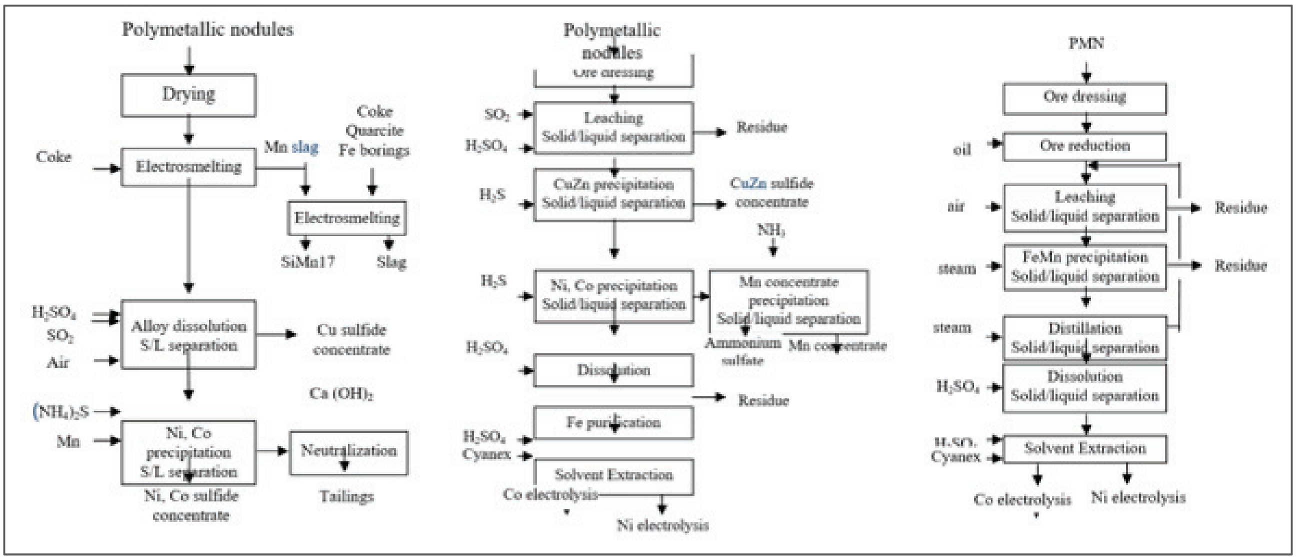
Figure 6.36 Conceptual nodule mining collector designed by IOM



Source: Kotlinski et al. 2008; 1 – caterpillar belts, 2 – collecting devices, 3 – operations and control equipment, 4 – power units, 5 – riser system, 6 – buoyant elements

Metallurgical research included desktop development of a pyro-hydrometallurgical processing circuit at the University of Chemical Technology and Metallurgy, Sofia, Bulgaria and Hutny projekt, Bratislava, Slovakia (Figure 6.37).

Figure 6.37 Preliminary metallurgical processes studied by IOM



Pyro-hydrometallurgical (L), acid leach (C) and ammonia leach (R) processes. Source: Kotlinski et al. 2008

Hydrometallurgical acid leach nodule processing was also studied at CNIGRI Moscow, Russia, including benchtop test-work and hydrometallurgical acid and ammonia leach processing options at the Nickel Research Centre in Moa, Cuba.

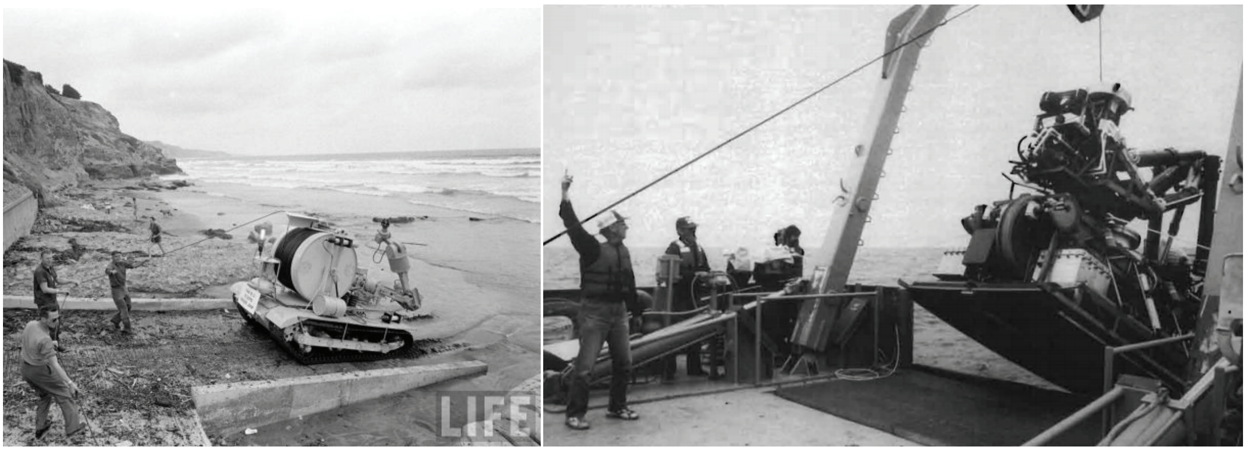
All of the process route options studied gave good metal recoveries but there were clear (unpublished) differences in terms of likely capital and operating costs.

6.3.6 Benthic Impact Experiments

The benthic impact experiments were born out of US environmental studies in the 1970s, including DOMES. The first known disturber system was built in the late 1970s by Sound Ocean Systems Inc (Brockett 2016, pers comm.). This device was configured to be similar to the INCO EH collector but its function was to create near seafloor sediment plumes, not to collect nodules. The device was tested off the coast of Southern California from the R/V Oceanographer. The test results were mixed because while the device seemed to have worked, NOAA was not able to track the sediment plume and little or no sediment was subsequently found in the sediment traps that had been deployed around the site.

In 1988, after a consultative process that started in 1982 (Ozturgut et al, 1997), NOAA decided to pilot a second disturber system, Scripps' RUM III (Remote Underwater Manipulator). This was one a series of pioneering tracked deep water ROVs that were designed for a range of applications and equipped with a manipulator arm (Cyberneticzoo, 2015; Figure 6.38).

Figure 6.38 RUM I undergoing engineering trials off San Diego (L), Recovery of RUM III after engineering trials (R)



Source: Cyberneticzoo, 2015; Scripps (1989)

DOMES site C was subjected to detailed bathymetry and baseline near-bottom current survey and box-cores. Trials with RUM III were done in 1988, 1989 and 1990 but despite modifications RUM III "did not perform as intended" (it was mechanically complex and presumably it did not make a significant plume) and it was decided to try another device.

The third disturber system was formally termed DSSRS (Deep Sea Sediment Re-suspension System; Figure 6.39) and this was developed in conjunction with the Russian Pioneer Investor Yuzhmorgeologiya (YMG). NOAA built and supplied the disturber as well as sediment traps, current meters and samplers, and YMG supplied vessels and crew as well as a long baseline acoustic navigation system and winch and cable.

Figure 6.39 DSSRS Benthic Disturber

Source Tim McGinnis pers comm. (2016)

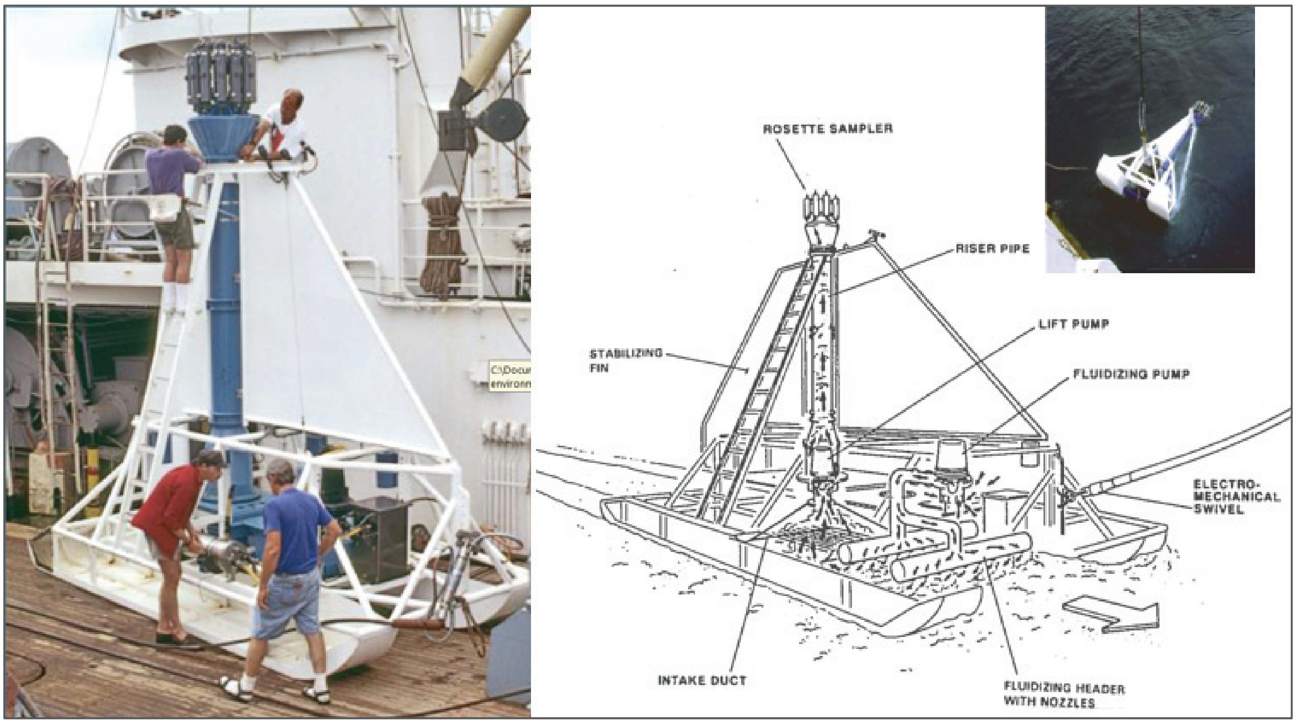
After tests off the California coast in mid-1991 the team moved immediately to the CCZ (within the USA licenses and well south of DOMES C), where baseline survey was conducted before a single trial. Winch problems curtailed the cruise. The following year the team returned and after completing baseline measurements and deploying sediment traps completed 44 tows before conducting post disturbance measurements. Again the disturber "did not work properly due to design problems" (presumably insufficient plume was generated).

