JOINT CCOP/SOPAC-IOC FOURTH INTERNATIONAL WORKSHOP ON GEOLOGY, GEOPHYSICS AND MINERAL RESOURCES OF THE SOUTH PACIFIC

24 September - 1 October 1989
Canberra, Australia

PROGRAMME & ABSTRACTS
VOLUME

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PROGRAMME AND ABSTRACTS VOLUME

for the

JOINT CCOP/SOPAC-IOC FOURTH INTERNATIONAL WORKSHOP

ON GEOLOGY, GEOPHYSICS AND MINERAL RESOURCES

OF THE SOUTH PACIFIC

24 September - 1 October 1989

Canberra, Australia

compiled by

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WORKSHOP PROGRAMMME

Sunday: 24th September

14.00-16.00	Member Country and Techsec staff meet
16.00-18.00	Registration
18.30-20.00	Reception

Monday: 25th September

08.30-09.00	Chairman	-	welcoming remarks
	Australia	-	host country and sponsor
	CCOP/SOPAC	-	remarks from Director
	IOC	-	remarks from Representative
	ANU	-	Opening Address

09.00-09.15 Chairman - Introduction to the Workshop

09.15-10.45 Plate Boundary Tectonics (2 papers)

GREENE, H.G.
Exploration for Mineral and Hydrocarbon Resources Along Plate Boundaries in the Southwest Pacific.

KROENKE, L.W.
Tectonic Setting of the Southwest Pacific.

10.45-11.15 Tea

11.15-12.45 Plate Boundary Tectonics (3 papers)

ZONENSHAIN, L.P.
Mussau Ridge, Southwest Pacific: Geology, Origin and Plate Tectonic Setting.

VEDDER. J.G., BRUNS, T.R. and COLWELL, J.B.
Geologic Setting and Petroleum Prospects of Basin Sequences, Offshore Solomon Islands and Eastern Papua New Guinea.

ROGERSON, R. and HILYARD, D.
Scrapland: A Suspect Composite Terrane in Papua New Guinea.

12.45-14.00 Lunch

14.00-15.30 Plate Boundary Tectonics (3 papers)

BINNS, R.A. and SCOTT, S.D, and PACLARK participants
Propagation of Sea-Floor Spreading into Continental Crust, Western Woodlark Basin, Papua New Guinea.

COLEMAN, P.J.
Composite Transient Transform Fault Complexes in Island Arcs: Their Effects on Arc Hydrocarbon and Mineral Resources.

MUSGRAVE, R.J.
Inter and Intra-arc Rotations and Palaeomagnetism in the Southwest Pacific.

15.30-16.00 Tea

16.00-18.00 Plate Boundary Tectonics (4 papers)

DANIEL, J. and SHIPBOARD PARTY
First Results of the Dives of the SUBSPO 1 Cruise.

MAILLET, P., MONZIER, M., EISSEN, J.P. and LOUAT R.
Geodynamics of an Arc-Ridge Junction: The case of the New Hebrides Arc/North Fiji Basin.

URABE, T.
An Overview of the Seafloor Hydrothermal Mineralization in Northwestern Pacific Basin.

KURNOSOV, V.B.
Hydrothermal Processes at Oceanic and Backarc Rifts and Seamounts, and Associated Metals and Phosphates.

Tuesday: 26th September

08.30-10.00 Plate Boundary Tectonics (3 papers)

TANAHASHI, M., KISIMOTO, K., JOSHIMA, M., LAFOY, Y., HONZA, E. and AUZENDE, J.M.
Geological Structure of the North Fiji Basin.

JARVIS, P.A.
The Central North Fiji Basin Triple Junction.

AUZENDE, J.M., URABE, T. and SHIPBOARD PARTY
Preliminary Results of the STARMER I Cruise of the Submersible "Nautile" in the North Fiji Basin.

10.00-10.30 Tea

10.30-12.30 Plate Boundary Tectonics (4 papers)

EISSEN, J.P., MORVAN, G., LEFEVRE, C., MAILLET, P., URABE, T., AUZENDE, J-M. and HONZA, E.
New data on the Petrology and Geochemistry of the Central North Fiji Basin Spreading Center, SW Pacific.

PRICE, R.C., KROENKE, L.E. and JOHNSON, L.W.
Geochemistry of Basalts from the North Fiji Basin: Tectonic implications.

NOHARA, M., URABE, T., JOSHIMA, M. and HONZA, H.
REE and Isotope Constraints on the Origin of Backarc Basalts in the North Fiji Basin.

McMURTRY, G.M., SEDWICK, P., MURPHY, E., KARL, D., GAMO, T., STOFFERS, P. and CHEMINNE, J.L.
International Cooperative Investigations of Hydrothermal Systems in Back-Arc Basins and on Intraplate Hotspots in the South Pacific.

12.30-13.30 Lunch

13.30-15.30 Plate Boundary Tectonics (4 papers)

ARTEMIEV, M.E. and KOZLOV, V.V
Tectonic Faults of Viti Levu Island, Fiji as they are seen on Satellite Imagery.

SCHOLL, D.W., HERZER, R., and VALLIER, T.L.
Tonga and Lau Ridges: Implications of Tectonism and Submergence Histories for Petroleum Resources in the Southwest Pacific.

WRIGHT, I.
Tectonics of the Havre Trough - Taupo Volcanic Zone, Bay of Plenty: Evidence from Gloria Side-Scan.

LISITSYN, A.P. BOGDANOV, Y.A., ZONENSHAIN, L.P., KUZ'MIN, M.I. and SAGALEVICH, A.M.
Soviet Research from Submersibles of Hydrothermal Ore Occurrences in Oceanic Rifts.

15.30-16.00 Tea

16.00-18.00 Plate Boundary Tectonics (4 papers)

FOUQUET, Y. and SHIPBOARD PARTY
High Temperature Polymetallic Sulphide Deposits in Backarc Environment: Diving with "Nautile" in Lau Basin.

VON STACKELBERG, U. and SHIPBOARD PARTY.
Extensive Low-temperature Hydrothermal Activity in the Southern Lau Basin.

HENLEY, R.W.
Epithermal Gold Mineralisation and Epithermal Exploration in the Circum-Pacific Rim.

LUM, J.
An overview of Gold Mining and Exploration in the Southwest Pacific.

19.30 Workshop dinner

Wednesday: 27th September

08.30-10.00 Plate Boundary Tectonics (2 papers)

PELLETIER, B. and LOUAT, R.
Present-Day Relative Plate Motion in the Southwest Pacific.

COLEMAN, P.J.
From Tectonics to Eldorado - The Prospect of Benefits to the Island Countries.

10.00-10.30 Tea

10.30-12.30 Plate Boundary Tectonics Discussion

12.30-14.00 Lunch

14.00-15.30 Intraplate Dynamics (2 papers)

CRONAN, D.S., HODKINSON, R.A. and MILLER, S.
An Overview of Manganese Nodules and Cobalt-rich Crusts in the CCOP/SOPAC Area.

VON STACKELBERG, U.
Growth History of Manganese Nodules of the Equatorial North Pacific Ocean.

15.30-16.00 Tea

16.00-18.00 Intraplate Dynamics (4 papers)

KEATING, B.H.
Seamount Morphology and Manganese Crust Resources in the Central Pacific Basin.

BOLTON, B.R.
Platinum-rich Ferromanganese Crusts from the Southwest Pacific.

DE CARLO, E.H.
Relation of Intrasample REE Variability in Pacific Ocean Ferromanganese Crusts to Paleoceanographic Conditions over Geologic time.

LE SUAVE, R., PAUTOT, G. and HOFFERT, M.
French Exploration of Cobalt-rich Crusts in Tuamotu Archipelago, French Polynesia.

19.30 Plate Boundary Tectonics Working Group Meetings

Thursday: 28th September

08.30-10.00 Intraplate Dynamics (3 papers)

HAWKINS, W.J.
Intra-plate Volcanism - Louisville and Samoan Linear Volcanic Chains as Possible Hotspot Traces.

STOFFERS, P., BOTZ, R., DEVEY, C.W., HARTMANN, M., KOGLER, F., MUHE, R.K. and PUTEANUS, D.
Geology and Petrology of Active Hotspot Volcanism in the Austral Islands: The Macdonald Region.

STOFFERS, P., PUTEANUS, D., GLASBY, G.P. and KUNZENDORF, H.
Hydrothermal Iron-rich Deposits from the Teahitia-Mehetia and Macdonald Hot Spot Areas, SW Pacific.

10.00-10.30 Tea

10.30-12.30 Intraplate Dynamics (4 papers)

COULBOURN, W.T., HILL, P.J., BOGI, J., DE CARLO, E.H., KEATING, B.H., BERGERSEN, D., PENNYWELL, P.A., KAMU, S. and YEETING, B.M.
Moana Wave Cruise 3 to the Territorial Waters of Western Samoa, the Cook Islands and Kiribati: A Summary of Results.

HILL, P.J. and COULBOURN, W.T.
Geophysical Expression, Distribution and Origin of Manihiki Plateau Mud Volcanoes.

LARUE, B.M.
Biological Resources Associated with Seamounts.

COCHONAT, P., LE SUAVE, R., CHARLES, C., GREGER, B., HOFFERT, M., LENOBLE, J.P, MEUNIER, J. and PAUTOT, G.
The First Nautile Submersible Dives in French Nodule Mining Area.

12.30-13.45 Lunch

13.45-15.30 Intraplate Dynamics (3 papers)

USAMI, T.
Research and Development of the Marine Technology in Japan.

LENOBLE, J.P.
Deep Seabed Mining for Polymetallic Nodules.

EXON, N.F.
Manganese Nodule and Crust Resources in the SW Pacific, and What They Mean to Island Countries.

