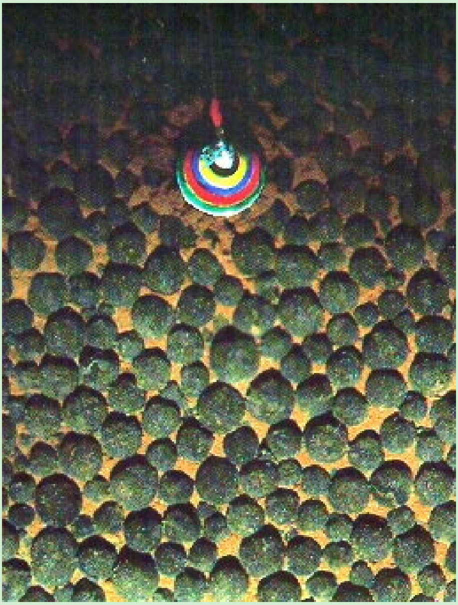
MANGANESE NODULES

of the Cook Islands



by Stuart G. Kingan

COVER PHOTO:

Photo of the sea bottom shows an almost complete coverage by spherical nodules. The abundance is 39.8 kg/m^2 and the photo was taken at 160°00'W 15°59'S.

Manganese Nodules of the Cook Islands

by

Stuart G. Kingan

Published by the

South Pacific Applied Geoscience Commission (SOPAC)

September 1998

Bibliographic Reference:

Kingan, S.G. 1998: Manganese nodules of the Cook Islands.
SOPAC Miscellaneous Report 295. SOPAC Secretariat. iv, 24 pages.
September 1998

ISBN: 982-207-008-x

This booklet is designed to complement the East-West Center study conducted by Dr Allen Clark and others, see Clark & others, 1995 in the list of references at the end of this booklet.

Reprinted August 1999

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ABOUT THE AUTHOR

A New Zealander by birth, Stuart G. Kingan came to the Cook Islands as a radio communications engineer in 1944 to set up an Observatory in Rarotonga for investigating ionospheric conditions. Rarotonga has been home for him since then.

While the Cook Islands became a member of CCOP/SOPAC (now the South Pacific Applied Geoscience Commission [SOPAC]) in 1973, a year after its establishment, Stuart Kingan's association with the organisation began in 1975 and ended with his retirement in 1996.

His involvement with the manganese nodules work in the Cook Islands was in his capacity as scientific research officer for the Government of Cook Islands. Stuart and 'science' were inseparable, and he brought this special giftedness into his service to the betterment of the standard of living of the islanders of his adopted home.

He continued into his retirement to maintain his interests in radio propagation and Cook Islands politics.

INTRODUCTION

This brochure is aimed at creating awareness of the unique resource of very abundant manganese nodules that occur in the EEZ of the Cook Islands.

Manganese nodules are concretions of many metallic oxides that grow on the deep ocean floor. Their genetic process is not fully understood but it is partly chemical with a biological component. The nodules have built up very slowly. In the centre is a small piece of rock or a sharks tooth. Around this the nodules have grown in layers with a cross section like that of an onion. The cover of this brochure shows a sea-bottom photo of abundant nodules and photos of individual nodules and their cross sections. Nodules have absorbed many of the elements present in seawater and contain over seventy elements including practically all metals.

Growth has been very slow, (in the order of about of two millimetres each million years).

Deep-sea mining is attracting new interest with many new technological advances making the mining and processing of nodules much more practical and economically attractive. *The New York Times* announced the beginning of deepsea mining in Papua New Guinea waters (21 December 1997).

Unlike other nodule deposits, Cook Islands nodules have a high cobalt content. In the Cook Islands EEZ, they are conveniently sitting on top of the sediment and in many places are on large plains on the sea floor, facts which could make mining in the Cook Islands very attractive.

In a 1985 Japanese publication (Dawn for Resources in Deep Seabed) it was stated that, in the case of cobalt, 95.2% of known world resources were on the seabed. This was before the full significance of the cobalt in Cook Island nodules had been evaluated.

As the Cook Islands EEZ contains comparable nodules with any other area it is reasonable to suggest after a study of the content of other areas that 25% of nodules in the world are in the Cook Islands and as they are higher in cobalt, it is not an exaggeration to suggest that they contain almost 20% of the worlds known cobalt resource.

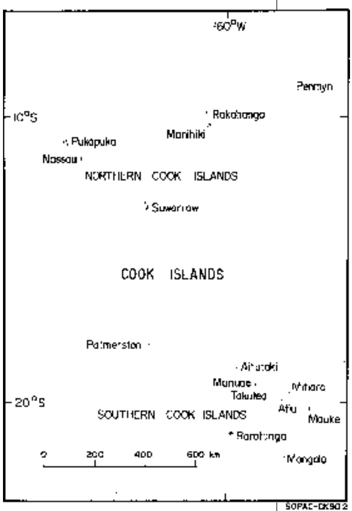
This brochure is an attempt to summarise the knowledge which has been gained in the last twenty years during fourteen SOPAC supported or coordinated cruises in the Cook Islands EEZ. It attempts to give as much detail as possible on the Cook Islands resource in a brief form without discussing mining, processing and economics. It complements the reports produced by PIDP at the East West Centre.