After review, including input from Japanese and US Engineers (Brockett and Richards, 1994), NOAA had Sound Ocean Systems build a fourth disturber system, the second generation DSSRS-II (Figure 6.40). This device was specifically designed to lift and then suspend sediments at 5 to 10 m above the seafloor using two 7.6 hp pumps. Testing in early 1993 was followed with a cruise to the CCZ (BIE-II) with YMG, including baseline survey, recovery of the previous year's sediment traps and a programme of 49 tows. This time the disturber worked well and sediment was dispersed. Key conclusions from the trial (Ozturgut et al, 1997) were positive, i.e.:

- Sediment dispersed as a turbidity flow rather than as a low density plume - initial estimates of the far field range of dispersion may have been overestimated;
- Burial of up to 1-2 cm thick appeared not to have the catastrophic effect that was once predicted as both meio- and macrofauna appeared to burrow or recruit to the deep-sea benthos if needed;
- Some questions would remain until a full scale mining test is monitored.

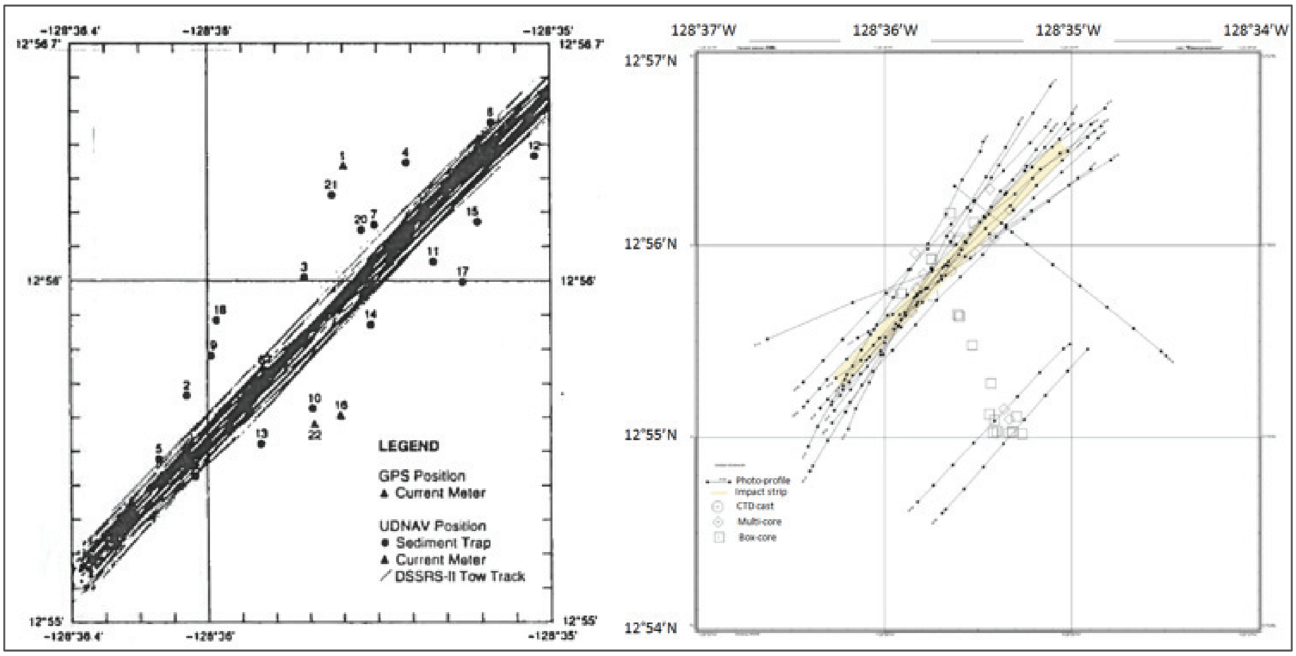
The impact assessment of the site, when revisited after 9 months, indicated that, while some of the meiobenthos showed a decrease in abundance, the macrobenthos showed an increase in their numbers, probably because of increased food availability (Yamazaki, 2011). The site was then revisited again in 2000 by YMG (Figure 6.41) and the key finding was that "Decreasing of macrofauna is observed on physical disturbed areas (on disturber tracks) but not on the areas of re-sedimentation" (Melnik and Lygina, 2010). Note that with a commercial mining system, that sediment from mined areas will be progressively redeposited alongside or immediately behind the collector or concentrator.

Figure 6.40 DSSRS-II Benthic Disturber



Modified from: Stoyanova (2010), Brockett (1994)

Figure 6.41 BIE-II programme and post-trial survey by YMG in 2000



Source: Brockett and Richards (1994); Melnik and Lygina (2010)

Subsequently the DSSRS-II "benthic disturber" was used by several other groups per Table 6.3.

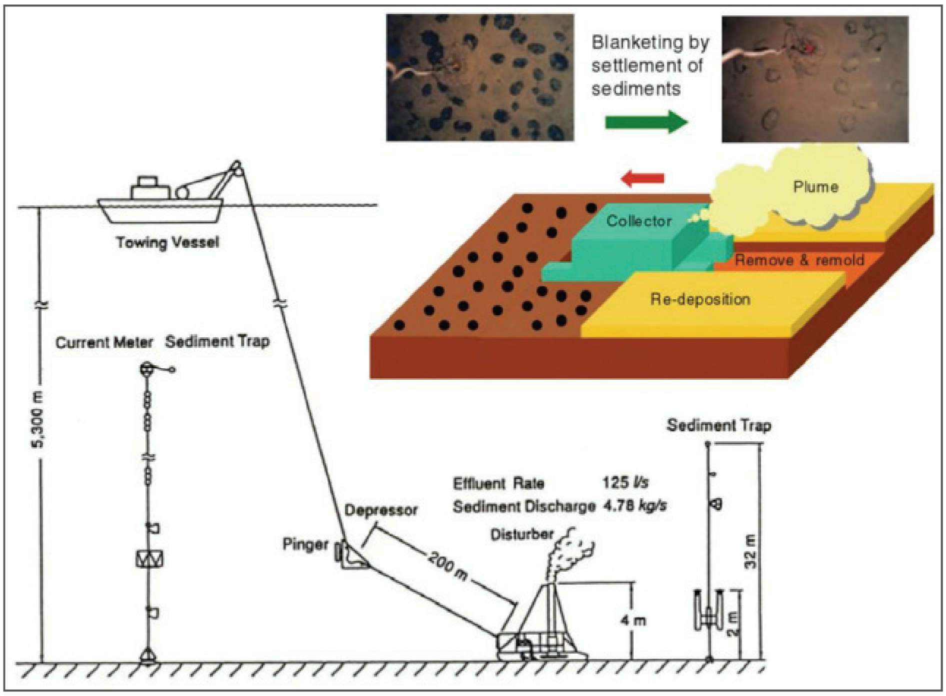
Table 6.3 Benthic Impact Experiments

Experiment (device)	**Year**	**Tows**	**Duration**	**Distance**	**Discharge**
DISCOL – Peru Basin (plough harrow)	1989	78	~12 days	10.8 km^2 (crisscrossed circular area)	?
BIE-II. (DSSRS -II)	1993	49	5290 mins	141 km	6951 m^3
JET (DSSRS -II)	1994	19	1227 mins	33 km	2495 m^3
IOM (DSSRS -II)	1995	14	1130 mins	35 km	2693 m^3
INDEX – Indian Ocean (DSSRS -II)	1997	26	2534 mins	88 km	6015 m^3
DIETS – Marcus Island (6 m wide scraper)	1999	15	?	~15 km	?

Sources: Das (2010), YMG (2010) IOM (2010), Yamazaki (2011)

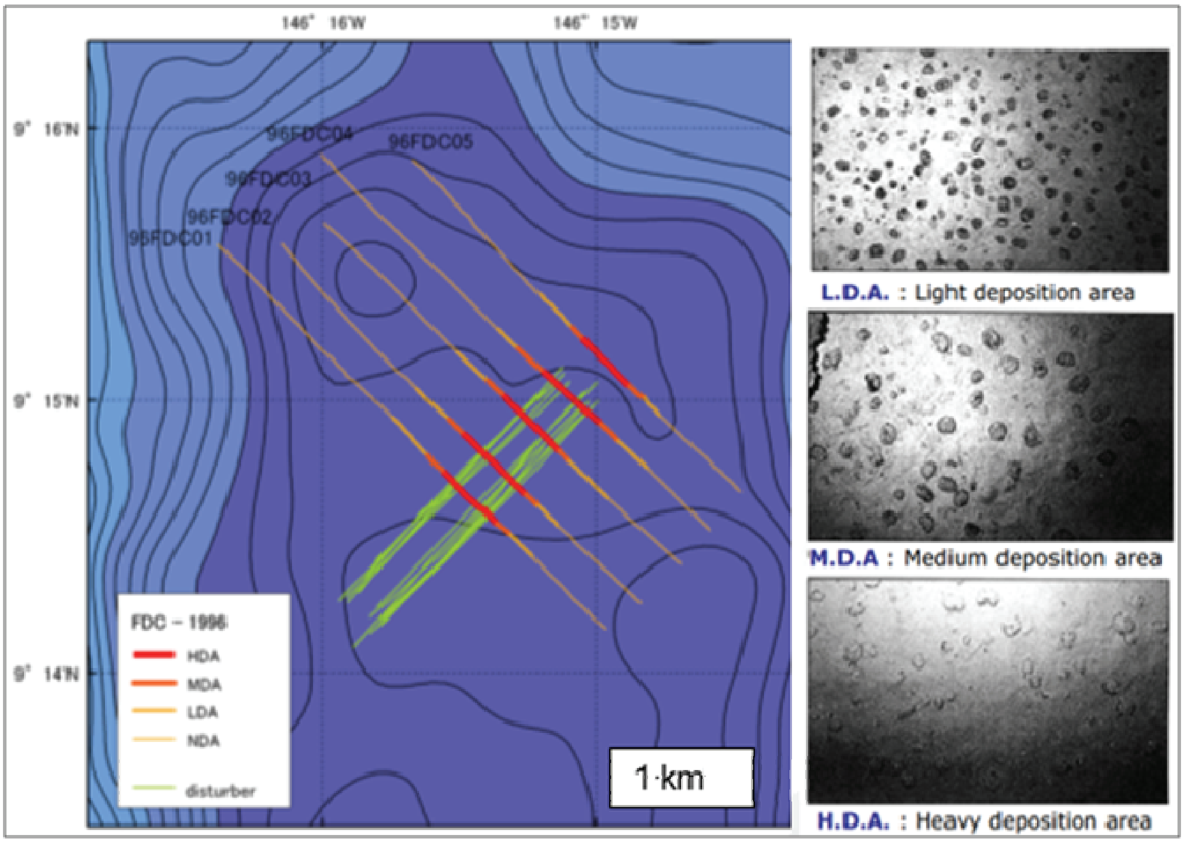
One of the best reported experiments was JET (e.g. Yamazaki et al 1997; Yamazaki and Kajitani, 1999; Yamazaki, 2011; Figure 6.42). This study included baseline data collection, sediment traps, current meters etc, but the Japanese also developed a quantitative photographic analysis method to try and more intensively measure distance of sediment redeposition from the disturbance tracks (Figure 6.43).