15.30-16.00	Tea
16.00-17.30	Intraplate Dynamics Discussion
19.00	Intraplate Dynamics Working Group Meetings

Friday: 29th September

08.30-10.00	Poster Session: Authors to be at posters
10.00-10.30	Tea
10.30-12.00	Plenary: Member Country comments
12.00-13.30	Lunch
13.30-15.30	Plenary: Consideration and Adoption of Workshop Report and Recommendations
15.30-16.00	Tea
16.00	Field Excursion departs from Geology Department carpark.

POSTER PAPERS

CROOK, K.A.W., TAYLOR, B. and MUSGRAVE, R.J.
Triple-junction Tectonics, Eastern Woodlark Basin, Solomon Islands.

EXON, N.F. and MARLOW, M.S.
Petroleum Prospects of the New Ireland Basin in Papua New Guinea.

FALVEY, A., GREENE, G.H. and FISHER, M.A.
The Sedimentary Basins of the New Hebrides Arc and their Petroleum Potential.

GREENE, H.G.
Multiple Beam Echo Sounding Systems - A New Tool for Geologic Mapping.

HILL, P.J., COULBOURN, W.T., GLASBY, T.G., MEYLAN, A.M. and SHIPBOARD SCIENTISTS
Manihiki Plateau Results of Recent SeaMARC II Geophysical and Seafloor Sampling Investigations.

HILL, P.J., COULBOURN, W.T., GLASBY, T.G., MEYLAN, A.M. and SHIPBOARD SCIENTISTS
Subduction of Capricorn and Machias Guyots - Structural and Sedimentological Processes.

JOHNSON, H.
Petroleum Geology of Fiji.

JOHNSON, H. and PFLUEGER, J.
Potential Reef Traps in the Ironbottom Basin, Solomon Islands.

KISIMOTO, K., JOSHIMA, M. and LAFOY, Y.
Geophysical Structure of North Fiji Basin.

MONJARET, M.C., BELLON, H. and MAILLET, P.
Magmatism of the troughs at the rear of the New Hebrides Island Arc: K-Ar Geochronology, Petrology, and Relationships with the Arc Volcanism.

PFLUEGER, J.
Structure and Stratigraphy of the Tonga Ridge from 19.5° S to 21.5° S.

PFLUEGER, J., HAVARD, K., GATLIFF, R. and HELU, S.
Structural Style and Petroleum Prospects of the Tonga Ridge.

SCHOLL, D.W., STEVENSON, A.J., VALLIER, T.L. RYAN, H.H. and GEIST, E.L.
Arc-massif shearing, block rotation and transportation -- a consequence of oblique convergence along the Aleutian Ridge.

TAYLOR, B., LIU, L., MALLONEE, R., SINTON, J. and CROOK, K.A.W.
Transtension in the Manus backarc basin.

RESERVE PAPERS

COLLEY, H.
Metallogenic Evolution in Fiji.

GREENE, H.G., and JOHNSON, P.
Geology of the Central Basin Region of the New Hebrides Arc Inferred from Single-Channel Seismic-reflection Data.

HAWKINS, W.J.
Backarc Basins - Their Evolution/Geological Characteristics and Importance in Crustal Evolution.

HODKINSON, R.A. and CRONAN, D.S.
Regional Variability in Cobalt-rich Ferromanganese Crusts from the Central Pacific.

KEATING, B.H.
Island Arc Rotations - In Review.

MALAHOFF, A.
Magnetic Fabric and Contempory Rifting Patterns in the North Fiji Basin and Lau Basin.

ROGERSON, R.J., FINLAYSON, E.J., HILYARD, D.B. and HEKEL, H.
Revised Stratigraphic Framework for Bougainvile and Buka Islands, Papua New Guinea: Mineral Deposit Models and Petroleum Prospectivity.

ABSTRACTS

ARTEMIEV, M.E. and KOZLOV, V.V.

Tectonic Faults of Viti Levu Island, Fiji As They Are Seen on Satellite Imagery

Colour synthesized satellite imagery of the island of Viti Levu, Fiji, made using the MKG-200 camera from a Soviet satellite, was analysed for geological information. A system of linear tectonic dislocations of different trends, both local and island-wide, was identified and numerous large unmapped ring structures were discovered. Comparison of the satellite analysis with a map of tectonic structure on Viti Levu shows that known volcanoes are well pronounced on the imagery, but only some of the fault zones identified, and none of the ring structure are mapped. The possible nature of the faulting is discussed.

AUZENDE, J.M., URABE, T. and SHIPBOARD PARTY

Preliminary Results of the STARMER 1 Cruise of the Submersible "Nautile" in the North Fiji Basin

A geological and geochemical study of the active spreading ridge using a submersible and associated hydrothermalism in the North Fiji Basin (NFB) considered Seabeam bathymetry, magnetics, dredges, multiprobes, TV, photos and sonar deep tows acquired during two previous cruises of the French-Japanese STARMER project (R/V Kaiyo, 1987, 1988) for the selection of diving sites.

The main dive site was located in the axial graben on top of the dome forming the northern tip of the N15E spreading axis whose depth is anomalously shallow at 1900 m. An active hydrothermal site was discovered there during the Kaiyo 1988 cruise.

The junction with the North Fiji Fracture Zone (NFFZ) is a depression interpreted as a pull-apart basin linked to left lateral motion along the NFFZ. It is limited north and south by 1000 m high, N60 trending cliffs, and occupied in the center by a N60 double ridge thought to be a neovolcanic axis propagating toward the NE.

A structural map was established from observations made during six dives in the axial graben between 16° 58'S and 17° S. This part of the spreading axis is formed by a series of N15E trending horst and graben. The central graben, 200 m wide and 20 to 40 m deep, is flanked by two small horsts and two lateral grabens a few tens of meters wide and 10 to 20 m deep. Tectonic features are mainly N25E trending normal faults and open fractures. Most of them occur in the central graben and on its border scarps. Except for the fault scarps, the area is covered with a thin pelagic sediment layer which shows that volcanism has not been active recently.

Extinct hydrothermal sites occur all along the graben. They consist of fossil chimneys, oxide staining, and dead shells. In the center of an extinct hydrothermal area at 16° 59'S, an active vent was discovered and named the "White Lady" because it consists of a 3 m high accumulation of anhydride. Three main vents expel transparent shimmering water at 285°C with very few solid particles. Abundant animal colonies, including mostly gastropods, crabs, galatheans and cirripeds, are located around minor vents at the base of the chimney.

Basaltic lavas present various morphological aspects typical of oceanic ridges: pillows, tubes, and lava lakes, sheeted or massive flows. North of 16° 58.30'S, the three grabens progressively disappear in a complex area where more diffuse deformation occurs along N15E and N140E trending faults. The later direction coincides with that of the limit between the triple junction area and the N15E spreading axis. Collapsed lava lakes and pillars characterise this area. In the northernmost part of the survey area, abundant fossil hydrothermal deposits outcrop. Their thickness locally exceeds 30 m.

The second dive site was the graben located east of the N15 and N160 ridge junction along the NFFZ. Three dives followed a NS transect from the northern wall of the graben to the central volcanic ridge axis. The northern wall exposes a 1200 m thick continuous section through the upperpart of the oceanic crust. The bottom of the graben is structurally complex. The succession observed shows parallel dykes, lava tubes and pillow lavas, as well as massive or prismatic lava flows in several places along the wall. Tectonic breccias a few meters thick, which are flattened against the wall, are a result of vertical faulting. Both dives carried out to the south revealed the structural complexity of the bottom of the graben. The graben appears like an alternation of small depressions and recent scarps associated with open fissures. The bottom of some circular lows is occupied by collapsed lava lakes. Along some of the scarps, the lava tubes are vertical, implying that the magma flowed on pre-existing topography. In summary, the observations done in this area suggest that the volcanic activity is scattered through several parallel ridges, but current tectonic activity seems to prevail on the whole system.

Samples of hydrothermal waters have been collected from the "White Lady" chimney. The curve of sulfide concentration as a function of Cl-defines the mixing between bottom seawater and the purest sample (ISIS-2). It allows us to infer the characteristics of a hydrothermally pure sample as follows: 1- chlorinity: < 0.3 mol/l; 2-pH: -4.5; 3- relatively high alkalinity; 4- low concentration of silica: (< 15 nmol/l). These characteristics are clearly different from hydrothermal waters collected on the EPR and the MAR.

Thirteen on-bottom gravity and 6 heat flow measurements were obtained in the axial graben and along an E-W cross section, 12 hydrothermal deposits sampled, 25 basalt and 4 sediment samples and a few animals were also collected. Samples hydrothermal deposits consist of pyrite-rich massive sulfides, fragments of active chimneys (anhydride), and altered sulfides.

BINNS, R.A., SCOTT, S.D. and PACLARK PARTICIPANTS

Propagation of Sea-Floor Spreading into Continental Crust, Western Woodlark Basin, Papua New Guinea

In the vicinity of D'Entrecasteaux Island, southeastern PNG, the Woodlark spreading axis is actively propagating westwards into continental crust. As an unusual modern tectonic environment and a possible analogue for the geological settings of many ancient volcanogenic massive sulfide ore depsits, the western Woodlark Basin is being explored by the PACKLARK research project, a collaborative venture between the Geological Survey of Papua New Guinea, CSIRO Australia, and the Universities of Toronto and of British Columbia, Canada.

Three PACKLARK cruises (1986-88) conducted from RV FRANKLIN and HMAS COOK have concentrated on the area west of 151° 55'E with special emphasis on previously uncharted waters west of 151° 15'E. In addition, a prominent graben in Goodenough Bay to the west of Normanby Island was visited. Besides 12 kHz and Seabeam echo-sounding, an extensive program of dredging, sediment coring, camera and video bottom photography, CTD-hydrocast-transmissometer soundings, magnetometer tows and limited seismic traversing has been conducted over much of the sea floor shown in Figure 1, which gives informal names used below for major bathymetric features.