Rarotonga from 2700 metres looking north (Photo Ewan Smith)

THE COOK ISLANDS

The Cook Islands, a self-governing country in the central South Pacific consists of fifteen islands, all islands between 8°S and 23°S and 156°W and 167°W. It is geographically divided into two groups a Northern Group comprising Penrhyn, Rakahanga, Manihiki, Suwarrow, Nassau and Pukapuka. All are atolls except Nassau. The Southern Group comprises Palmerston, Rarotonga, Mangaia, Mauke and Atiu as high islands; Aitutaki a part atoll with a volcanic peak and a large lagoon; Mitiaro an elevated coral island and Manuae and Palmerston atolls. Tukutea is a small island near Atiu.

The Cook Islands, a British Protectorate in the late 19th century, became a colony of New Zealand in 1901 and finally self-governing in 1965. It still works in close association with New Zealand and all Cook Islanders have New Zealand citizenship. The present population is about 17,500, practically all Polynesian. Nearly half the population live on the capital island, Rarotonga, the largest island of 67 square kilometres, Rarotonga is the seat of Government where a Parliament of twenty-five members represents every island and elects a Prime Minister who governs through a Cabinet of eight ministers. The country retains ties with the British Commonwealth through its New Zealand association and the appointed Head of State is the Representative of the Queen.



In recent years, tourism has replaced agriculture as the main industry of the Cook Islands. About 55,000 tourists from all parts of the world now visit the Cook Islands each year. Agriculture, which in the past exported copra, bananas, citrus fruit and pineapples to New Zealand is now mainly concerned with supplying the tourist market. However, significant airfreighting of papaya and vegetables to the New Zealand market continues.

Fishing in Cook Islands nearshore areas is all for the local and tourist markets and forms a large part of the subsistence diet. What in the past was a very significant export trade of black lipped pearl shell from the islands of Manihiki and Penrhyn has now been replaced by the production and export of black pearls from these two islands, following the successful introduction of pearl farming.

Trocus shell is exported from Aitutaki.

United States and Taiwan pay fees for fishing in the Cook Islands EEZ.

EXPLORATION OF THE COOK ISLANDS EEZ

The Cook Islands has a 200 nautical mile EEZ of 2,000,000 square kilometres, more than half of which is deep water (4500 to 5500 meters) containing seabed deposits of manganese nodules.

The presence of these nodules was first reported in the early 1970s by Russian and American research vessels.

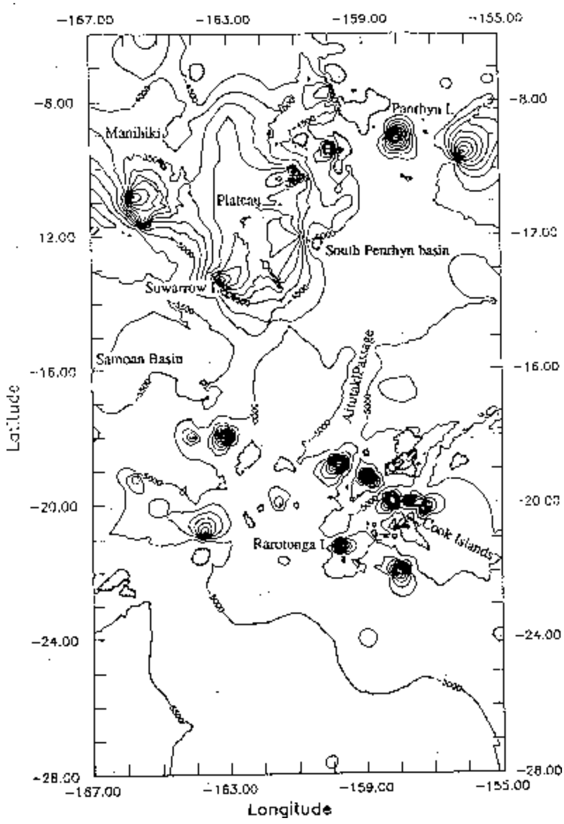
CCOP/SOPAC or the Committee for the Coordination of Offshore Prospecting in the South Pacific was a United Nations funded organisation, whose founding members were the Cook Islands, Fiji, New Zealand, Papua New Guinea, Tonga, and Western Samoa.

Under the United Nations it concentrated on surveys in the South Pacific region either with chartered vessels or by arrangements with research vessels from other countries.