Figure 6.42 Schematic arrangement of JET



Source: Yamazaki (2011)

Figure 6.43 Review of the DORD 1994 JET Benthic disturber site in 1996 using a Finder-installed Deep-sea Camera



Source: DORD (2010, 2014). Heavy deposition was defined as >0.26 mm (Yamazaki, 2011). NDA is no deposition.

Post-experiment observations took place just after the experiment (J2 survey), about 1 year later (J3), and about 2 years later (J4), by which stage DORD's main conclusion was that any impact had been significantly reduced. The observations centred around sediment sampling and camera surveys to determine resedimentation impact on the benthos.

Attempts were made to scale up the JET results to full commercial scale, but these were dependent on a number of fundamental assumptions including penetration depth (Yamazaki, 2011).

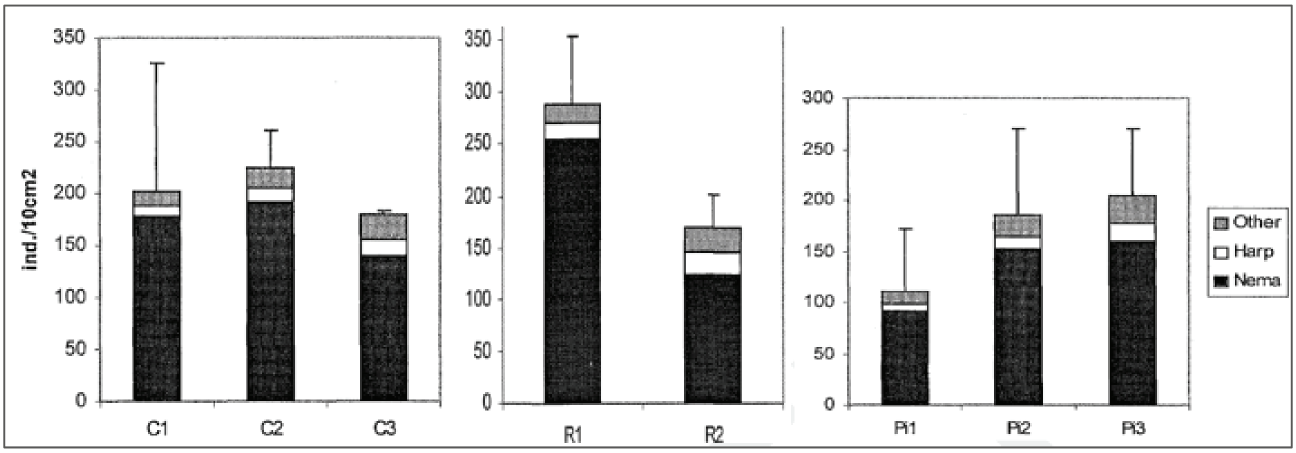
Radziejewska et al (2001) summarised three surveys at the IOM BIE site, namely those of 1995 (immediately pre and post disturbance), 1997 and in 2000. Research on the IOM site essentially:

- Struggled in 1995 to find significant impact to the meiobenthic communities outside of the tracks left by the DSSRS-II;
- Found in 1997 widespread changes (e.g. in nematode familial make-up) as a result of a phytodetritus sedimentation event (likely a natural plankton bloom event) as well as that the tracks were now substantially "leveled off", presumably due to action of currents or bioturbation;
- Found in 2000 that response to the phytodetritus sedimentation event was more or less reversed to the condition at the start of the trial.

Radziejewska et al (2001) interpreted that the implications of this are that:

- Certain significant processes take place in the abyssal communities without human intervention;
- This supports the notion of there being no absolute, inherent stability on the abyssal seafloor;
- These natural processes can induce changes of greater magnitude than induced by the BIE (and by extension potentially by commercial production)
- That quantitative monitoring of mining impacts will be challenged by the naturally occurring variations.

Figure 6.44 IOM BIE meiobethos populations for control, resedimentation and impacted area stations



Source: Radziejewska et al (2001) C1, C2, C3 are control stations in 1995, 1997 and 2000; R1, R2 are resedimentation stations in 1997 and 2000, Pi1, Pi2, Pi3 area impacted stations in 1995, 1997 and 2000. Nema is Phylum Nematoda (round worms), harp is Harpacticoida (copepod crustacean)

Kim et al, (2011) looked at sinking particle flux relationships with ENSO and found up to three fold increase against background during a moderate La Nina event in 2007/08. Significantly with regards to the IOM experiences regarding their BIE site, the winter of 1995 was also a moderate La Nina event (1996 was neutral and 1997 a 'super' el Nino; NOAA NWS, 2016).

6.3.7 Summary Table: Reciprocating States Regime and the Pioneer Investors

A chronological summary of the period of the Reciprocating States Regime (RSR) and the Pioneer Investors is summarised Table 6.4. References are elsewhere in the text above.

Table 6.4 Chronological summary of the period of the Reciprocating States Regime (RSR) and the Pioneer Investors

Years	History of the Discovery & Exploration of Polymetallic Nodules	History of the Law of the Sea and International Seabed Authority
1982	DORD takes over research from DOMA.	Conclusion of the Third United Nations Conference on the Law of the Sea. Canada signs the Law of the Sea on 10/12/1982 (and ratifies it on 7/11/2003). Interim Agreement of the RSR signed
1983	KORDI starts conducting cruises to the western CCZ.	RSR states progress domestic deep-sea mining legislation through the 80s and 90s.
1984		Provisional understanding of the RSR signed. Russia and India register as Pioneer Investors, followed by France and Japan
1987/88	Large scale Soviet cruises cover most of the CCZ in the late 80s and early 90s, including some in conjunction with IOM China intensifies research in the CCZ, Afernod starts detailed work with the NIXONAUT programme including 16 dives with the Nautile GEMONOD belatedly trial an autonomous shuttle carrier in the Mediterranean	Midnight Agreement leads to raft of registrations and re-registrations of Pioneer Investors
1989/90	First set of Benthic Impact Experiments with the RUM III	Secretary General starts consultation to modify Part XI
1992	Second set of BIE with the DSSRS-I	China (COMRA) and IOM register as a Pioneer Investors
1993	Third set of Benthic Impact Experiments with the DSSRS-II	
1994	JET BIE in the Japanese area	The Boat Paper circulates Agreement relating to the implementation of Part XI of the UNCLOS negotiated and signed by almost all parties. UNCLOS comes into force technically a year after Guyana becomes the 60th nation to sign the treaty Canada signs the Agreement relating to the implementation of Part XI on 29 Jul 1994 (and ratifies it on 7 Nov 2003) Korea registers as a Pioneer Investor
1995	Benthic Impact Experiments in the IOM area	

6.4 1996 onwards: The International Seabed Authority

With entry into force of UNCLOS in 1994 the ISA technically came into existence. In actuality the ISA started working as an autonomous international organisation, domiciled in Kingston Jamaica, two years later in June 1996. All signatories of UNCLOS are members of the ISA which operates through the following organs as mandated by UNCLOS.

Odunton (2011) defines three principal organs and two subsidiary organs, namely:

- The Assembly is the supreme organ of the Authority, containing all its members (167 as of January 2015);
- The Council is the executive organ of the Authority, it has 36 members in five geopolitically arranged chambers that are periodically elected by the Assembly;
- The Secretariat is the administrative organ of the Authority and headed by the Secretary General. Amongst other things, it maintains a legal advisory function and a central data repository;
- The Legal and Technical Commission recommends to the council on regulations, applications and protective measures. Its minimum 15 members are elected by the Council from nominated candidates every five years;
- The Finance Committee monitors budget and expenditure and informs and recommends to Assembly and Council the financial implications of operation and plans of work. Its 15 members are elected by Assembly from state nominations (subject to certain guidelines).

In the future they may be joined by an Economic Planning Commission (once exploitation commences) and the Enterprise (the ISA's own mining division; ISA, 1994).

As per UNCLOS the Authority has four main functions. Essentially these are:

1 To administer the mineral resources of the seabed in the Area (currently to comprise polymetallic nodules, polymetallic sulphides and cobalt-rich crusts);
2 To enact rules, regulations and procedures relating to these resources;
3 To promote and encourage marine scientific research and development in the Area (e.g. ISA, 2001a);
4 To protect and conserve the natural resources of the Area and prevent significant damage to the environment.

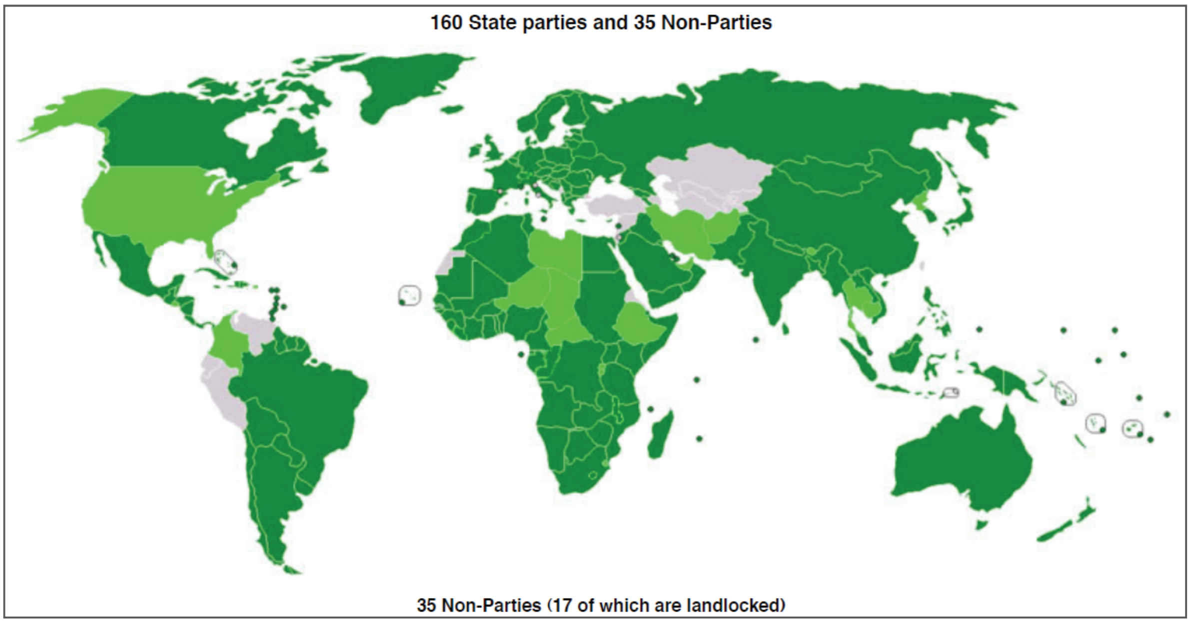
As well as the ISA, UNCLOS mandated the International Tribunal of the Law of the Sea (ITLOS; https://www.itlos.org/). The structure of ITLOS was planned by PrepCom and the tribunal established shortly after UNCLOS entered into force (it is domiciled in Hamburg, Germany). ITLOS deals with disputes and judgement arising from all areas covered by UNCLOS.