Conventional sea-floor spreading characteristic of the Woodlark Basin further east stops near Franklin Seamount (an axial volcano of basaltic andesite) at 151° 50'E. The propagation zone to the west comprises a complex of relatively short rifts and basins. Most bathymetric highs appear composed either of continental metamorphics (e.g. mafic greenschists on Moresby Seamount) or subhorizontal sedimentary rocks provisionally correlated with the Neogene sequence (Cape Vogal Basin) covering the Trobriand Platform north of the Woodlark Basin.

The area is characterized by rapid pelagic and terrigenous sedimentation. Recent turbidities cover basement under the floor of most bathymetric deeps, but magnetic and seismic data interpreted in the light of lithified Trobriand-like sediments dredged from a small axial horst in South Valley suggest some other rift structures (e.g. Pierson Basin, Lonely Basin) may be down-faulted outliers of the Cape Vogel Basin rather than segments of the sea-floor spreading zone.

Only East Basin has a confirmed volcanic floor, including lightly sedimented flows of N-MORB and Fe-Ti basalt. The three thickly sedimented basins extending WSW from Franklin Seamount conceivably represent an early attempt by the spreading axis to propagate around the south end of continental Moresby Seamount, which became frustrated by an encounter with Normanby Island. The system then diverged northward around Moresby Seamount, forming East Basin very recently. Current seismic activity is concentrated along a zone from West Basin via Cook Valley to North Valley, which consequently appears the most likely locus of continued propagation and future MORB-like volcanicity.

A recent, probably dormant, submarine volcanic province of different character (K-Mg on and near Dobu Seamount at the western head of South Valley) possibly extends to, or is repeated in, North Valley. The rhyolites are similar to those erupted from dormant, hydrothermally active volcanoes on Dobu, Sanaroa and SE Fergusson Islands. Geochemical and isotopic characteristics of the basalts and andesites suggest derivation from a mantle source modified by prior subduction events in the region. While an association with rifting is obvious, the exact relation to mantle phenomena underlying the propagating Woodlark spreading axis is less clear. Similar andesites occur on Cheshire Seamount, apparently a flanking (older?) volcano relative to the East Basin spreading segment.

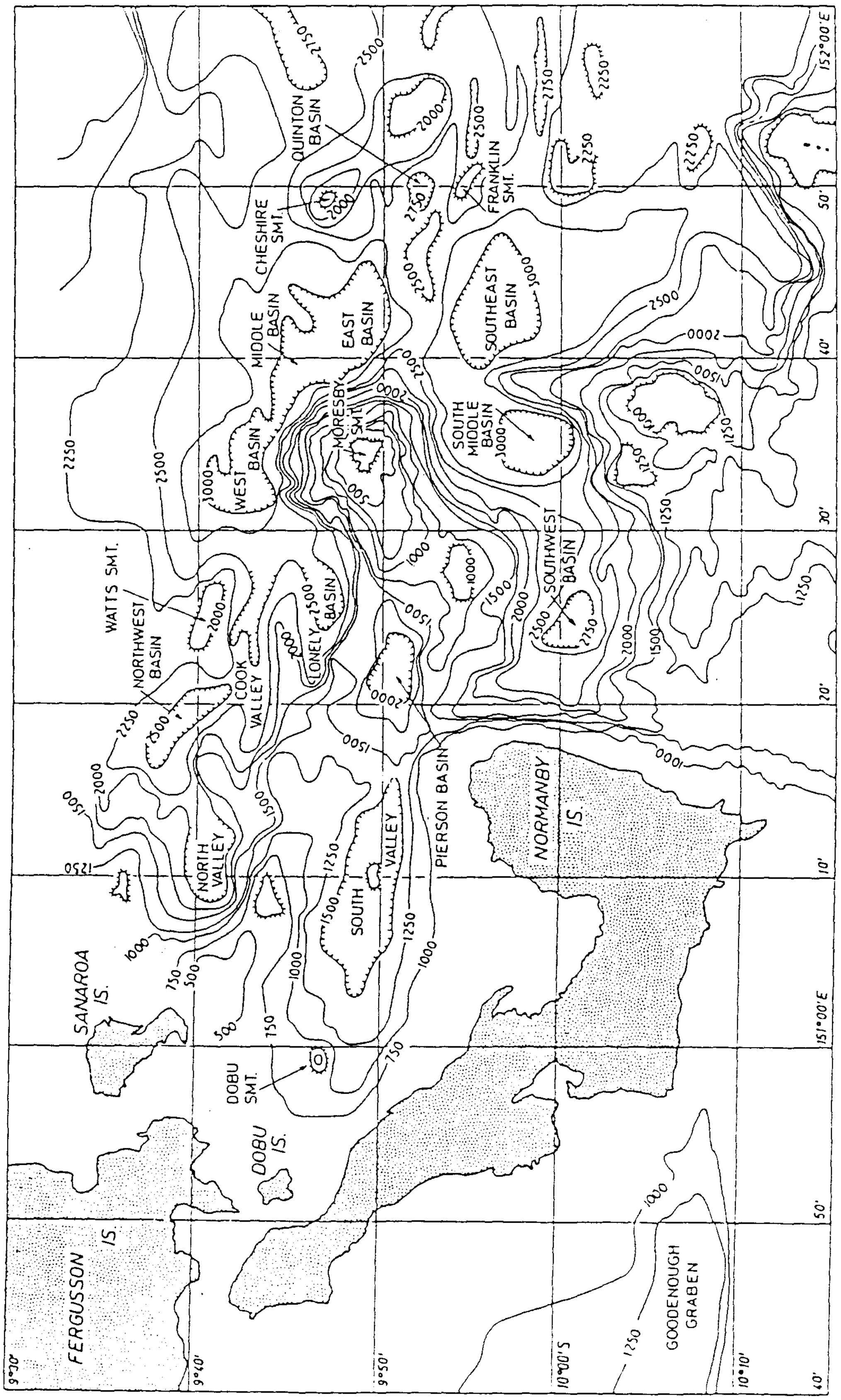


Figure 1: Bathymetric features of the western Woodlark Basin.

BOLTON, B.R.

Platinum-Rich Ferromanganese Crusts from the Southwest Pacific

Ferromanganese crusts are common throughout the southeast Pacific in areas of significant topographic relief. Crusts, which may be up to 20 cm thick, occur on a variety of substances including basalt, granite, volcaniclastics, carbonates and chert. Crusts are mainly composed of vernadite (5-MnO^2) with lesser amounts of detrital impurities, quartz and feldspar. No crystalline Fe phases were observed. Crusts show Mn, Fe, Cu, Ni and Zn concentrations typical of deposits formed by hydrogenous processes. Cobalt, which may attain concentrations of economic interest in similar crusts elsewhere, is, in the samples analyzed here, of unexceptional abundance, averaging 0.26%.

Platinum, together with Pd and Ir are significantly enriched in three crusts from the region analyzed for platinum-group elements. Two of the samples from the vicinity of the South Rennell Arc, south of the Solomon Islands, contain 263 and 336 ppb Pt, 2.06 and 1.91 ppb Pd, and 3.71 and 4.13 ppb Ir, respectively. The third sample from the D'Entrecasteaux Ridge, west of Vanuatu, contains 174 ppb Pt, 2 ppb Pd and 243 ppb Ir. This sample is also enriched in Ag (472 ppb).

This paper summarizes the distribution of metallic and platinum-group elements in crusts from the Southwest Pacific region and briefly discusses their possible origins and economic potential.

COCHONAT, P., LE SUAVE, R., CHARLES, C., GREGER, B., HOFFERT, M., LENOBLE, J.P., MEUNIER, J. and PAUTOT, G.

The First Nautile Submersible Dives in a French Nodule Mining Area

Manganese nodules fields and their sedimentary environments have long been studied by means of sampling, photographs and indirect acoustic surveys. Direct observations and in situ specific measurements have never been carried out previously. In December 1988, 16 dives were completed by IFREMER in the Northeast Central Pacific Ocean at a water depth of about 5000 m between the Clarion and Clipperton fracture zones. The dives were focused on specific targets selected from previous data and particularly from high resolution seismic profiles and sonar images collected by the French deep tow SAR ("Systeme Acoustique Remorque").

The regional morphology of the sea bottom is usually an abyssal hills landscape with a sedimentary cover deposited on Oligocene oceanic crust built at the East Pacific Rise.

The objectives of the cruise were to obtain ground truth on: the morphostructural and sedimentary environments of the nodule area; the nodule distribution; and the geotechnical properties of surficial layers using a vane shear device operated by submersible.

The results show that Oligocene and lower Miocene deposits above basalt appear to be essentially calcareous up to the Mio-Pliocene hiatus, overlain by a Fe/Mn impregnated level below Plio-Quaternary pelagic clays. This must be considered in order to understand the regional paleogeography during the northwestward migration of the Pacific plate. When the calcareous layers draping the topography of the basement are in outcrop, significant erosive processes occur related to dissolution of these thick carbonate facies (50 m). Consecutively, faulting and slumping may occur to create steep slopes observed in cliffs and troughs.

Investigation focused on the upper pelagic clay formation, recognized on acoustic records as a transparent unit. In situ measured values of cohesion vary significantly more than expected from laboratory measurements, suggesting that different geotechnical facies can exist in the same apparent lithology. This may be explained by: dynamic sedimentary processes occurring during deposition, variation of sedimentation and/or compaction rates, and a possible early digenesis. Correlatively, the nodule distribution and the variability of nodule types appear also to be clearly related to, and controlled by, the sedimentary environment.

We propose a revised description of the entire sedimentary sequence and its specific morphology, and demonstrate correlations between the geological environment and shear strength of recent surficial sediments, and nodule distributions.

COLEMAN, P.J.