It is now the regional body: South Pacific Applied Geoscience Commission, headquartered in Suva with seventeen member countries - Australia, Cook Islands, Federated States of Micronesia, Fiji Islands, French Polynesia (Associate), Guam, Kiribati, Marshall Islands, New Caledonia (Associate) New Zealand, Niue, Papua New Guinea, Samoa, Solomon Islands, Tonga, Tuvalu and Vanuatu.

Early interest in seabed resources was coincident with the formation of CCOP/SOPAC in 1972. The first CCOP/SOPAC-coordinated cruise into Cook Islands waters was by the NZ Oceanographic Institute using the RV *Tangaroa*. The vessel approached Rarotonga from the south west and ran into significant manganese nodule deposits about 750 km from Rarotonga. These continued until the shallower seas about 90 km from Rarotonga. On its return voyage the vessel went south from Rarotonga, encountering more nodules.

This cruise aroused interest and the need for further surveys became apparent. But CCOP/SOPAC resources were limited. In 1976 the Cook Islands made their small research vessel, RV *Ravakai*, available, CCOP/SOPAC obtained freefall equipment and recorders for deepsea bathymetry and a very successful survey was conducted between Rarotonga and Penrhyn (Landmesser, 1976). High abundances were indicated in dredge samples and sea bottom photos in the South Penrhyn Basin and high cobalt and platinum contents were identified.



Bathymetry of the Cook Islands EEZ

Confirmation of these results was obtained by the French vessel *Coriolis* in two 1977 cruises (Monzier & Misscque, 1977; Recy & others, 1977).

Further work was then conducted by CCOP/SOPAC with the UN chartered vessels *Acheron* in 1977 and *Machias* in 1978 and 1980. The *Acheron* discovered nodules northeast and east of Rarotonga on a rather limited cruise and *Machias* sampled nodules east of the South Penrhyn Basin and west of Suwarrow in 1978 and in the North Penrhyn Basin in 1980.

In 1978 the German research vessel *Sonne* studied nodules west of Rarotonga and up through the Aitutaki Passage to about 17°S.

In 1980 the *Hakurei Maru*, in a transect from the North Pacific to Tahiti and back, made two significant passes through the South Penrhyn Basin. All these efforts had shown the presence of nodules and the need for more detailed surveys.

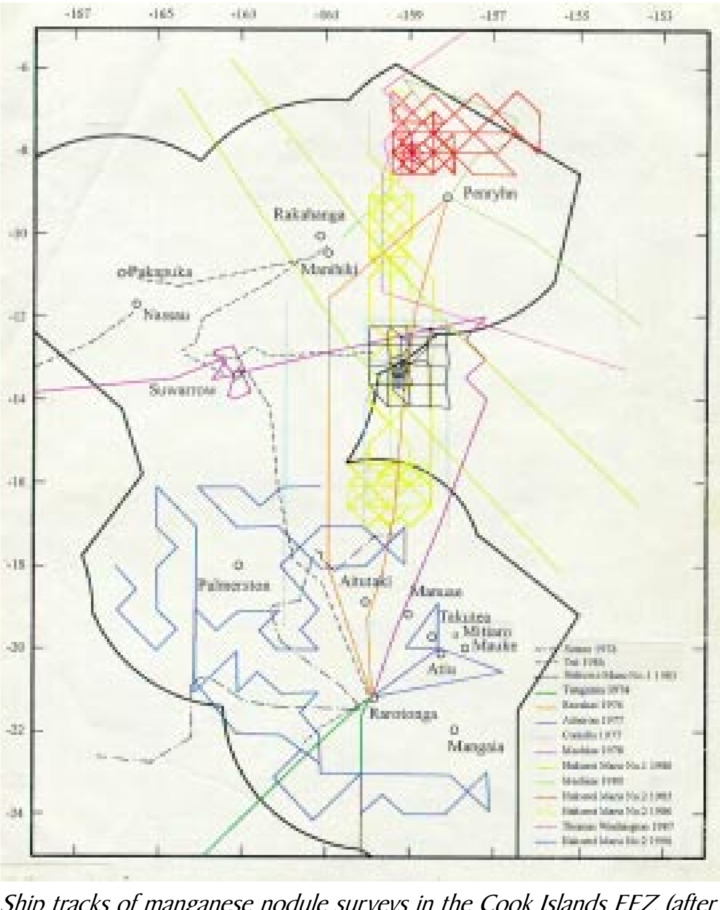
In 1983 the Geological Survey of Japan used the *Hakurei Maru* for a detailed survey in part of the South Penrhyn Basin (Usui, 1994).

CCOP/SOPAC negotiated with Japan a five-year program starting in 1985 for the use of their new survey vessel, *Hakurei Maru No.2*. The first survey in 1985 covered the North Penrhyn Basin (JICA/MMAJ, 1986).