In 2011 the ISA Assembly agreed that preparations should start on the formulation of a mining code for exploitation of deep-sea minerals in the international seabed Area (SB/17/18). The first draft for debate is due July 2016, following on from two exploitation regulation related stakeholder surveys conducted by the ISA in 2014 & 2015.

The entire ISA meets only once per year (originally in April and now in July) but from 2014 a second meeting for the LTC was established in February. This was in response to a significant increase in applications at that time for both polymetallic nodules (Figure 6.46) and other minerals. A full list of current CCZ contract holders and approved applicants comprises Item 23.

In 2016 the U.S.A. has still not ratified UNCLOS despite the desire of some stakeholders, e.g. the US Navy and the incumbent President (JAG, 2015; Figure 6.45). A description of US debate on the subject, including the "24 star" and "33 star" hearings as well as the influence of topical domestic politics can be found at Wikipedia (2016). In 2011, Lockheed Martin Corporation successfully applied for an extension to the USA-1 and USA-4 licenses (which originally notionally lasted until 2004) that it holds under the US Deep Seabed Hard Minerals Resources Act as administered by NOAA. This included submission of an amended two phase work plan and with portions subject to market conditions (GPO, 2011).

Figure 6.45 UNCLOS parties and signatories October 2010



Source: Rule of Law Committee for the Oceans (Dark green signed and ratified, light green signed not ratified, grey not signed)

Since 1999 the ISA has promoted exchange of information, environmental science best practice and technology regarding CCZ nodules amongst the contractors using a series of workshops, namely:

- Proposed Technologies for Mining Deep-Seabed Polymetallic Nodules, Kingston Jamaica 3-6 August 1999
- Polymetallic Nodule Mining Technology - Current Status And Challenges Ahead - National Institute Of Ocean Technology, Chennai India 18 - 22 February 2008
- The Results of a Project to Develop a Geological Model of Polymetallic Nodule Deposits in the Clarion-Clipperton Zone, Kingston, Jamaica 14-17 December, 2009
- The Establishment of a Regional Environmental Management Plan for The Clarion Clipperton Zone in the Central Pacific, Kingston, Jamaica 8 – 12 November, 2010
- Environmental Management Needs for Exploration and Exploitation of Deep Seabed Minerals Fiji Islands 29 November – 2 December 2011
- Standardise Megafaunal Taxonomy for Exploration Contract Areas in the Clarion-Clipperton Fracture Zone Wilhelmshaven, Germany 10 - 15, 2013
- Polymetallic Nodules Resource Classification Goa, India 13 - 17 October 2014
- Standardize Macrofaunal Taxonomy for Polymetallic Nodules Exploration Areas in the Clarion-Clipperton Zone Gyeongsangbuk-Do, Korea 23 - 30 November 2014
- Mineral exploitation in the Area – joint Center for International Law - ISA Workshop, Singapore 16-17 June 2015
- Standardize Meiofaunal Taxonomy for Deep-Sea Exploration Areas Ghent, Belgium 14 to 17 December 2015

Agendas, abstracts, presentations and in some cases video of the presentations can be downloaded for many of these workshops at https://www.isa.org.jm/workshops.

The workshops canvas the knowledge and opinions of independent experts and contractors to the ISA and usually result in either a technical summary or set of operational guidelines from the LTC for the contractors reference.

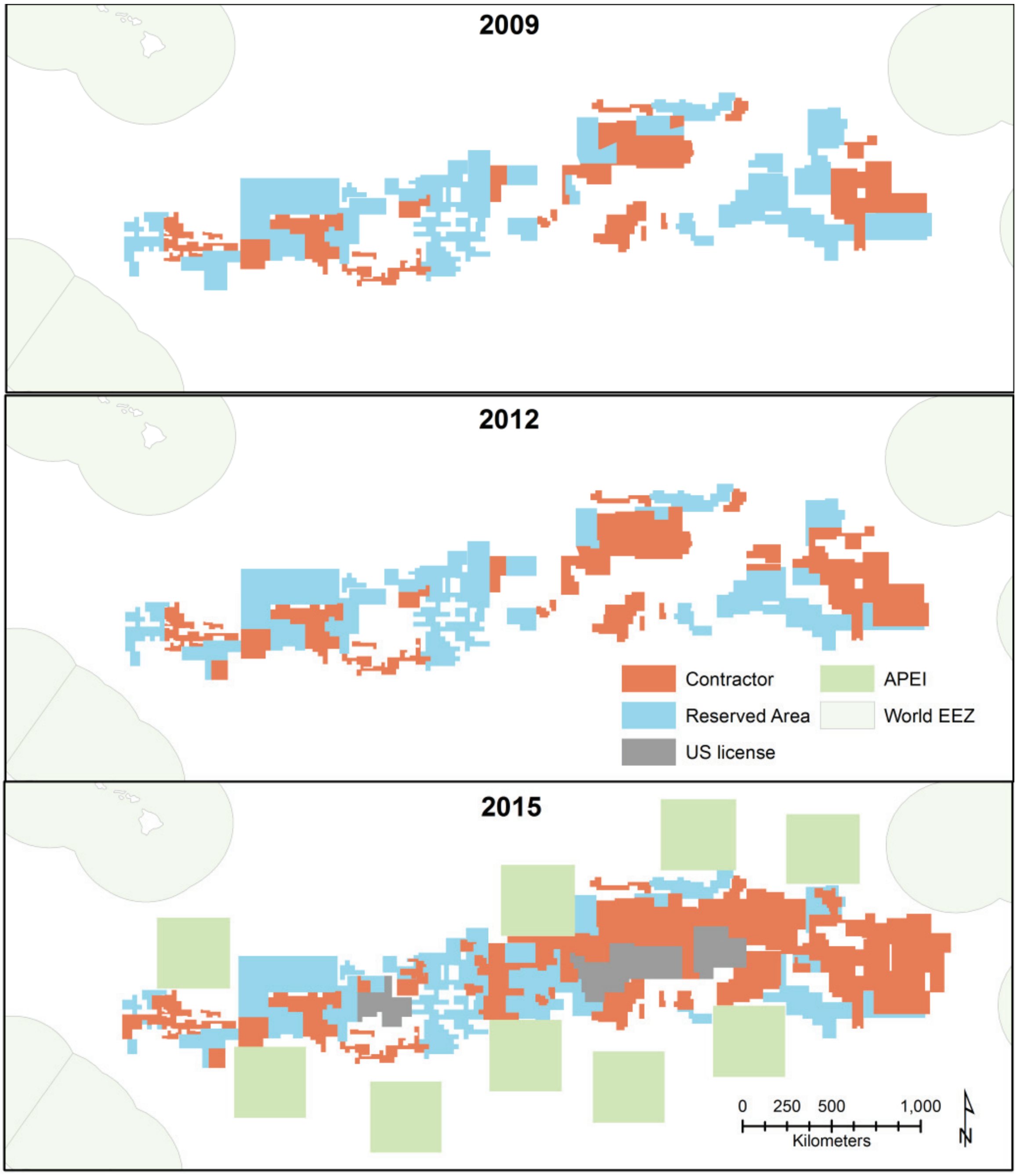
The ISA has also produced a series of over two dozen Technical Studies, Brochures and Briefing Papers, that are referred to, as relevant, elsewhere in this report but that can downloaded at https://www.isa.org.jm/documents-resources/publications.

The ISA has consulted widely with stakeholders including industry, government and marine scientists and non-governmental organisations regarding process for contractors to obtain environmental permits prior to commerical production. While this process is not yet finalised, it appears that the ISA is considering a fairly government-industry standard of the operator supplying an acceptable Environmental Impact Study based on environmental baseline studies, then working to an approved Environmental Management Plan.

The Kaplan Project (see below) and the 2010 workshop on the Regional Environmental Management Plan for the CCZ led to a 2012 Council decision (ISBA/18/C/22) to establish Areas of Particular Environmental Interest (APEIs; Figure 6.46). While each APEI was originally planned as 200 x 200 km blocks with a 100 km buffer aside (e.g. Smith et al, 2010), these were formalised by the ISA as uniform 400 x 400 km blocks (ISA 2012b).

The 2014 workshop on polymetallic nodule resource classification has particular relevance to this report. After that workshop the ISA decided to require reporting of all contractors to a customised CRIRSCO (Committee for Mineral Reserves International Reporting Standards) template (Annex V in ISA, 2015c). The Canadian Institute of Mining Metallurgy and Petroleum or CIM (NI 43-101) is a member of CRIRSCO.