From TECTONICS To EL DORADO - The Prospect of Benefits to the Island Countries

Geological surveys in the SW Pacific have had a major pragmatic content: the discovery of El Dorado (ore bodies or petroleum or both). Beginning with the field survey, exploration has become increasingly sophisticated. The range of Theme 1 contributions (some 44) shows just how sophisticated. Several large-scale regional tectonic papers supply the essential, broad canvas on which more specific, more applied studies are placed. Several more localised palaeomagnetic/tectonic papers show that search strategies can be severely constrained by realisation of such things as exotic terranes and rotating blocks. Detailed field mapping, with refined micropalaeontology, suggests lateral shift of large blocks. The petrological/geochemical projects, nearly ten, range from concern with mineralization directly on the seafloor (as part of spreading processes) to later-state emplacement of hydrothermally induced ore bodies in arcs. As with companion papers, the understanding of backarc mineralisations as incipient ore bodies is advancing rapidly, so also are the processes by which concentration of metals, especially gold, can lead to ore-bodies. This is of interest, though long-term, to the island countries. Epithermal systems seem to be especially well understood.

The over-riding impression given by the range of papers is of concern with origins, mechanisms and processes, and discovery tactics. All this is a far cry from early times, in the fifties and sixties, when straightforward prospecting, albeit severely geological, was the order of the day, and luck was crucial for success. The results and intimations gained from recent refinements - an understanding of seafloor processes, the realisation of the awesome dynamics of arcs, and the companion adjustment of search strategies and tactics - will reduce the need for luck (but not remove it). To name two especially promising areas: it is beginning to look as though hydrothermal ore deposits are a normal, even necessary, part of arc build-up; and the rate of discovery of such ores, especially epithermal ones, will continue to accelerate. So too, the selection of areas for their petroleum potential will become refined, and hinge upon the discovery of reefal reservoirs.

The member nations of CCOP/SOPAC can feel ever more hopeful of final benefit, although the methodical, long haul often lacks the heady excitement of the quick gamble. Somewhat paradoxically, the time is close when field exploration will again be a major activity to test theoretical models derived from more exotic studies.

COLEMAN, P.J.

Composite Transient Transform Fault Complexes in Island Arcs: Their Effects on Arc Hydrocarbon and Mineral Resources

Most island arcs are split by large strike-slip faults, even in relatively rare instances where convergence is orthogonal. Oblique convergence together with episodic coupling of downgoing and overriding slabs encourages strike-slip faulting sufficient to form a braided system in which activity is shared differentially by the component faults. The system is composite transient. Along the trend of the arc the system may give way to pure shear without a subduction component. The system fills the role of a transform-a composite transient transform. The Philippine Fault, Barisan (Sumatra) and Solomons are some postulated examples. As a result of strike-slip activity, portions of the forearc terrane may be carried inboard of the nominal boundary, the locus of which is the trench for hundreds of kilometres. Some of these portions may be translated onto the descending plate. Agglomerations of so-called exotic terranes, the Alaskan for example, may consist not only of truly exotic blocks carried in by the downgoing plate but also of slivers of the host plate. As well, strike-slip movement along undulatory fault planes, the usual condition, will result in strong vertical movements and rotations of blocks about both vertical and horizontal axes.

Piecemeal slicing of the arc and translation of slices can threaten not only the initial accumulation of petroleum but also the integrity of reservoirs. This negative aspect may be compensated by increased development of reefal bodies on fault crowns and large-scale growth of marginal marine areas rich in organic material. These are swept periodically by storm and/or tsunami action into sedimentary sequences adjacent to reefs. These sediment piles may be thick enough and deep enough to be sites of favourable 'oil kitchens' from which young oil can be fed into the reefal reservoir.

An awareness of the vigorous vertical movement of, and between, discrete blocks and the effects of differential erosion, should be an important part of the search strategy for epithermal/hydrothermal deposits. Such deposits are probably a necessary part of arc growth, but the discovery rate does not reflect this, probably because many of the deposits are physically veiled by graben infill or because they are tilted to give a misleading outcrop pattern.

RESERVE PAPER

COLLEY, H.

Metallogenic Evolution in Fiji

The geological evolution of Fiji can be conveniently separated into 4 major periods:

Eocene to Mid-Miocene

During this period the development of Fiji was essentially that of an immature arc. The generally accepted view is that Fiji was part of the proto-Melanesian arc generated above the southward directed subducting Pacific plate. Subduction occurred along the Vitiaz Trench and associated backarc spreading took place in the South Fiji Basin. Thus, the mineralisation of this stage is related to conventional subduction with some backarc spreading.

The dominant rocks belong to the island arc tholeiite series (IATS) and show a range from basic andesite through to dacite. Basic andesite is the most abundant rock-type but there are substantial outcrops of dacitic to ryholitic rocks; andesitic rocks are comparatively rare, generally occurring as small, isolated plugs. Much of the material is fragmental and pillow lavas are not common. There is very little evidence to indicate substantial development of subaerial islands and it is likely that island shoals were quickly eroded with reworking of material into deeper water. Plutonic rocks are rare and the only significant pluton is found in western Viti Levu. The Yavuna pluton is a trondhjemite-tonalite body of Oligocene age. Rocks of this Eocene to Mid-Miocene period are largely restricted to southern Viti Levu.

The early Eocene to Mid-Miocene period has very little mineralisation. Minor Fe-Mn metalliferous sediments are associated with sediment/lava interfaces in SW Viti Levu. Colley and Walsh (1987) liken these occurrences to mineralisation currently forming on the ocean floor in places like the Galapagos Ridge. This Fe-Mn mineralisation is associated with a period of extension in the Fiji arc during the late Oligocene to early Miocene. The deposits occur in relatively deep water hemipelagic sediments and the underlying lavas hava some MORB characteristics to their chemistry. Minor copper mineralisation occurs in these underlying lavas. In addition sub-economic amounts of copper sulphides along with very rare Ni-Co minerals and gold have been noted in some of the oldest (Eocene) basaltic lavas and small gabbroic bodies related to these. Some of these lavas have a boninitic chemistry and appear to represent the very earliest volcanic activity in the arc.

Mid - to Early Late Miocene

This short period is dominated by a major plutonic event with the intrusion of the Colo Plutonic Suite. A number of plutons with radiometric ages generally between 12Ma and 8Ma occur in southern Viti Levu. They have compositions similar to the Yavuna pluton with trondhjemite and gabbro being the dominant rocks; intermediate rocks of dioritic composition are generally restricted to the marginal zones of the plutons and appear to be the products of magma contamination. Geochemically the rocks belong to the IATS suite. There is some debate concerning the generation of these plutonic bodies. Colley and Hindle (1984) relate the bodies to the 'Colo Orogeny' with the plutons being intruded along anticlinal axes in a broad anticlinorium that runs roughly east to west across the southern half of Viti Levu. Overturned bedding in the Yasawa Islands appears to confirm the occurrence of significant deformation. However, Gill et al. (1984) and Hathway (1988) have questioned the occurrence of such an event. They regard the plutonism as a 'normal' if rather intense igneous event with the intrusion of the gabbro-trondhjemite bodies leading to the formation of the anticlinorium and its constituent open folds. All parties are agreed that the geochemistry of the plutonic rocks indicates that they are remelts of earlier crustal material. Whichever hypothesis should prove acceptable it can be said that this period marks the transition of Fiji to a mature arc. It also heralded a radical re-organization of plate spreading in the SW Pacific.

Mineralisation is more notable in this ensuing plutonic period but again is sub-economic. Within the plutonic bodies and particularly along their margins, copper and molybdenum mineralisation, in dissiminated form, has been recorded. Considerable exploration, including major drilling programmes, has so far failed to reveal an exploitable body. Additionally the plutonic activity has generated large quartz veins which cut the intrusive rocks and their enclosing country rock. Copper, lead and zinc sulphides are the principal economic minerals, and gold has been noted in a significant number of the veins. Again exploration so far has not revealed an economic body.

Late Miocene to Mid-Pliocene

This was a period of very widespread and voluminous volcanism in Fiji. The northern part of Viti Levu, most of Vanua Levu, and nearly all the other island groups were formed during this short period. In addition the volcanic rocks show considerable diversity of composition with the occurrence of IATS basic andesites, low-K rhyodacites, calcalkaline andesites (s.s.), and shoshonitic rocks. It is difficult to relate these variations to subduction zone geometry but Gill et al. (1984) suggest that the rock variation may be related to increasing depth along the Tonga subduction zone with arc tholeiites (e.g. Vanua Levu) in the east and shoshonites (e.g. western Viti Levu) in the west. However, there are many anomalous islands and centres that cast doubt on th validity of this simple scheme. The major volcanic period following the plutonic activity marks the major time for mineralisation in Fiji. Around 75% of the known mineral deposits were formed between 7Ma and 4Ma and these include bodies of economic importance. The Namosi porphyry copper prospect is associated with calcalkaline andesites between 6.0Ma and 6.5Ma, the Kuroko deposits of NE Vanua Levu occur in low-K rhyodacites of 6.5Ma to 7.0Ma, and the epithermal Au-Ag-Te deposit at Vatukoula is associated with shoshonitic rocks of 4.0Ma to 4.5Ma. In addition there are a large number of important prospects (e.g. Vuda, Mt Kasi) currently the subject of intensive exploration.

Mid-Pliocene - Recent

This last period marks the divorce of Fiji from subduction dominated igneous processes. The latest volcanism is marked by the extrusion of alkali olivine basalt series rocks with the geochemical characteristics of oceanic islands. During this period Fiji was progressively isolated from the influence of both the Tonga and New Hebrides subduction zones as a complex transform system, accompanied by the opening of marginal basins formed between these two trench systems.

The final period of ocean island type basaltic volcanism has no significant mineralisation associated with it.

COULBOURN, W. T., HILL, P. J., BOGI, J., DE CARLO, E. H., KEATING, B. H., BERGERSEN, D., PENNYWELL, P. A., KAMU, S. and YEETING, B.M.