In 1986, the *Hakurei Maru No.2* surveyed the South Penrhyn Basin, confirming the very high abundance of nodules over a large area and the predominance of cobalt in the nodules (JICA & MMAJ, 1987). In 1987, the vessel *Thomas Washington* surveyed the North Penrhyn Basin.

CCOP/SOPAC then negotiated a second five-year program and at the start of this, 1990, a survey of 1,000,000 square kilometres in the southern part of the economic zone was conducted (JICA & MMAJ, 1991). From the available data a study was conducted at the East-West Centre for the Pacific Islands Development Program under Dr Allen Clark with contributions by SOPAC and MMAJ (Clark & others, 1995).

In this study 652,000 km^2 of the Cook Islands Exclusive Economic Zone, where abundances are greater than 5 kg/m^2, were estimated to contain 7,474,000,000 tons of nodules which in turn contain 32,541,000 tons of cobalt, 24,422,000 tons of nickel and 14,057,000 tons of copper. These figures refer to the total resource not what may be recoverable.



Ship tracks of manganese nodule surveys in the Cook Islands EEZ (after Clark & others, 1995).

Resource Quantities and Grade

Table 1 has been prepared based on average grades and the total metal content in this area, approximately one third of the Cook Islands EEZ (referred to as CIZ). Grades for the Clarion Clipperton Zone (CCZ) are included for comparison.

It will be noted that Si, Ti, Al, Ca, K, Pb, V,B and Y have higher grades in the CIZ than the CCZ but that Mg, Ba, Na, P, Sr, Mo & Zn have higher grades in the CCZ.

The Cook Islands nodules are characterised by their very high abundances, some areas have been estimated to have abundances of over 60 kg/m^2 and one bottom photograph showed an abundance of 56.5 kg/m^2.

In the early 1970's the Russian vessel *Vityaz* had reported abundances: as high as 62 kg/m^2 and in the MMAJ report on the 1986 survey the results of the multi-frequency exploration system (MFES) survey indicated abundances of greater than 60 kg/m^2 at two sites, 16°20'S, 159°50'W and 16°30'S, 160°30'W.

The report suggests that the area containing these two sites appears most promising because of this very high abundance and the flat sea floor.

The report also mentions two very good areas, 6200 km^2 between 10°S and 11°S where the average abundance is 20.5 kg/m^2 with a maximum of 34 kg/m^2 and 12,300 km^2 between 15°S and 16°30'S where the average abundance is 24.7 kg/m^2 and the maximum is 34.6 kg/m^2.

During the 1986 survey an area of 237,700 km, was covered and the average abundance was over 17 kg/m^2. The high abundances of over 30 kg/m^2 were shown to be consistent over large distances by the continuous deep sea camera which photographs the bottom every 2 Nm.

Table 1. Cook Islands resource quantities and grade.

Element	Grade CCZ	North CIZ Grade	Middle CIZ Grade	South CIZ Grade	Weight in best 650,000 km^2 CIZ (in million tonnes except where noted)
Mn	25.43	17.99	16.12	14.93	1112.2
Fe	6.66	10.84	17.78	17.22	1198.1
Ni	1.27	.74	.24	.39	24.4
Co	.22	.39	.47	.42	32.5
Cu	1.02	.27	.14	.39	14.0
Si	7.81	12.0	8.9	6.7	650
Ti	.61	.88	1.14	.95	71.5
Al	2.84	3.7	2.9	2.8	226
Mg	1.80	1.32	1.52	1.20	98
Ca	1.47	1.60	1.65	1.63	118
Ba	.32	.07	.10	.12	7.2
Na	1.87	1.62	1.73	1.42	114.7
K	.82	1.03	1.15	.67	68.6
P	.32	.35	.20	.28	20.0
Pb	.048	.070	.102	.089	6.3
Sr	.066	.075	.022	.028	3.0
Mo	.048	.029	.018	.013	1.4
V	.03	.062	.048	.033	3.4
B	.016	.062	.036	.023	2.9
Zn	.13	.044	.035	.054	3.2
Y	.01	.013	.015	.014	1.0
Zr	NA	NA	.063*	.013	2.7
Nb	NA	NA	.0087*	NA	.63
W	NA	NA	.0084*	NA	.61
Pt	NA	NA	.000015*	.000013	1046 tonnes
			**Ravakai* 1976 Cruise		

Although Table 1 gives the total amounts of metals in the study area many of these may not be economically recoverable. Iron and manganese are predominant in quantity but their recovery may prove uneconomic.