Figure 6.46 Recent growth in seabed claims in the CCZ



Sources: www.isa.org.jm; NOAA (2016)

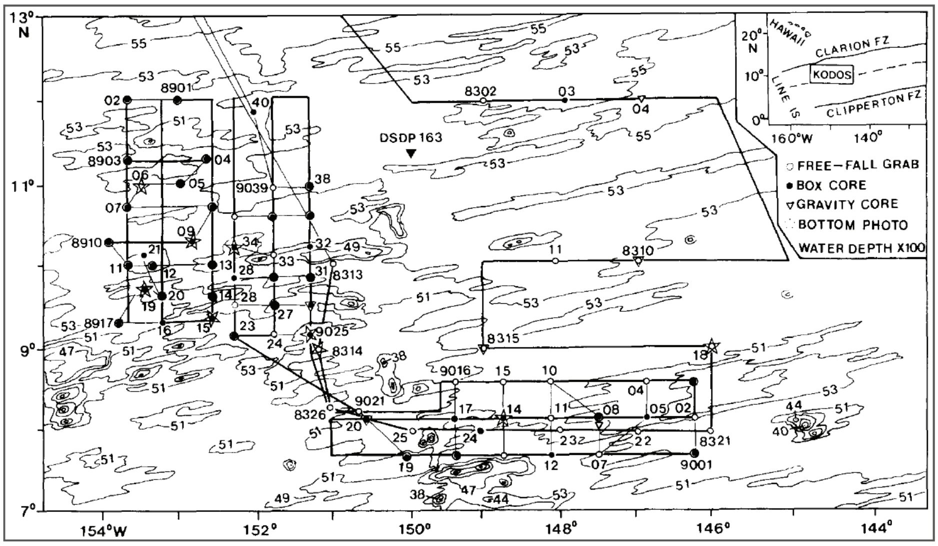
To meet its objectives, the ISA also conducts a range of other meetings and consultations outside of annual meetings and workshops. These include receiving official guests, addressing the UN, sensitisation seminars, attendance at third party meetings and interviews.

6.4.1 Korean Research Groups

Korean Ocean Research and Development Institute (KORDI) was established in 1973, with a broad mandate for Korean interests in marine science and engineering.

Work on CCZ nodules began as early as 1983 with three cruises to the western CCZ in what was called the KODOS Area (Korea Deep Ocean Study; Jeong et al., 1994; Jung et al., 1997; Figure 6.47). This was followed up with two in 1989/90 in collaboration with the University of Hawaii (Kang, 2008). A combination of samples, bathymetry and seismic data was collected.

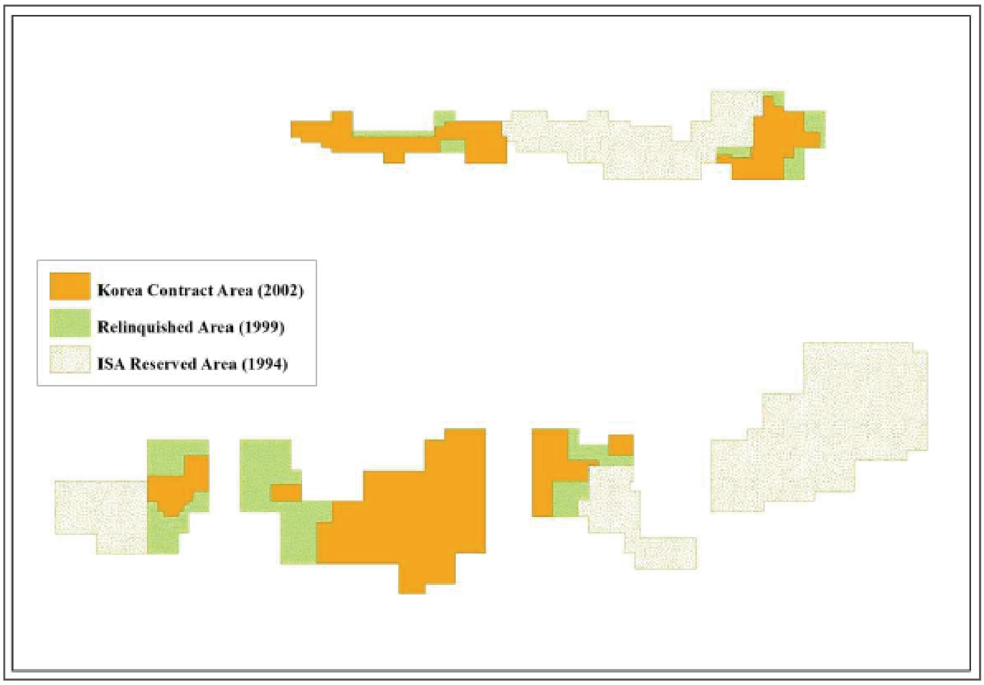
Figure 6.47 Early Korean work in the CCZ



Source: Jeong, et al. (1994)

The Korean government decided to commit to nodules in 1991 and in 1994 the Government of Korea registered as a Pioneer Investor with PrepCom, but the areas considered were central and eastern parts of the CCZ. In line with the terms extended to the Pioneer Investors, this area was progressively reduced through the 1990s and 2000s (Figure 6.48). The Korea Institute of Geology, Mining and Materials (KIGAM) and the Korea Mining Promotion Corporation (KMPC) joined KORDI to cooperate in this survey programme.

Figure 6.48 Korean contract area reduction in the CCZ

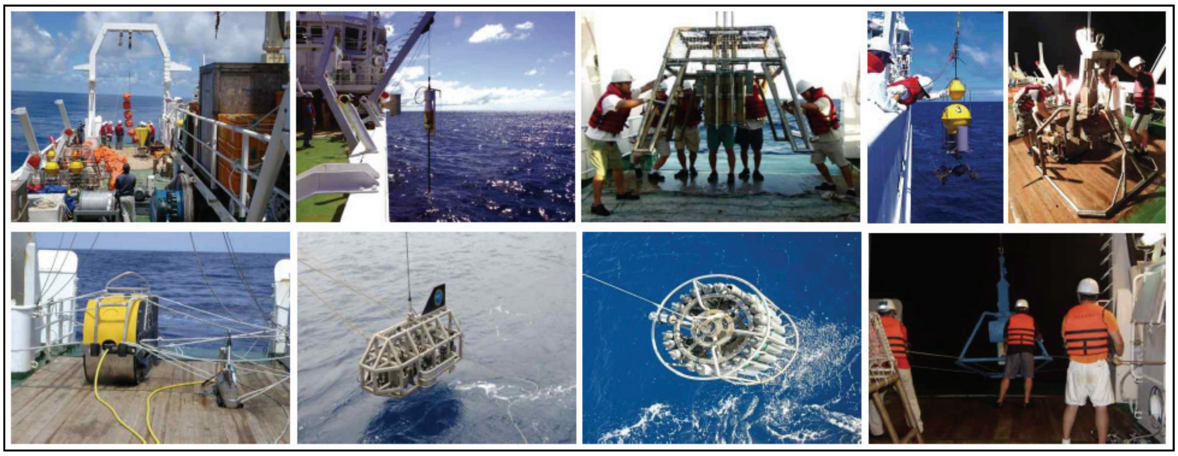


Source: KIOST (2014)

Between 1995 and 2002, KORDI focused on exploring their contract area defining mineral inventory of some 510 Mt (Kang, 2008; Figure 6.49) and environmental baseline data collection (KIOST, 2014). Exploration, environment and mine development programmes were consolidated under one government ministry.

Since 2002 their focus on environmental studies has increased, including research into a Priority Mining Area and preparations for a benthic impact experiment (KIOST, 2014). This has included detailed towed sonar surveys and sampling.

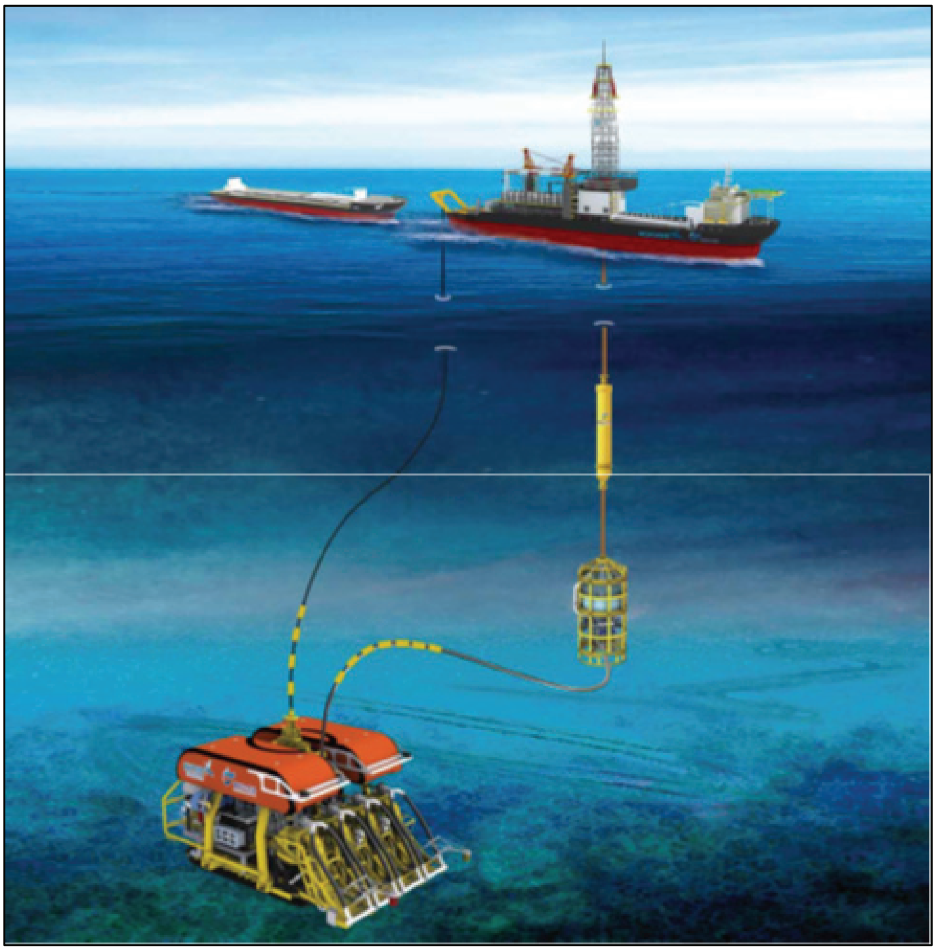
Figure 6.49 Korean researchers have used a wide array of exploration tools



Source: KIOST (2014)

KORDI became KIOST (Korean Institute of Ocean Science and Technology) in mid-2012 and in recent times development of their advanced mining concept has been managed by KRISO (Korea Research Institute of Ships & Ocean Engineering).

Figure 6.50 Korean mining concept – pilot scale subsea devices shown



Source: KIOST (2014)

The concept involves a track driver collector with colander electro-hydraulic heads feeding a sub-sea buffer with inline pumps delivering to a surface vessel (Figure 6.50). As of 2015 all of the sub-sea components had been built at a pilot scale and tested in relatively shallow waters.