Moana Wave Cruise 3 To The Territorial Waters of Western Samoa, Cook Islands and Kiribati A Summary of Results

In February 1987, portions of the territorial waters of Western Samoa, Cook Islands and Kiribati were surveyed for their resource potential.

SeaMARC II images in Western Samoan show normal faults paralleling the local strike of the Tonga-Kermadec Trench and dissecting Machias Seamount. Extensive remobilization of sediment from the summit and slopes of this flat-topped edifice greatly reduce its potential for metalliferous crust growth. Offshore of Savaii, rocky sea-floor and numerous small cones, too small to show on bathymetric maps available align with the southwest rift onshore. The platform area off the western point of Savaii comprises mixed sediment and rock exposures. Debris flows cover half of the submarine slopes offshore of the south and southwest facing coasts. The offshore area surveyed is limited to a 20 km wide swath and no attempts were made to dredge the rocky substrate in this area because of time constraints. Preliminary result, suggest that the economic potential of this area is limited to sand accumulations for future construction or beach replenishment needs.

Six days were spent in Cook Island waters surveying parts of the Suwarrow Trough, the eastern escarpment of the Manihiki Plateau, and the Rakahanga-Manihiki Island area. An excellent exposure of the potential copper-bearing beds of the Upper Cretaceous volcaniclastic sediments was located by seismic reflection profiling of Suwarrow Trough. A single dredge attempt returned only Recent foraminiferal ooze. Spectacular SeaMARC II coverage and successful dredging of the eastern escarpment of the Manihiki Plateau near 12-04'S and 160-57'W was obtained. Manganese-encrusted volcaniclastic and phosphatized carbonate cobbles were recovered.

A mud volcano of about 2200 m relief was discovered in the Rakahanga-Manihiki Island area. The edifice is composite, with numerous flows and satellite conical vents, some showing multiple flows. The side-scan images of the small satellite cones are remarkable in their quality and detail. A free fall core was lost on one of these small cones and a grab sampler returned from its summit with no sample. Two free fall cores were retrieved from the flanks of another cone. Manganese crusts on Eocene foraminiferal limestone were dredged from the center of the composite edifice, indicating mixing and outpouring of portions of the underlying sedimentary section. Sapropelic, Upper Cretaceous sediments correlative with those drilled at DSDP Site 317 are probably the source of overpressured pore water and gas necessary to produce these features. Dredging of a nearby escarpment retrieved Mn-coated, altered rock that may be phosphatic, plus samples of the Manihiki Plateau basal volcaniclastic rocks.

Surveying and sampling in the Line Islands, Kiribati, discovered potential sites of metalliferous crust growth, uncharted seamounts located by SEASAT/GEOS-3 satellite anomalies, obtained SeaMARC II side-scan images of seamounts and ridge segments, and sampled manganese crusts along depth and latitudinal transects.

Three uncharted seamounts were located, and two charted seamounts were surveyed with complete side-scan coverage. A seamount at about 0-91'S and 157-03'W is probably too young and too steep-sided to provide a suitable substrate for Mn crust growth. Chapman Seamount in the Central Line Islands is a guyot and sediment drapes its entire summit and portions of its flanks. In contrast to these unpromising sites, a ridge segment located at about 1-19'S and 155-46'W provided more than 500 lbs of rock in a dredge haul on its northeast flank. About one third of the haul comprised manganese crusts in excess of 1 cm thickness, while some crusts were as thick as 5 cm.

CRONAN, D.S., HODKINSON, R.A., and MILLER, S.

An Overview of Manganese Nodules and Cobalt-Rich Crusts in the CCOP/SOPAC Area

Studies on polymetallic manganese nodules and Co-rich crusts in the EEZ's of the Cook, Line, Ellice and Phoenix Islands between 0-20°S show that Ni and Cu reach their greatest combined abundances of over 2% between 2-8°S on the southern margin of the equatorial zone of high biological productivity, as a result of biological fluxing of Ni and Cu to the nodules at and just below the CCD. By contrast, Co reaches its greatest abundance of 0.6% south of 8°S in nodules on non-biogenic clays well below the CCD where little biological Co supply is likely. Nodule abundances are greatest (up to 30 kg/m_2) in the Co-rich area in part due to AABW flow, giving highest overall metal quantities per sq meter in the nodules there. There are approximately 110 x 10^6 tonnes of combined Ni + Cu + Co expressed as Ni equivalent in Cook Islands EEZ, approximately 12 x 10^6 tonnes in Phoenix Islands, and approximately 1.4 x 10^6 tonnes in Ellice Islands, in areas where nodule abundance is greater than 5 kg/m^2.

In the Co-rich crusts, Co averages about 0.7% and average crust thickness is about 1.6 cm, both related to metal fluxes in and adjacent to the 0_2 minimum zone in association with which both maximum thicknesses and highest Co grades occur. Within the Cook Islands permissive area there are about 930 x 10^3 tonnes of Co and 630 x 10^3 tonnes of Ni in crusts; in Phoenix Islands crusts there are about 69 x 10^3 tonnes of Co and 55 x 10^3 of Ni, and in Ellice Islands crusts there are about 750 x 10^3 tonnes of Co and 500 x 10^3 tonnes of Ni, based on the assessment methods of Clark et al (1985).

The much greater quantities of metals in the nodules than in the Co-rich crusts suggest that the nodules represent a greater future metal resource than the crusts in the areas studied, even for Co. If only a limited number of Co-rich crust mining operations are needed to satisfy future world demand for Co, Co-rich nodules could provide an even better source than Co-rich crusts within the EEZ's studied.

POSTER

CROOK, K.A.W., TAYLOR, B., and MUSGRAVE R.J.

Triple Junction Tectonics, Eastern Woodlark Basin, Solomon Islands

A triple junction between the Indo-Australia, Solomon Sea and Pacific plates lies immediately west of the New Georgia Islands, Solomon Islands, on the NE margin of the Woodlark Basin. On the basis of data collected in 1982 by the R/V Kana Keoki as part of the Tripartite I program, Taylor (1987) identified a TTF triple junction west of Ranongga, and delineated plate boundaries (Fig. 1).

Volcanic centres in the triple junction region on the Indo-Australian plate (Fig. 1) are of island arc type. Simbo Island has andesitic to dacitic cumulo-domes and Kana Keoki submarine stratovolcano has yielded dacite and rhyolite. High-silica andesite hyalocalastite dredged from 35 km ESE of Kana Keoki volcano indicated another submarine volcanic centre nearby. This was confirmed in 1985 by a detailed SeaMARC II side-scan sonar, bathymetric and geophysical survey which identified Coleman stratovolcano 15 km SE of Kana Keoki volcano. Both submarine stratovolcanoes are magnetically transparent. This, and the available marine acoustic data, imply that they consist largely of volcaniclastics.

Modelling of seafloor magnetic anomalies confirms Taylor's (1987) suggestion that a spreading centre formerly existed along the Ghizo Ridge (Fig. 1), terminating eastwards at a sinistral fracture zone. The Ghizo Ridge spreading centre became extinct progressively from east to west. At the eastern end, where Coleman submarine volcano was subsequently built, spreading ceased at 0.64Ma; on the site of Kana Keoki submarine volcano, spreading ceased at 0.60Ma; the western end of the ridge remained active until 0.50Ma. The ridge has since been extensively deformed, and probably uplifted, along faults parallel to its length.

Sediment ponds, corresponding to negative free-air gravity anomalies, flank the Ghizo and Simbo Ridges. NE of Ghizo Ridge, an undeformed sediment pond adjoins the steep SW-facing scarp marking the convergent plate boundary (Fig. 1). This pond unconformably overlies the lower part of a sediment drape that covers the NE flank of Ghizo Ridge. A narrow valley separates Kana Keoki and Coleman edifices from the SW-facing scarp. Neither edifice is internally deformed. Depths >4400 m occur in chains of sediment ponds on the West side of Simbo Ridge, and South of Ghizo Ridge. These chains are linked by a saddle with a closed depression that interrupts the continuity of Simbo Ridge.

Subduction of an active spreading centre did not occur in the region between the contemporary TTF triple junction (Fig. 1) and the Eeast end of Ghizo Ridge. Instead, the area between the Ghizo Ridge and the convergent plate boundary (Fig. 1) was progressively transferred from the Solomon Sea to the Indo-Australian plate, as spreading ceased along the Ghizo Ridge between 0.64Ma and 0.50Ma.

The Indo-Australian and Pacific plates converge at 107 mm/yr. Conventionally, this convergence rate implies that spreading ceased as points on the Ghizo Ridge progressively reached a critical distance 70 km away from the convergent plate boundary. But why should spreading cease before the ridge reached the convergent plate boundary? Why are the sediment pond and volcanic edifices undeformed immediately adjacent to the convergent plate boundary? Why did three island arc stratovolcanoes develop on the enlarged Indo-Australian plate as it converged with the Pacific plate? We suggest that these features reflect stags in an on-going process of episodic transfer of extinct spreading centre segments from the Indo-Australian to the Pacific plate.

The inferred sequence of stages is as follows:

(i) the West end of a transferring segment (A) interferes with the East end of an adjoining segment (B);

(ii) as spreading ceases along segment B it rotates clockwise, is uplifted and tilted NE;

(iii) the transform-fracture zone at its West end leaks, building a transform ridge;

(iv) a tear, focussed on the North end of this ridge, opens in the subducting rotating slab;

(v) magma ascends obliquely from beneath the approaching Pacific plate, erupting at the focus of the tear;

(vi) with completion of the transfer of segment A, which entails clockwise rotation, a tear focussed on the East end of segment B opens, and step (v) is repeated at that focus;

(vii) with further convergence, the lithosphere fractures South of segment B & West of the transform ridge, and transfer of segment B to the Pacific plate commences.