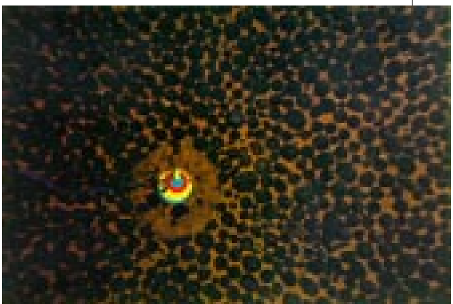
86/09/14

ON-DECK

SAMPLE #	: 86S1436FG01
Latitude	: 13° 00.00'S
Longitude	: 160° 00.02'W
Topography	: Plain flat
Depth	: 5275 m
SBP	: bc (10 m)

Abundance	: 29.41 Kg/m²
Coverage	: on-deck 62.9%
	: bottom 86.3%

BOTTOM



SED. 1	: Brown Clay
Color	: 10YR2/2
Gr. size	: fine

SED. 2	: —
Color	:
Gr. size	:

Size (cm)	0 - 2	2 - 4	4 - 6	6 - 8	8 - 16	16 -	Total/Ave
Wet Weight g	67	1,722	1,892	142	0	0	3,823
Percentage	2	45	49	4	0	0	100
Spc. Gr. (wet)	1.97	1.93	1.97	1.97	–	–	1.95
Ni %	0.32	0.24	0.25	0.23	–	–	0.25
Cu %	0.22	0.13	0.12	0.12	–	–	0.13
Co %	0.42	0.51	0.56	0.51	–	–	0.53
Mn %	16.30	17.36	18.59	17.93	–	–	17.95
Fe %	16.77	18.96	18.35	18.30	–	–	18.60
H_2O %	31.3	31.1	35.2	31.1	–	–	33.1
Shape	P.Sp	Sp	Sp	E	–	–	Sp.E
Single/Poly	25/8	57/10	25/3	1/0	0/0	0/0	S>> P

The following tables give analyses of nodules made in areas of average to high abundance where cobalt grades are above average. Page 9 is extracted from the full report, similar pages are available for several hundred stations, spade core samples and bottom photos are shown.

Size (cm)	0 - 2	2 - 4	2 - 4	4 - 6	6 - 8	8 - 16	Total/Ave
Wet Weight g	104	3,132	504	0	0	0	3,740
Percentage	3	84	13	0	0	0	100
Spc. Gr. (wet)	2.00	1.97	2.00	–	–	–	1.97
Ni %	0.19	0.15	0.16	–	–	–	0.15
Cu %	0.11	0.08	0.08	–	–	–	0.08
Co %	0.46	0.61	0.60	–	–	–	0.60
Mn %	15.60	16.70	16.64	–	–	–	16.86
Fe %	18.40	19.57	19.06	–	–	–	19.47
H_2O %	33.3	32.0	27.8	–	–	–	31.5
Shape	P	Sp.P	Sp	–	–	–	Sp.P
Single/Poly	31/0	124/6	6/20	0/0	0/0	0/0	S>> P

Latitude : 16°00.00'S
Longitude : 160°29.53'W Abundance 28.77 Kg/m^2

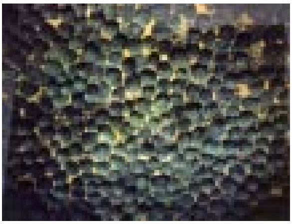
Size (cm)	0 - 2	2 - 4	4 - 6	6 - 8	8 - 16	16 -	Total/Ave
Wet Weight g	142	1.945	1.355	134	0	0	3.576
Percentage	4	54	38	4	0	0	100
Spc. Gr (wet)	1.97	1.94	1.93	1.81	–	–	1.93
Ni %	0.17	0.13	0.12	0.12	–	–	0.13
Cu %	0.11	0.08	0.08	0.08	–	–	0.08
Co %	0.44	0.55	0.53	0.56	–	–	0.54
Mn %	14.59	15.45	15.00	14.85	–	–	15.22
Fe %	17.80	19.91	19.52	18.64	–	–	19.63
H_2O %	28.1	32.0	30.8	30.6	–	–	31.3
Shape	P	Sp.P	E.M	E	–	–	Sp.E
Single/Poly	57/3	114/2	22/0	1/0	0/0	0/0	Single

Latitude : 15°29.26'S
Longitude : 160°01.10'W Abundance 27.51 Kg/m^2

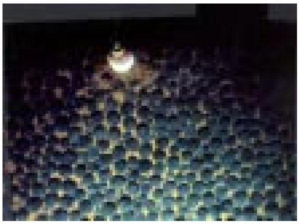
Source: JICA/MMAJ, 1986; 1987; 1991

Research vessels that have conducted manganese nodule surveys in the Cook Islands EEZ:

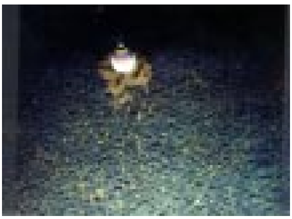
Tangaroa	1974	NZ
Ravakai	1976	Cook Islands
Acheron	1977	CCOP/SOPAC
Coriolis	1977	France
Sonne	1978	Germany
Machias	1978	CCOP/SOPAC
Hakurei Maru	1980	Japan (GSJ)
Machias	1980	CCOP/SOPAC
Hakurei Maru	1983	Japan (GSJ)
Hakurei Maru No. 2	1985	Japan (MMAJ)
Tui	1986	NZ (Tripartite with US & Aust)
Hakurei Maru No. 2	1986	Japan (MMAJ)
Thomas Washington	1987	US (Scripps)
Hakurei Maru No. 2	1990	Japan (MMAJ)



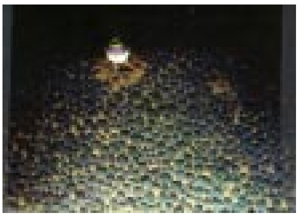
56.5 kg/m² 10°S 159°42'W



55 kg/m² 16°S 159°52'W



27 kg/m² 16°S 159°44'W



35 kg/m² 16°S 159°56'W

The 1990 survey of 1,000,000 km, in the southern area yielded an average abundance of 8.8 kg/m^2. The 1985 survey in the North Penrhyn Basin as well as the 1980 Machias cruise and the 1987 Thomas Washington cruise showed very low abundances but higher grades of Cu and Ni. Only on the western limits of the survey area were there high abundances but lower Cu and Ni grades. But overall the nodule abundances in the CIZ are about double those reported from the CCZ. This is borne out by sample photographs from the CCZ.

Buried nodules are very rare. Nodules nearly all sit on the surface of the sediment.

In 1986 the Hakurei Maru No.2 used a Continuous Deep Sea Camera on two W to E tracks, one at 10ºS and the other at 16ºS. Most significant results of photographs taken at around 1 km spacing on average are the consistently high abundances at 10ºS between 158º52'W and 159º20'W and between 159º14'W and 160º00'W at 16ºS. In one continuous run of 30 km, 53 photographs show abundances of between 26.8 and 55.2 kg/m^2 and an average of 34.9 kg/m^2. Only ten photos are below 30 and five are over 40 kg/m^2.

The highest abundance in the 10ºS track, at 159º42'W, was 56.5 kg/m^2 and is shown across.

Photos shown (across) for the 16ºS track show the highest abundance of 55 kg/m^2 at 159º52W, the lowest of 27 kg/m^2 at 159º44'W and an average one 35 kg/m^2 at 159º56'W.

The coloured weight used to trigger the camera which took the pictures across the page is 10 cm in diameter.

EXPLOITATION

The high abundance in the Cook Islands resource makes it attractive to potential mining operations.

In the past many concepts for mining operations were developed. Some remained theoretical, others were actually tested.

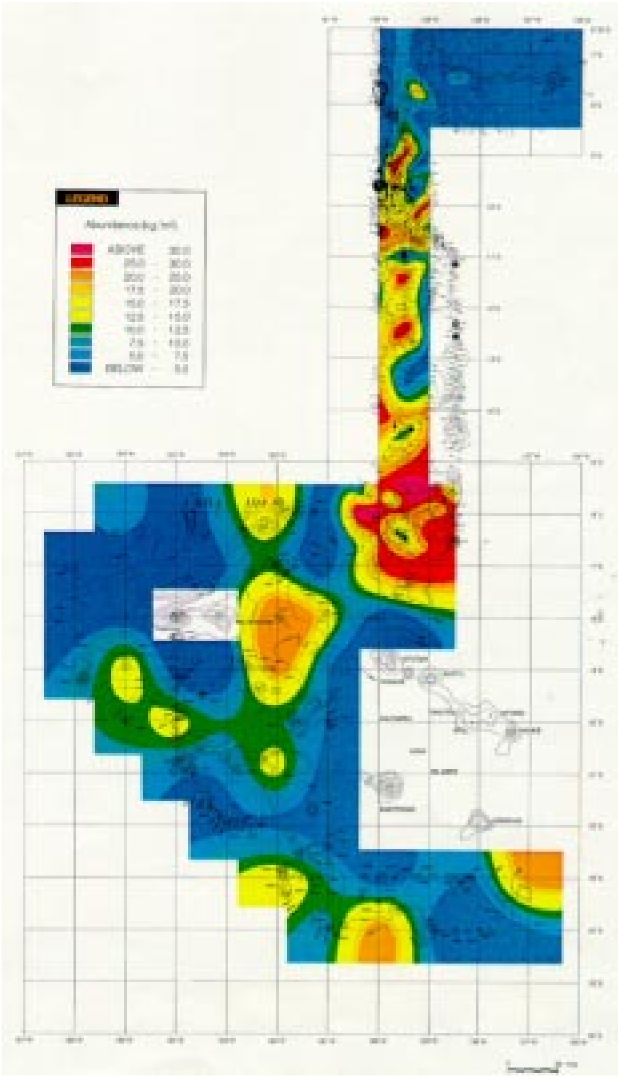
But since these concepts were developed there have been rapid advances in technology, some of which will completely revolutionise future mining, making it much more efficient and economical. More efficient electric motors of less weight and bulk have made remote operations much easier and advances in optic fibre cables have enhanced remote sensing by underwater television.