Lab (pool) scale testing was conducted between 2002 and 2010, as well as shallow water tests in 2009 and 2010 with a first generation device (MineRo-I). Collector efficiencies as high as 95% were achieved when the collector head was manually adjusted in terms of height above the seafloor.

Sea trials with the second generation MineRo-II were conducted in 2012 & 2013, with shallow water tracking tests (130 m) followed by a simpler deep water test (1370 m). The shallow water test included collection and subsea crushing of seeded nodules (KIOST, 2014). Sea-trials of the buffer and lift system were completed in late 2015.

6.4.2 The first exploration contracts with the Pioneer Investors

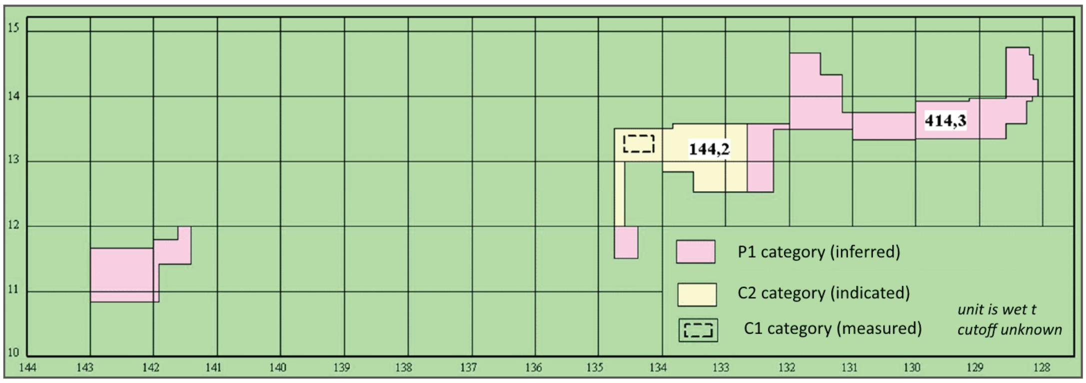
By 2001 the ISA had exploration regulations (ISBA-6A-18; ISA, 2000a) and guidelines to a stage that exploration contracts could be signed with the Pioneer Investors as their initial term of exploration and reduction of areas was complete. During the year CCZ oriented exploration contracts were duly signed with COMRA, Yuzhmorgeologiya, IOM, DORD, Ifremer and the Korean government (Item 23).

During these new exploration contract periods, all of the contractors are thought to have conducted broadly similar programmes (e.g. as reported in the 2010 environmental and 2014 resource workshops mentioned above), essentially:

- Cruises on a roughly an annual basis;
- Emphasis on environmental baseline survey (biology and oceanographic measurements);
- More detailed survey on PMAs or in some cases a systematic basis across their entire area (Figure 6.51).

In the annual council session in 2015, agreement was reached to renew these 15 year contracts for an additional period if “for reasons beyond the contractor's control it has been unable to complete the necessary preparatory work for proceeding to the exploitation stage or if the prevailing economic circumstances do not justify proceeding to the exploitation stage” (SB/21/15; ISA, 2015d).

Figure 6.51 Status of the mineral resource in the Yuzhmorgeologiya contract area by 2014



Source: YMG (2014). mineral resource estimated by YMG and not to NI 43-101 requirements

6.4.3 The new developed nation contractors

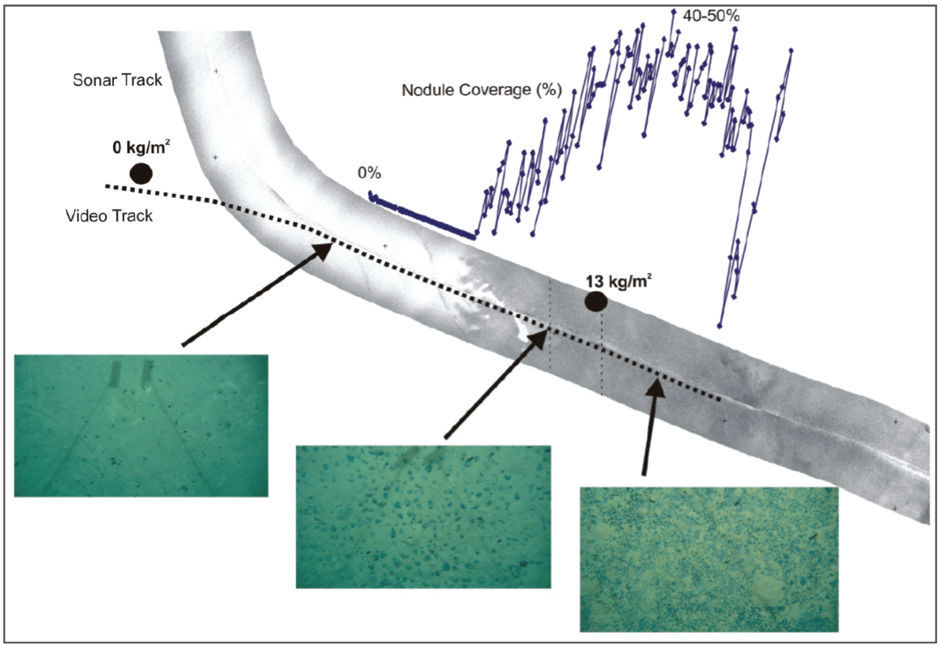
In July 2006, Germany (through its geological survey Bundesanstalt für Geowissenschaften und Rohstoffe or Federal Institute for Geosciences and Natural Resources of Germany (BGR)), received an exploration contract in the CCZ. This was the first contract under UNCLOS not to have been granted to a Pioneer Investor.

Sponsored by Germany as a developed nation, the BGR claimed patrimonial links and supplied historical data of the OMI German license area (Figure 6.23) to define approximately 150,000 km^2 of seabed with half entering the ISA reserved areas and half falling under their contract (Figure 4.1).

Since then the BGR has been an active explorer and developer with numerous publications, including an informal mineral resource estimate (Ruhlemann et al, 2011; Kuhn et al, 2011 and Kuhn et al, 2012). These include modern and well document reestablishment of many of the basic relationships found in the CCZ (e.g.

Figure 6.52) and significant contributions to current geological understanding (Item 7). The BGR is a partner within the JPI Oceans - Ecological Aspects of Deep-Sea Mining project.

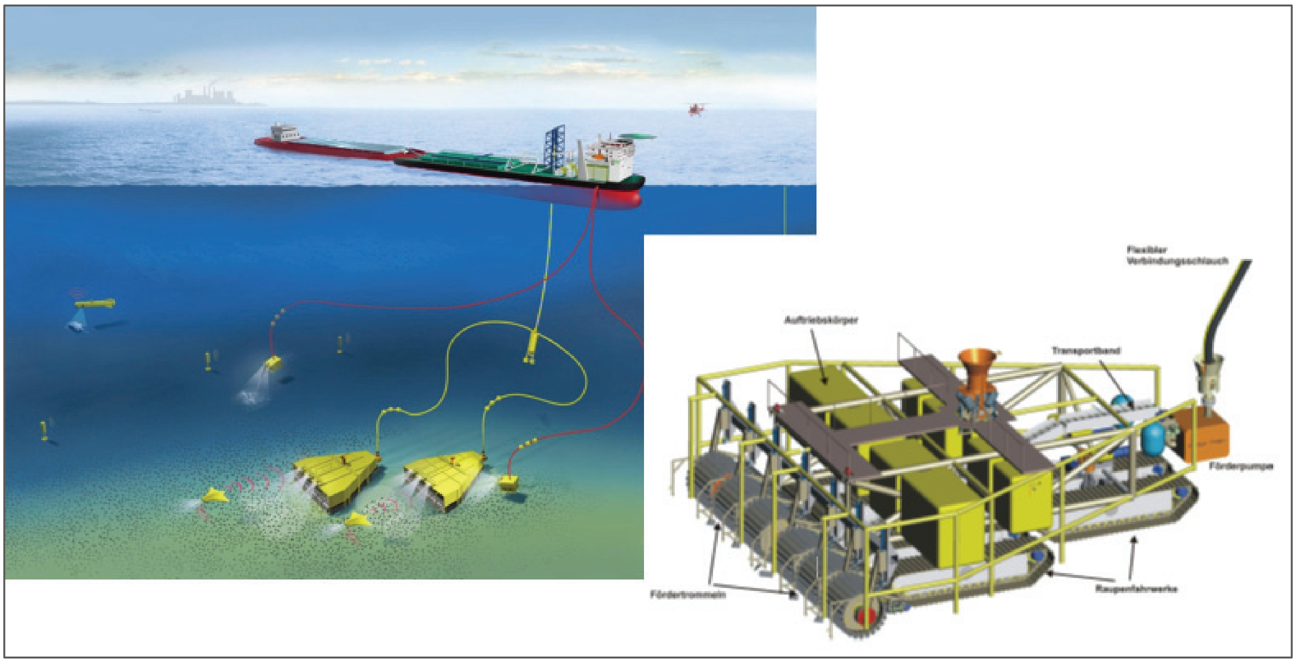
Figure 6.52 BGR correlation between towed camera, towed side-scan sonar and nodule coverage and abundance



Source: Khun et al (2011)

BGR also commissioned preliminary work on mining and processing technology (e.g. Figure 6.53).

Figure 6.53 2012 Aker Wirth - BGR nodule mining concept



Sources: Austmine (2013), Wiedicke et al (2012)

In early 2013, UK Seabed Resources Ltd started an exploration contract in the eastern CCZ. The previous year they submitted an application, sponsored by the United Kingdom, based on the former KCON Frigate Bird area (UK area in Figure 6.23, Figure 6.8). The resultant UK 1 area was 58,000 km^2 (Figure 4.1) and the equivalent returned area was promptly acquired by partner Ocean Minerals Singapore (see below).

Field work to date by UK Seabed seems to have focused on benthic biological baseline studies, specifically two cruises in 2013 and 2015 (AB01 and AB02) that supported the Abyssline Project (http://abyssline.info/). The project is being conducted by a consortium of 7 non-profit academic research institutes (University of Hawaii, USA; Hawaii Pacific University, USA; Natural History Museum, UK; Uni Research, Norway; National Oceanography Centre, UK; Senckenberg Institute, Germany; IRIS, Norway).

Figure 6.54 Training and Relicanthus anemone

Source: http://abyssline.info/

A publicity push by UK Seabed's owner Lockheed Martin and the UK government led to several articles being published including an animated mining and minerals processing concept (Figure 6.55) with strong links to the OMCO pilot (Figure 6.20).