The Simbo and Ghizo Ridges have reached state (vi) in this process, with the building of Kana Keoki and Coleman submarine volcanoes. The Simbo edifice was constructed during stage (vi). The large sediment ponds South of the Ghizo Ridge, the saddle transecting the southern Simbo Ridge, and the sediment ponds West of the Simbo Ridge may be an indication of the onset of stage (vii). This could be tested by seismotectonic analysis of data from ocean bottom seismometers deployed in the vicinity.

Stage (vii) is exemplified by a triangular region East of Ghizo Ridge (Fig. 1) which is geometrically and tectonically analogous to the triangular area described above. Rendova Island, with a stratovolcano at its NE end, is analogous to Simbo. Tetepare island, which shows >2.5 km of uplift since the early Pleistocene, is analogous to the Ghizo Ridge. Kavachi, an active submarine volcano only 30 km NE of the convergent plate boundary, erupting quartz tholeiite and low-silica andesite of island arc type, is analogous to Coleman volcano. The Blanche Channel Basin lying between NE Rendova and Kavachi, which contains a thick sedimentary sequence in water depths >1 km, is analogous to the topographic depression and sediment pond NE of the Ghizo Ridge. The hypothesis that this region has been transferred to the Pacific plate is testable by fieldwork.

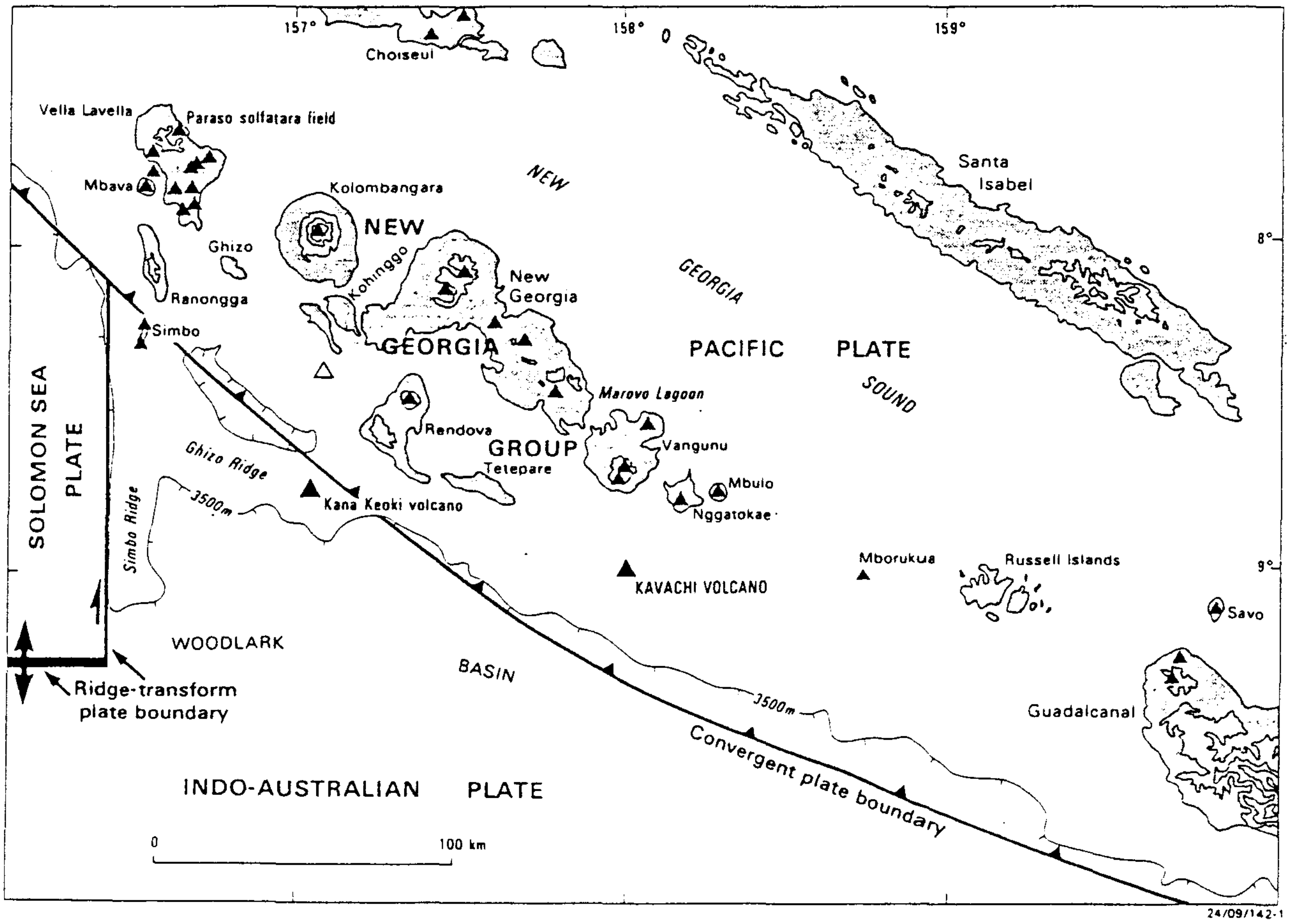


Figure 1: Plate boundaries in the NE Woodlark Basin after Taylor (1987). Small triangles are subaerial volcanic centres, large triangles are submarine volcanoes. Map is from Johnson & Tuni (1987).

DANIEL, J., and SCIENTIFIC PARTY

First Results of the Dives of the SUBPSO 1 Cruise

During the SUBPSO I cruise, eleven dives of the French submersible NAUTILE were made in the d'Entrecasteaux and Loyalty collision zones, along the New Hebrides subduction zone.

Geological cross-sections obtained during seven dives in the collision zone between the North d'Entrecasteaux Ridge, the Bougainville guyot and the New Hebrides island arc, reveal that the arc slope is primarily composed of volcanic and volcanoclastic rocks probably shed from the arc. Arc-slope rocks are deeply incised by erosional channels and show numerous slump scars. These scars confirm the relative importance of gravity erosion along the deformation front. Direct observations indicate that the bedding of the arc-slope, which generally dips trenchward in this collision zone, has been tilted upward and dips strongly arcward in the contact area of the colliding features. In this particular area, arc-slope rocks are highly fractured and sheared, with the exception of those forming the ridge that supports the Bougainville guyot. No evidence for fluid venting was observed during the dives.

The results obtained during four dives in the collision zone between the Loyalty Islands ridge and the New Hebrides island arc show that the Loyalty Islands ridge consists of an alkaline basaltic and rhyolitic volcanic series overlain by about 100 m of algal limestone. Normal faulting affects this series, and some blocks, with their limestone cover, were observed as deep as 4500 m. At the base of the outer wall of the trench, folds are observed in some parts, due to the morphology of the Loyalty salient involved in the collision. The inner wall of the trench consists of andesitic tuffs and breccias derived from the island arc. Sedimentary accretion, if any exists, is therefore not very active.

DE CARLO, E. H.

Relation of Intrasample REE Variability in Pacific Ocean Ferromanganese Crusts to Paleoceanographic Conditions over Geologic Time

Our research suggests that the chemical composition and microstructure of marine ferromanganese crusts are a function of prevailing oceanographic conditions and depth of formation of the deposits in the ocean. These findings imply that well preserved Fe-Mn crusts represent a geologic record extending back to the onset of Fe-Mn oxide precipitation on the substrate material. If current radiometric crust growth-rate estimates of 1 to 5 mm per million years are accurate, then 6-10 cm Fe-Mn oxide accumulations may represent a growth record of 12 to 100 million years.

Detailed chemical and mineralogical analyses performed on thin layers of selected thick (5-10 cm) crusts reveal significant variations in the distribution and abundance of the REE as a function of depth within the crusts. The trivalent REE generally exhibit sympathetic concentration changes in pure Fe-Mn oxides but display a greater degree of fractionation between the light and heavy REE in layers enriched in phosphatic matter. This can be explained partially by mineralogical control but it is also believed to reflect differing depositional conditions and composition of the seawater from which the deposits formed. The elements Ce and Eu, which are the only redox sensitive REE, can exist as tetravalent $Ce0_2$ and Eu(II) under oxidising and reducing conditions respectively. Because Fe-Mn crusts accrete primarily under oxidising conditions, variations in the Ce content of crusts (present as the highly insoluble $Ce0_2$) may be useful as a paleoredox indicator.

The REE patterns observed in this study are discussed in terms of their relations to the major element composition and mineralogy of the crusts, and the results of experiments work carried out in our laboratory with pure synthetic mineral phases are given. It is hoped that nannofossil biostratigraphy will help us constrain the growth history of the crusts and allow the reconstruction of paleoceanographic conditions from REE stratigraphic analyses.

EISSEN, J.P., MORVAN, G., LEFEVRE, C., MAILLET, P., URABE, T., AUZENDE, J-M. and HONZA, E.

New Data on the Petrology and Geochemistry of the Central North Fiji Basin Spreading Center (SW Pacific)

The North Fiji Basin (NFB), intensively studied since 1982, presents a spreading axis, roughly situated along the 173°30'E meridian (Fig. 1), composed of three segments: 1-north of the triple junction at 16°40'S, a N160 axis; 2-between 16°40'S and 18°30'S, a N15 segment, active since less than 1 Ma, which becomes shallower towards the triple junction; 3-between 18°20'S and 21°S, a very well defined NS ridge. This spreading ridge results from a complex spreading history which started some 8 to 10 Ma ago. Previous petrological data recognized three different basalt types: 1-N-MORB (stations KK13, 16 and 21); 2-BABB (station KK17) slightly enriched in K, Rb, Zr, Nb, and volatiles relatively to N-MORBB; 3-transitional basalts (KK19 and 20) associated with the South Pandora ridge, a newly active axis reactivating an old intra-oceanic lineament.