The Cook Islands is unique, not only in having the largest area of very abundant nodules in the world but of having them in their own EEZ and thus under Cook Islands jurisdiction.

Much has been stated in recent years on the value of cobalt rich crusts. But the crusts would be much more difficult to mine than nodules - they are attached to rocks, not just waiting to be picked up like nodules. Two good reasons given for crust mining have been

1. The high cobalt content and present high price of cobalt.
2. The fact that they occur in the EEZ of many countries such as the Hawaiian Islands, Marshall Islands, Tuvalu, Kiribati, French Polynesia or Cook Islands.

But both these advantages apply to Cook Islands nodules. Table 2 compares the contents of crusts from many parts of the Pacific, (Hein, 1990) and Cook Islands nodules.



Abundance map of manganese nodules

The Cook Islands would appreciate any interest that may be expressed in the resource or any plans for further exploration of their EEZ.

The Cook Islands encourages any future mining operations. Any requests for further information on the resource and any interest in the possible exploitation of it or requests to conduct more research in any particular part of the Cook lslands EEZ should be directed to:

The Secretary
Ministry of Marine Resources
Government of the Cook Islands
Rarotonga
COOK ISLANDS

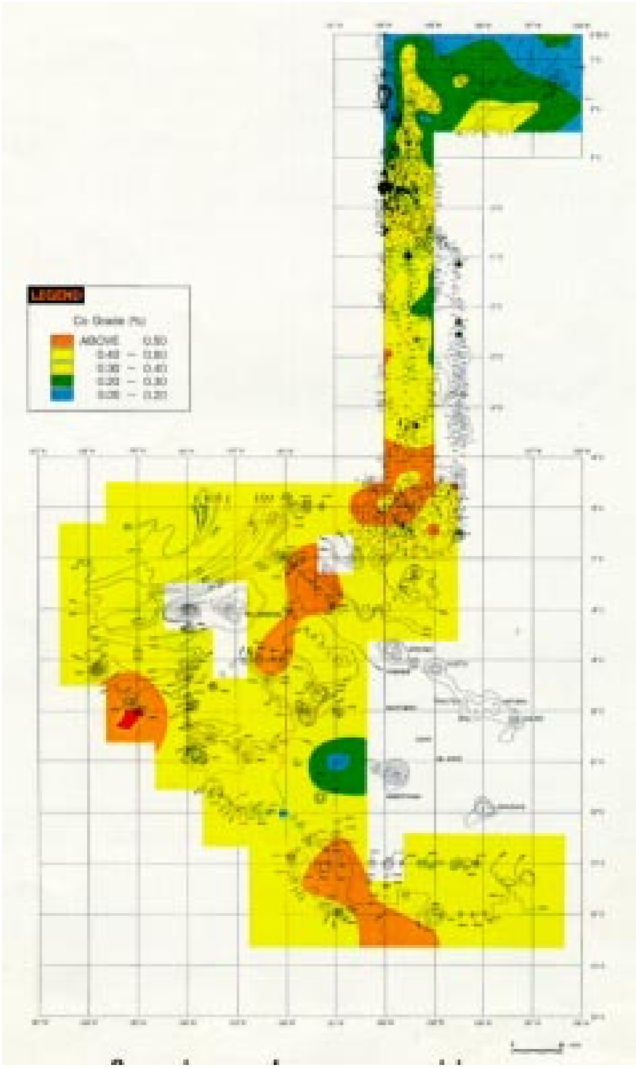
Present policy with regard to any research is that full discussion must be undertaken on any plans and that the Cook Islands appoint a person or persons to actively participate.

Following any research, preliminary findings must be made available to the Ministry within three months and a prearranged number of copies of final cruise reports made available as soon as possible.

Also, the South Pacific Applied Geoscience Commission, (SOPAC), can provide information from their extensive data base and give advice on any proposed research. In this respect correspondence may be directed to

The Director
South Pacific Applied Geoscience Commission
Private Bag, GPO
Suva
FIJI ISLANDS

Full files of the data and photographs from which this report was compiled are at the SOPAC Secretariat (Suva, Fiji Islands) and at the Ministry of Marine Resources, Rarotonga, Cook Islands; as are all other cruise reports produced over the past 20 years.