Figure 6.55 2013 UK seabed collector and buffer concepts

Source: Lockheed Martin Videos (2013)

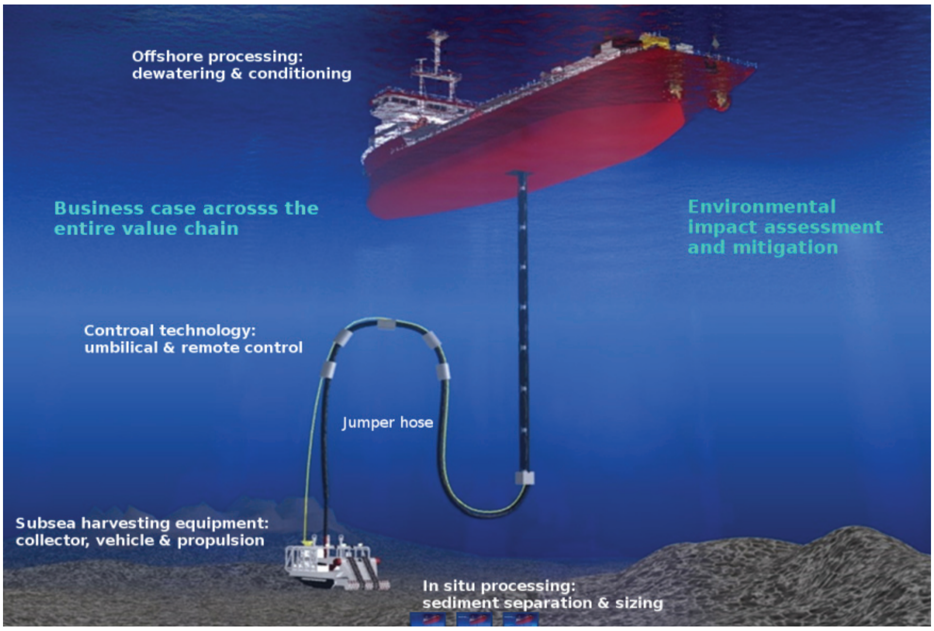
In March 2016, UK Seabed signed a second exploration contract (UK2), this time for an area in the central CCZ (based on former USA-2 area held for OMI (Figure 6.23, Figure 6.8, Figure 4.1). The retained and returned areas are each about 75,000 km^2.

Global Sea Mineral Resources (GSR), formerly G-TEC Sea Mineral Resources, also started an exploration contract in early 2013. GSR is owned by dredging company DEME and sponsored by the Belgian government. GSR successfully claimed patrimonial links to Union Miniere, the Belgian member in the OMA consortium, and retained and returned areas are each about 75,000 km^2 (Figure 4.1) that correspond to the former USA-3 license area (Figure 6.23, Figure 6.8).

The equivalent returned area was promptly acquired by partner Cook Island Investment Corporation (see below).

Since 2013 GSR has mounted at least one cruise of their own (GSR, 2014) with box-coring and multibeam survey. GSR may also have participated in a JPI Oceans cruise to the CCZ in 2014 (see below).

Figure 6.56 Blue Nodules mining concept



Source: http://www.blue-nodules.eu/

GSR worked on nodule mining technology with IHC Merwede forming for some time a group called OceanFlore. More recently both IHC and DEME have joined the “Blue Nodule” initiative (Figure 6.56; http://www.blue-nodules.eu/) along with a wide range of other European companies and research institutions.

6.4.4 The new developing sponsored nation contractors

Nauru Ocean Resource Inc (NORI) started their exploration contract with the ISA in July 2011. The stakeholders in the company are Nauruan and domiciled in Nauru. These are the Nauru Education and Training Foundation and the Nauru Health and Environment Foundation (ISBA/17/C/9; ISA, 2011). NORI conducted a cruise to the CCZ in 2013 that included seafloor mapping and sampling (Figure 6.57).

Figure 6.57 NORI Research

Source: NORI (2013)

Tonga Offshore Mining Limited (TOML) started its exploration contract with the ISA in January 2012. TOML is domiciled in Tonga. TOML is 100% owned by Nautilus Minerals Inc. which so far has supported TOML in terms of managing two cruises to the CCZ, environmental baseline data collection, mineral resource estimation (the main subject of this report) and mining and processing concept studies.

Figure 6.58 Tongan scientists at the mobilisation of a 2015 cruise to the CCZ

Marawa Research and Exploration Ltd started their exploration contract with the ISA in January 2015. Marawa's proposed scientific research and exploration programme will involve seafloor mapping, polymetallic nodule sampling as well as environmental baseline studies and environmental impact assessments in international waters (Marawa, 2012).

Ocean Mineral Singapore Pte Ltd (OMS) started their exploration contract with the ISA in January 2015. OMS is a Singapore-incorporated company majority owned by Keppel Corporation, with minority shareholders being UK Seabed Resources Ltd and Singapore-based private investment company Lion City Capital Partners Pte. Ltd., (Keppel, 2015a). Keppel is, amongst other things, a shipbuilding company, and OMS is sponsored by Singapore which was classified by the UN in 2014 as a developing nation (United Nations, 2014).

Figure 6.59 Excerpts from a Keppel project video

Source: Keppel (2015b)

OMS has collaborated with UK Seabed regarding the second of the Abyssline cruises (AB02; above).

In late 2013 the Cook Islands Investment Corporation (CIIC), sponsored by the Cook Islands applied for a nodule exploration contract in the reserved areas which was duly approved the following year (ISBA/20/LTC/3, ISBA/20/C/18, ISBA/20/C/29). CIIC have a formal arrangement with GSR regarding the area.

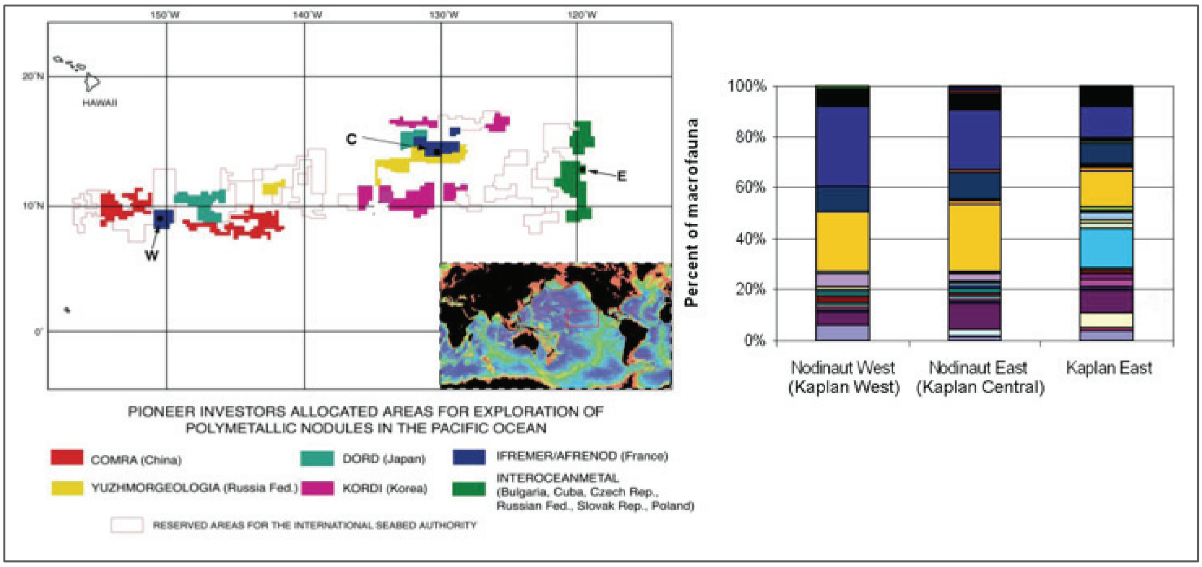
In late 2014 China Minmetals Corporation, sponsored by China, applied for a nodule exploration contract of about 73,000 km^2 in the reserved areas. This was duly approved the following year (ISBA/21/LTC/5, ISBA/21C/L.3).

6.4.5 Environmental Initiatives

The Kaplan Project ran between 2002 and 2007 (ISA, 2008) and focused on biology. During three cruises in 2003 and 2004, it collected fauna samples from three sites (west, central and east) focusing especially on polychaetes, nematodes and foraminifera, with an aim to characterise the biodiversity in the province. Both morphological and genetic taxonomy were carried out.

The programme was perhaps the first after the DOMES study to fully realise the biological diversity present at the scale of the CCZ and difficulties inherent in sampling macro and meiofauna. A project workshop sponsored by the Pew Foundation in 2008 (SOEST, 2007) also moved to recommend the establishment of marine protected areas, that became the APEIs mentioned above.

Figure 6.60 Kaplan sample sites on a historical contractor map and a chart of polychaete familial composition



Source and details: ISA (2008); Familial sample sizes are 99,345 and 253 for Kaplan West, Central and East respectively

The Abyssline project is in some ways the successor to Kaplan, involving many of the same principal scientists. So far however it has focused on the UKSeabed UK-1 and OMS areas as described above.