During SEAPSO Leg 3 and Kaiyo 87 cruises, 18 new stations of hard rock and bottom water sampling, and photo-TV deep tow lines gathered new data on the active spreading axis and older areas of the NFB. These 18 successful dredged collected freshd basalts from near the axis every 10 to 50 km between 16° S and 21° 30'S, and also in older parts of the NFB west of Viti Levu, Fiji. These are generally typical plagioclase >+/- olivine >+/- pyroxene >+/-spinel subaphyric to aphyric MORB. Only very few stations consist of more porphyritic basalts, like station K5 on the triple junction (16° 53'S), station K9 on the middle of the N15 segment near the bathymetrical rise south of the triple junction, and station S3, on a small seamount near the southern tip of the N15 segment.

Mineralogically, the clinopyroxene are augite similar to the pyroxene of other MORB, generally near equilibrium with their host magma. Plagioclase xenocrysts (An_{94-90}) of stations S1,SR and S7, are probably relic crystals in complete disequilibrium with their host magma. Plagioclase phenochrysts (An_{88-78}) in weak desequilibrium with their present host magma, have crystallized in a shallow magma reservoir.

Plagioclase skeletal microphenocryts (An_{78-65}) crystallized during the magma ascent. Olivine xenocrysts (Fo_{91-88}) are present in some samples of stations S1, S3, S5 and S7; the majority of their phenocrysts generally have a composition close to equilibrium with their host magma (Fo_{86-82}) whereas the microphenocrysts (Fo_{81-78}) are in equilibrium with it. But station K5 presents minerals either less or more evolved than what they should be if they were in equilibrium with their host magma, showing that this area has been subject to intense mixing.

All these dredged basalts are generally very fresh, except for some low or high-temperature-altered samples, discarded from the following comparisons. In a TiO_2 vs. FeO/MgO diagram, the observed correlation observed corresponds to normal crystal fractionation, except for station K15, slightly more Ti-rich, in response of a possible lower partial fusion rate. Some stations are very homogeneous (as K5, K12, K7, K6, S5, K4 and S7), some others are divided into two groups (as SR, S1 or K14) or are very heterogeneous (as K8, S3, S4 or K10); but most samples stay in the field of moderately evolved MORB, with a variability very similar to that observed in the Lau or the Mariana basins basalts. In a K_2O vs. FeO^*/MgO diagram, most samples are in the MORB field. Station S5 and samples S312, S332, and S342 are in the BABB field, and stations K15 and one group of station K14 are at the limit of the two fields. Thus, the NFB is mainly producing presently MORB with locally some relic BABB. Since older basalts (Stations S7 and K10) also consist only of MORB as some 8 Ma old basalts from the Northwest NFB [18], the NFB, has been producing MORB since its earliest stages. If some specifical chemical parameters are plotted versus of latitude, the three morpho-structurally defined segments show different signatures. In particular the N15 segment is muchmore heterogeneous that the two others, perhaps because of the recent spreading rearrangement. Its chondrite-normalised K/Ti ratio suggests that it might also result from an locally heterogeneous mantle source.

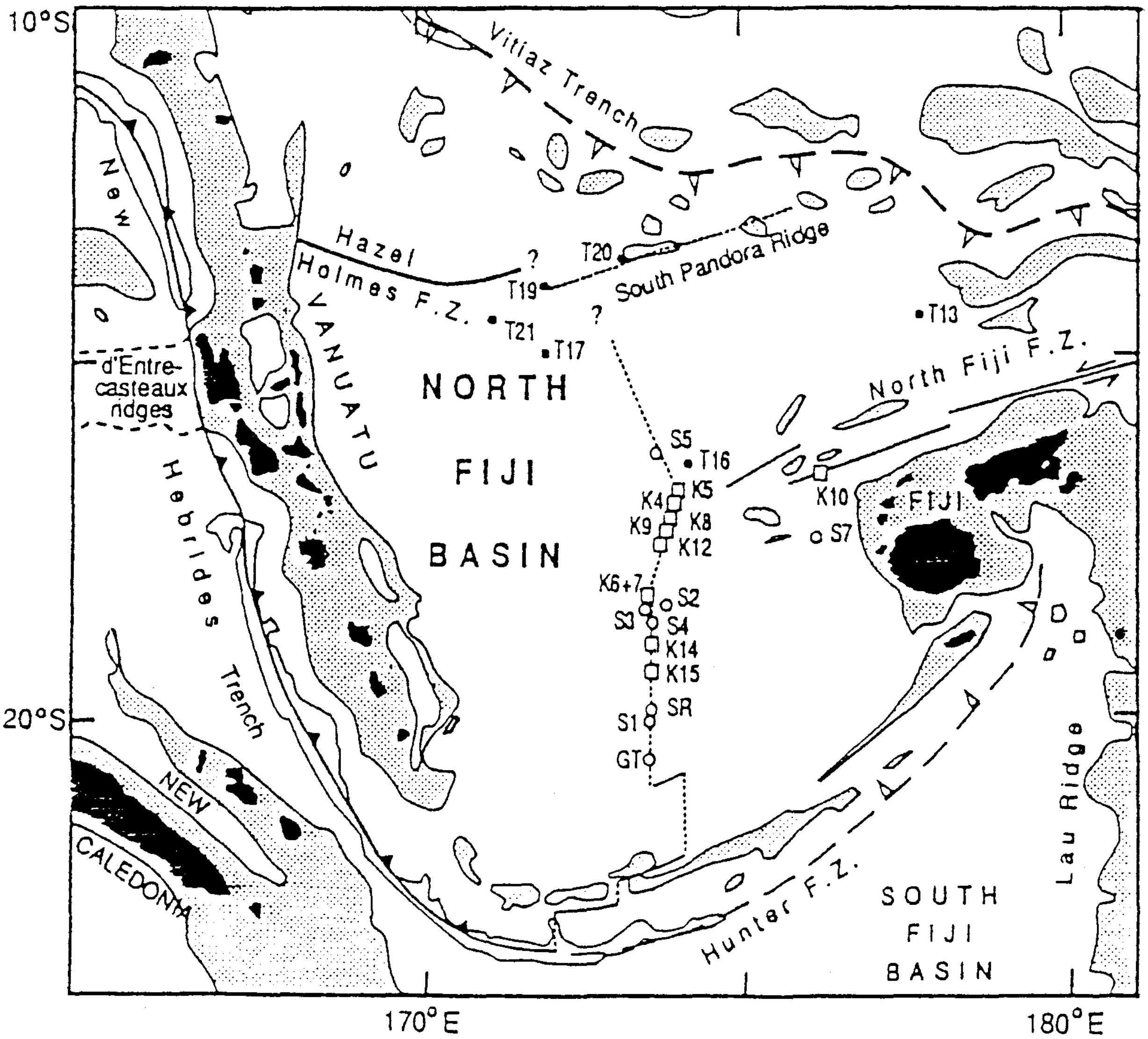


Figure 1: Location map of dredge samples from the North Fiji Basin used in this work. New data: SEAPSO Leg 3 cruise = open circle, KAIYO 87 cruise = open square. Data from the literature: GEOTRANST cruise = point, and KANA KEOKI cruise = closed square. Dashed lines show known or assumed spreading centers. F.Z. = fracture zone.

EXON, N.F.

Manganese Nodule and Crust Resources in the SW Pacific, and What They Mean to Island Countries

Manganese nodules

The first deep-sea manganese nodules were dredged from southwest of the Canary Islands during HMS Challenger's pioneering research cruise of 1872-1876. The famous "Challenger Reports" contain careful descriptions of the dredged nodules, which vary in size and shape from something much like a potato, to something like a clump of sheep manure. Most nodules are onion-like in structure, and have formed by the precipitation of metal oxides concentrically about a nucleus. In places the nodules are distributed so densely as to form immense carpets on the abyssal plain in water depths of around 5000 m, and in other places they are joined together to make a continous crust of manganese and iron oxides up to 10 cm thick. Such carpets and crusts form an immense mineral resource.

The discovery of manganese nodules led to a continuing debate on their origin. Nodules are most abundant where sedimentation rates are lowest, which generally means far from major land masses. They are believed to form at rates of about 1 mm/million years at the sediment/water interface - higher grade nodules from pore water in the surrounding sediments, and lower grade nodules directly from sea water. Grades of valuable metals in the nodules tend to be highest near the equatorial zones of high biological productivity (the plankton contain considerable nickel and copper). About 10 kg/m^2 of manganese nodules, with about 2% nickel (Ni) + copper (Cu) + cobalt (Co) content, is generally taken as a minimum for potential nodule fields.

In the last 20 years, much work has been done on defining the potential mineral resources involved, and on finding the most economical method of recovering nodules containing valuable amount of Cu, Ni, Co and other metals. Because these metals ar abundant and readily mined on land, the conventional wisdom is that commercial deep-sea mining for manganese nodules is unlikely to be undertaken in the foreseeable future. However, the Soviet Union, Japan and France remain active in evaluation of new areas, and might even go ahead with mining for reasons other than purely economical ones. It is quite possible that mining could be arranged ona bilateral basis, in the Exclusive Economic Zones (EEZs) of small Pacific Island countries, to avoid the complexities of mining under the provisions of the UN Law of the Sea, or the political ramifications of ignoring the UN system.

The development of nodule-mining and processing systems peaked in the early 1970s, when deep-sea nodules were seen as a cornucopia of valuable metals. Such work has virtually stopped, with the notable exceptions of work on behalf of the Soviet Union and Japan.

The assessment of nodule fields is done by surface vessels and submersibles. The surface vessels have a variety of remote sensing systems based on sonar and other acoustic signals, and also free-falling and tethered samplers and camera. The

United States, France and the Soviet Union have submersibles capable of working in the 5000-6000 m water depths of nodule fields; the results of some submersible studies of nodules are reported at this workshop (P. Cochonat et al. :"Nautile" dives).

No fully developed nodule mining system exists, but several prototypes have been tested. Perhaps the most likely type is a giant self-propelled "vacuum-cleaner" which would suck up the nodules in the surface sediments, and send them up an incredibly long pipe to the surface vessel, for separation from sediments, possibly some initial processing, and transport to land by bulk carriers. Nodule mining could have a major impact on the price of metals from conventional mines, and is opposed by some major suppliers.