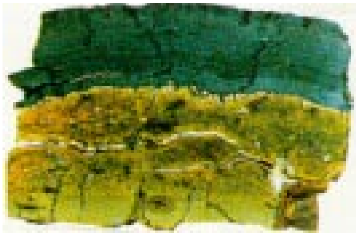


Co grade map of manganese nodules

Table 2. Comparison of crusts and nodules.

Metal and Grade	Mn%	Fe%	Co%	Ni%	Cu%	Pb%	Ti%	Pt PPM
Kiribati Crusts	23	15	.5	.47	.18	.08	.89	–
Marshall Is. Crusts	27	17	.8	.57	.11	.18	1.10	.06
Tokelau Crusts	17	19	.39	.25	.19	.09	–	–
Tuvalu Crusts	28	14	1.25	.73	.08	–	1.14	
French Poly. Crusts	23	16	1.0	.49	.10	–	–	.77
SOPAC area average	24	16	.78	.50	.13	.12	1.04	.42
Cook Is Nodule (Max Co)	16	20	.63	.20	.12	.12	1.24	.5
Cook Is Nodule (Average)	16	18	.45	.31	.19	.09	1.1	.2
Clarion Clipperton Nodule	29	7	.23	1.22	.99	.05	.61	–

The Hakurei Maru No.2, the research vessel that has done most of the work on nodules in the Cook Islands.



A cobalt-rich crust

The Environment

The total resource of nodules in the Cook Islands EEZ is about 14,000,000,000 tons. A mining operation, such as the proposed recovery of 1,500,000 tons of nodules per year, could therefore be sustained for at least 9,000 years. The area mined in the first 1,000 year would only cover an area of about 80,000 km^2, as it would be where the resource is most abundant. Certainly the sea floor life would be disturbed, but a move to another area in the next 1,000 years would allow what remained to recover.

A bigger problem is how to dispose of tailings (96% of the nodules if Manganese and Iron are not recovered). Returning them to the ocean may cause environmental problems.

At the Marine Minerals Technology Centre, Look Laboratory, University of Hawaii, some very interesting research is being conducted under the direction of John Wiltshire into ways of making use of these tailings. By powdering them and heating them with suitable fluxes they have produced very attractive building tiles, by mixing with cement they have produced concrete of greater strength and finer surface texture than normal, and by mixing with suitable epoxies they have produced attractive mouldings. All this work has great potential for the tailings to become a usable and valuable commodity and avoid what might otherwise become a difficult and expensive disposal problem.

Objects made from Tailings

Building tiles and artistic mouldings (see picture below) made with a tailings epoxy mixture, moulded fish made with cement with 30% tailings and ceramic tile with tailings and suitable flux baked in ceramic oven.

Building tiles (top) and artistic mouldings (bottom) made from a tailings epoxy mixture

CONCLUSION

The Cook Islands Exclusive Economic Zone contains the most consistently abundant field of manganese nodules to the found anywhere. Under CCOP/SOPAC (now SOPAC), fourteen exploratory cruises showed the value of this, as yet untapped, resource.

High abundance, high cobalt content and the fact that, unlike other significant nodule fields, they all come under the jurisdiction of the Cook Islands opens the way for the Cook Islands to be one of the world's first areas for deep-sea mining.

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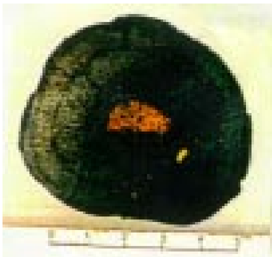
EPILOGUE

Morphology of Manganese Nodules

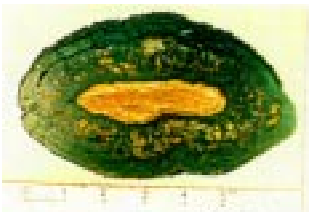
Most common are the Spheroidal referred to in tables as (sp) and Ellipsoidal (E). Besides these the illustration shows Platy (Pt) predominant in some small areas and the very rare Polygonal, referred to as (Poly) and occurring with any type. Very small nodules, say less than 2.5cm are referred to as Pebble (P) and nodules, of irregular shape are referred to as Massive (M).

Spheroidal nodules can be any diameter from 2 to 8cm. Ellipsoidal can be up to 16 cm long. Pebbles and pebble thin nodules are very common often occurring mixed with larger ones.



Spheroidal Nodule

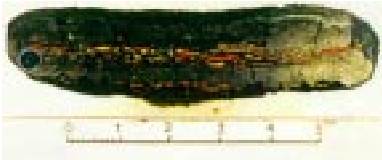
Section



Ellipsoidal Nodule

Section

Platy Nodule



Section

Polygonal/Spheroidal Nodule

Section