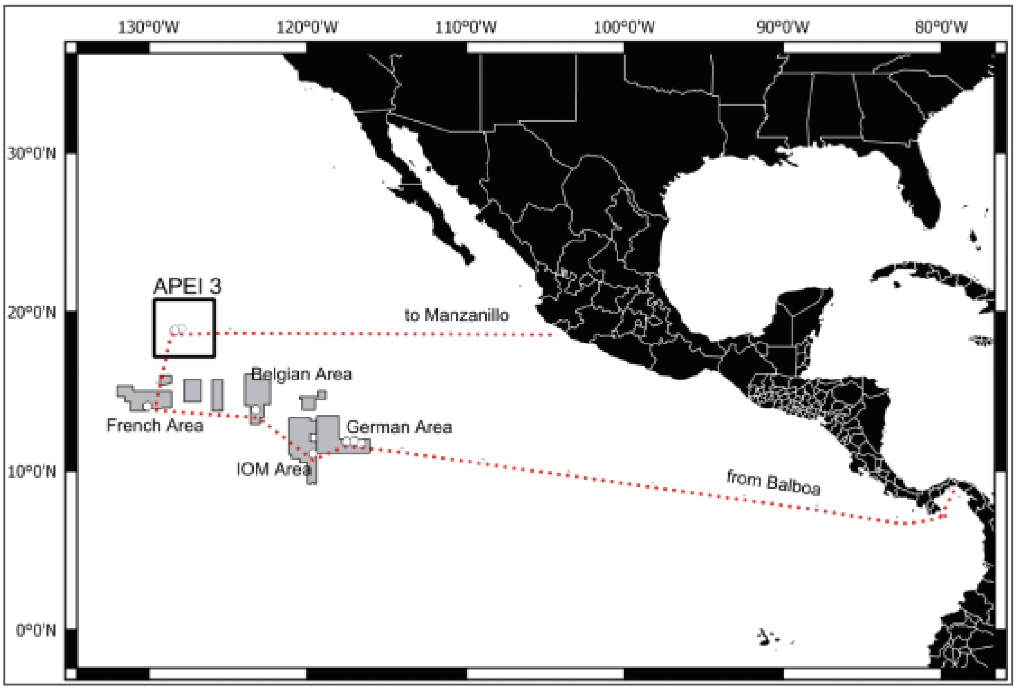
On 19 June 2015 the General Assembly of the UN adapted without a vote resolution A/RES/69/292 - Development of an international legally-binding instrument under the United Nations Convention on the Law of the Sea on the conservation and sustainable use of marine biological diversity of areas beyond national jurisdiction (United Nations, 2015). This resolution calls for a new PrepCom to be established to examine what this instrument could look like and what it would address specifically in addition to the existing environmental parts of UNCLOS. It would take into account the various reports of the Co-Chairs on the work of the relevant Ad Hoc Open-ended Informal Working Group. In due course an intergovernmental conference would review and debate the recommendations of the PrepCom.

The Joint Programming Initiative Healthy and Productive Seas and Oceans (JPI Oceans) is a coordinating and integrating platform, open to all EU Member States and Associated Countries. The platform covers a range of subjects including microplastic pollution in the seas and munitions clearing. The JPI Oceans Pilot Action "Ecological Aspects of Deep-Sea Mining" assesses the ecological impacts which could arise from commercial mining activities in the deep-sea (JPI, 2014).

In 2015 the JPI Oceans programme made three cruises to the Pacific on the R/V Sonne, two to the Peru Basin and one to the Clarion Clipperton Zone (Figure 6.61). The cruise aimed to revisit disturbed and undisturbed sites and utilise a range of sophisticated sampling devices to measure baseline conditions, regional variance and estimate rate of recovery after disturbance.

It is the stated intent of many workers in the CCZ to make environmental data and findings public so the results of the more recent research are awaited with interest.

Figure 6.61 JPI Oceans EcoResponse Cruise to the CCZ in 2015



Source: Martinez Arbizu (2015)

6.4.6 Summary Table: The International Seabed Authority

A chronological summary of the period of the International Seabed Authority is summarised in Table 6.5. References are elsewhere in the text above.

Table 6.5 Chronological summary of the period of the International Seabed Authority

Years	History of the Discovery & Exploration of Polymetallic Nodules	History of the Law of the Sea and International Seabed Authority
1996	Pioneer Investors keep running cruises detailing geology and environmental sampling	ISA starts operating Pioneer Investors progressively reduce their initial 150,000 km2 towards 75,000 km2 over 5 years
1999		First of numerous workshops on various technical, scientific and legal aspects of the CCZ hosted by the ISA
2001		Pioneer Investors sign exploration contracts under exploration regulations with the ISA
2002	Kaplan Project starts with cruises in 2003 and 2004 Koreans start pool testing of pilot miner	
2006		Germany signs a new exploration contract
2011-2015	New contractor run cruises to area Germans advance mining and processing studies in parallel with more detail site surveys The Koreans start sea trials of pilot miner and lift system (component testing in up to 1370 m depth)	A mixture of developed and developing nation sponsored commercial companies sign new exploration contracts. More detailed environmental and reporting guidelines for exploration contractors emerge Decision in the ISA to develop exploitation regulations in 2011 – discussions, stakeholder consultation and drafting follows Lockheed request an extension of USA-1 and USA-4, in 2011 which was duly granted by NOAA in 2012
2015	Independent EcoResponse environmental cruise	UN Resolution on the conservation and sustainable use of marine biological diversity

6.5 Prior Mineral Resource Estimates

6.5.1 ISA 2010

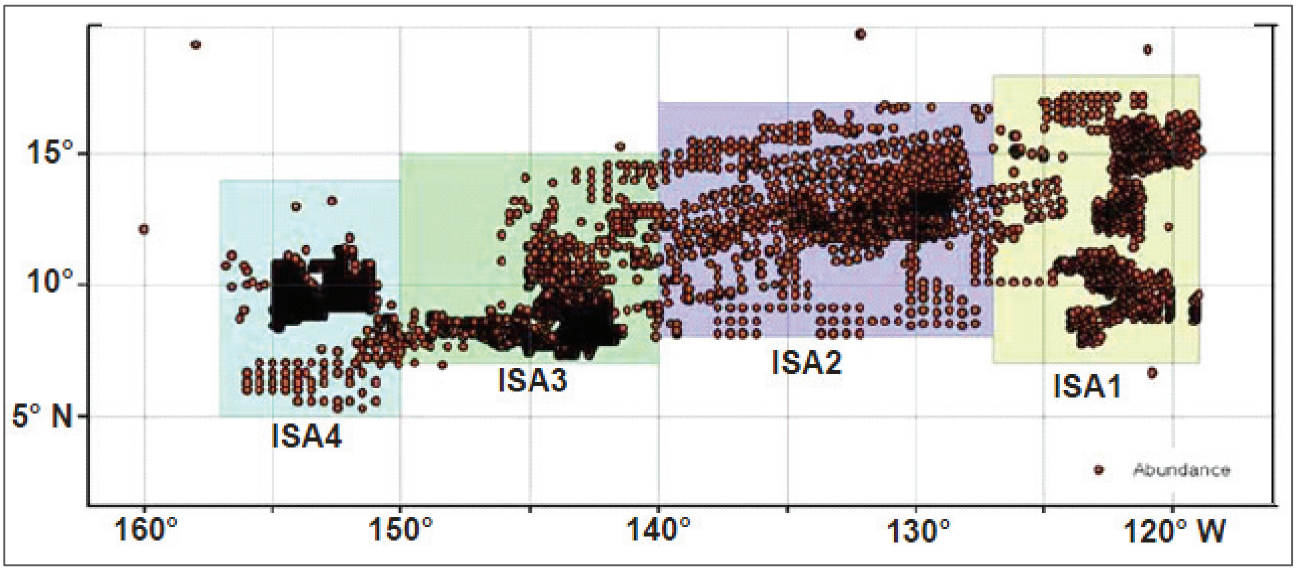
The ISA (2010) published a resource estimate for a large section of the CCZ that includes the TOML Licence Areas. This estimate did not conform to any international resource reporting standards or codes. Though recent, it is considered a "historical estimate" under NI43-101. The data used and the calculation and derivation of the estimate cannot be verified by TOML, and the estimate was undertaken prior to TOML acquiring the TOML Exploration Area. The resource estimate is reported here because it is already publicly reported and is relevant to the TOML Exploration Area in that it demonstrates the significance of the CCZ mineralisation and summarises the average results across the entire CCZ. There is no classification for the ISA estimate since it does not conform to NI43-101.

The estimate combined five different data sets from within 110° to 160° W and 0° to 20° N:

- All publicly available data in the Authority's Central Data Repository (CDR; http://www.isa.org.jm; Polymetallic Nodules - Major elements)
- A proprietary database used with the permission of the Lockheed-Martin Corporation (Ocean Minerals Company; OMCO)
- Data sets provided by the Government of the Republic of Korea
- Data sets provided by the China Ocean Mineral Resources Research and Development Association (COMRA) of China
- Data sets provided by the Interoceanmetal Joint Organization (IOM), composed of Bulgaria, Cuba, the Czech Republic, Poland, the Russian Federation and Slovakia

The data was modelled in four blocks (Figure 6.62) using a variety of methods including ordinary kriging of gridded data and sequential indicator simulation in ArcGIS.

Figure 6.62 Sample data and blocks used for the CCZ-wide Mineral Resource Estimate by ISA (ISA, 2010)



Estimation results are shown below in Table 6.6. Note that the different OK and SIS (Sequential Indicator Simulation) approaches used by ISA (2010) provided a range of nodule tonnage estimates between 23 100 Mwt and 30 700 Mwt. Tonnages were estimated from nodule abundances over the area that falls within one-half of the variogram range for the available sample data. Within the OMCO dataset box core samples results were adjusted (reduced) to estimated equivalent free fall grab recoveries and other datasets were assumed to all be freefall grabs. No correction was made to account for the likely underestimation in nodule abundance from the free fall grab samples.

The ISA estimate of nodule abundance and grade provided in Table 6.6 are not reported under any international code. Since it is not compliant to current reporting codes (such as NI43-101, JORC) no classifications were provided. The historical resource estimate for the total CCZ is provided here only to indicate the size and scale of the nodule deposits in the CCZ and to indicate how the mineralisation was previously defined and supported by an international body providing additional confirmation of the presence of nodules within the CCZ. A qualified person has not done sufficient work to classify this historical estimate as current Mineral Resources or Mineral Reserves and TOML is not treating such estimates as current Mineral Resources or Mineral Reserves.

Table 6.6 Tonnage and Grade of Nodules in the CCZ (ISA, 2010)

Tonnes (Mwt)	Abundance (kg/m^2)	Mn (%)	Co (%)	Ni (%)	Cu (%)
27 100 ± 660	5.58	27.1	0.22	1.25	1.08

6.5.2 Golder 2013

Golder Associates (2012) prepared a NI43-101 technical report for Nautilus Minerals that was updated in 2013 (Golder Associates, 2013). The results are summarised in Table 6.7 and changes with respect to the updated mineral resource reported in Item 14 are included in Item 14.

Table 6.7 2012 Mineral Resource Estimate for the TOML Exploration Areas A-D

Abundance Cut-off (wet kg/m2)	Abundance (wet kg/m2)	Ni (%)	Co (%)	Cu (%)	Mn (%)	Polymetallic Nodules (x106 wet t)
4	8.9	1.2	0.24	1.1	26.9	440
5	9.1	1.2	0.24	1.1	26.9	420
6	9.4	1.2	0.24	1.1	26.9	410
7	9.8	1.2	0.24	1.1	26.8	370
8	10.4	1.2	0.24	1.0	26.7	310

Note that the above Mineral Resource estimate is at an Inferred level of confidence.