The most prospective area in the world is considered to lie between the Clarion and Chipperton Fracture Zones, southeast of Hawaii. This area, which lies outside national EEZs, contains the richest known nodule fields, where a typical mining operation might recover about 3 million tonnes of nodules per year, containing about 30,000 tonnes Cu, 30,000 tonnes Ni, and 10,000 tonnes Co. Potential reserves are probably about 100 million tonnes of both Cu and Ni, and 20 million tonnes of Co - enormous figures. In 1987, a meeting under the auspices of the UN Preparatory Commission for the International Sea-Bed Authority, brought together four groups regarded by the UN as "pioneer manganese nodule investors", operating outside the UN system, all of whom had overlapping and competing claims in the Clarion-Clipperton zones. A fascinating display of co-operation led to agreed boundaries separating the claims of all the groups!

It is believed that a Japanese group will attempt to mine manganese nodules in their lease in the Clarion-Clipperton zone next year, for copper, nickel, cobalt and manganese. Their equipment should be able to mine 1500-2000 tonnes of nodules per day (say 500,000 tonnes per year). The nodules may be used as direct feed into steel furnaces, avoiding the considerable technological problems of refining the metals within them. Papers on nodule mining systems will be given at this workshop by J.P. Lenoble (French system) and T. Usami (Japanese system).

Nodule fields are widespread in the southwest Pacific; the most abundant nodules are in Cook Islands, eastern Kiribati, and French Polynesian waters. The nodules along the equator tend to be richest in nickel and copper, and those further south in the more valuable cobalt (see workshop paper by Cronan et al.). At present, nodule evaluation is being carried out by the Japanese Metal Mining Agency in the EEZs of Kiribati, Tuvalu and the Cook Islands. So far this has involved five major evaluation cruises and more such cruises are programmed. French research bodies are very active in nodule studies in French Polynesia. At this stage, SW Pacific manganese nodules still have to be regarded as medium to long-term resources. However, if fields with high metal grades and abundances of nodules could be defined inside EEZs, this assessment could change. Present information (D. Cronan, this workshop) indicates that there are very large resources of Ni+Cu+Co in Cook Island nodules (around 110 million tonnes), large resources in Phoenix Island nodules, and small resources in Tuvalu.

Manganese crusts

Manganese crusts coat rocky outcrops, largely on volcanic islands and seamounts. They are first clearly recognized as potentially economic sources of cobalt by Dr Peter Halbach and co-workers in 1982 (Erzmetal, v.35, no. 9). Since then the USA, in particular, has made a major effort to define the extent of cobalt-rich crusts in its economic zone, especially in the Pacific Ocean. Similar surveys have been carried out in the Southwest Pacific under the auspices of CCOP/SOPAC and other research organizations.

The richest cobalt deposits (1% Co) generally lie in water 1000-2500 m deep, commonly in crusts 2 cm or so thick, but sometimes up to 20 cm thick. It is clear that potentially economic crusts form very slowly, from metals dissolved in the water column, and only in areas where there is little other deposition of material. It is widely accepted that cobalt-rich crusts are related to the level of the oxygen minimum zone in the oceanic water column. Because North Pacific waters are more depleted inn oxygen than South Pacific waters, D. Cronan has suggested that the North Pacific is likely to be more prospective for cobalt-rich crusts.

Cobalt-rich manganese crusts have been found in the northeast Pacific and in the EEZs of the Line Island, Phoenix Island, Tuvalu, French Polynesia, and the Marshall Islands, and on the Norfolk Ridge and the South Tasman Rise. Relatively high grades of platinum (up to 3.8 grammes per tonne), have been reported in crusts (R. LeSuave and others, and B. Bolton, this workshop) from areas off the Tuamotus, south of the Solomon Islands, and off Vanuatu. In general, cobalt grades appear to be highest within 15° of the Equator, but exploration is at an early stage, and this perception may change.

High grade crusts already have been found as far from the Equator as 40°N and 40°S. David Cronan (this workshop) indicates that there are large resources of Co + Ni (about 1.5 million tonnes) in Cook Islands waters, and much smaller resources off the Phoenix Islands and Tuvalu. At this stage, mining seems a long way off.

Discussion

In considering all the above information, and especially the potential value of Cu, Ni and Co resources, it is important to note that (in 1987) worldwide consumption of Cu was about 9 million tonnes, Ni about 800,000 tonnes, and Co about 27,000 tonnes (ratios of 300:30:1 approximately). Thus marine mining could more easily flood the market for Co than for Ni or Cu, and would depress Co prices most. The price ratios for Cu:Ni:Co are about 1:4:10 at present (Co around $15,000 per tonne).

Points to be borne in mind in comparing the feasibility of nodule and crust mining include the physical difficulty of that mining. Cobalt-rich crusts occur in much shallower water (1000-2500 m) than high-grade (Ni+Cu) nodules (5000-6000 m), so in that sense are more mineable. However, crusts are generally bonded to a rough rocky surface, whereas nodules are cradled in soft sediments. Hence, the collection of nodules at the sea bed should be much simpler than that of crusts.

The feasibility studies for nodule mining are far more advanced than those for cobalt-rich crusts, and there is every chance of limited nodule mining going ahead soon. For the southwest Pacific countries with major manganese nodule resources (Cook Islands and Kiribati) they are clearly the better medium-term prospects. Much will depend on whether manganese nodule mining in the Clarion-Clipperson zone proves to be profitable, and on whether the activities of the Japanese Metal Mining Agency lead to definite mining proposals. For the other countries, cobalt-rich crusts may be a long-term prospect. In both cases continuing assessment is necessary, but in neither case should hopes be set too high.

POSTER

EXON, N.F. and MARLOW, M.S.

Petroleum Prospects of the New Ireland Basin in Papua New Guinea

In 1984, the USGS RV S.P. Lee carried out a three week geoscience cruise in Papua New Guinea, much of it over the New Ireland Basin north of New Ireland where 1600 km of multichannel seismic profiles were recorded and 10 sampling stations occupied. Results from the cruise, combined with those earlier cruises and known outcrop geology, enable us to present a complete regional study. The work was carried out as part of a Tripartite Marine Geoscience Program funded by Australia, New Zealand and the United States of America under the auspices of CCOP/SOPAC, and was designed as support for island countries resources programmes.

The simple arcuate downwarp of the New Ireland Basin lies mostly offshore; it extends 600 km southeastward from Mussau to Feni Island, and is about 150 km wide, bounded by the slope of the Manus Trench to the north and the active backarc Manus Basin to the south. It contains sediments as thick as 7 km of Eocene and younger strata, and the total basinal area is about 90,000 km^2.

In outcrop the Basin contains thick sequences of Eocene to earliest Miocene arc volcanic rocks, Miocene volcaniclastic sedimentary rocks, Miocene shelf limestone, and latest Miocene to Recent pelagic carbonates and volcaniclastic turbidites. The Miocene sedimentary rocks have some potential as source rocks for both oil and gas, although they are generally immature in outcrop.

A total of 2600 km of multichannel seismic reflection data supplemented by single channel seismic reflection data and dredge samples allow us to correlate the offshore basin fill with the land sequence. The correlation is based largely on seismic character, seismic interval velocities, and relative thicknesses. Offshore depocentres are interpreted to contain more than 1000 m of Miocene clastics, overlain by about 2000 m of Miocene shelf carbonates and 2000 m of younger volcaniclastic rocks and bathyal carbonates.

The top of the interpreted offshore carbonate sequence is shallow near New Hanover and New Ireland, and along the Emirau/Feni Ridge, and deep in the basinal area between. The major northwest trending Tabar fault system separates the Tabar-Tanga group of islands from structural lows to the southwest. The section overlaying the carbonate is 500 m thick along the Emirau-Feni Ridge, and more than 1500 m thick in depocentres. A flat seismic "bright spot" near Tanga Island may represent a gas/oil or gas/water contact.

The general structural configuration suggests that any hydrocarbons generated at depth could migrate up-dip to the southwest or northeast, where there are pinchouts and potential fault traps. However, the prime exploration targets are stratigraphic traps in the presumed offshore carbonate sequence, largely in buildups believed to be Miocene reefs, and in associated fore-reef debris flow deposits.

Only one-third of the basin is exposed or in water less than 1000 m deep. The greatest petroleum potential is where buildups are widespread, that is in the areas bounded by the Emirau-Feni Ridge and the New Hanover-New Ireland high between Mussau and Tabar. In that region, shallow water areas occur near the islands of Mussau, Emirau, and Tench, and along the coasts of New Hanover and New Ireland. Overall, the prospects of this frontier area should be rated as moderate.

POSTER

FALVEY, A., GREENE, H.G. and FISHER, M.A.

The Sedimentary Basins of the New Hebrides Arc and Their Petroleum Potential

In 1982 and 1984, the USGS R/V S.P. Lee, carried out marine geophysical surveys in the waters of Vanuatu under the 1982 Australia-New Zealand-United States Tripartite Agreement in association with CCOP/SOPAC. The primary objective was to evaluate the hydrocarbon potential of intra-arc and other sedimentary basins associated with the New Hebrides Arc. Marine geophysical data and geological samples were collected along more than 7,500 km of tracklines, including 24-channel common-depth-point (CDP) airgun profiles.

The New Hebrides Arc was once part of the outer Melanesian composite arc, which consisted of Solomon Islands, New Hebrides, Fiji and Tonga. A continuous forearc basin, like the Tonga Platform, existed from Oligocene to late Miocene time. The collision of the Ontong Java Plateau with the northern part (Solomon Islands) of the composite arc caused fragmentation of this arc at 10-6 Ma and induced arc reversal. With the onset of arc reversal and backarc spreading, intra-arc basins formed the Solomon Islands Arc, the New Hebrides Arc, and on the Fiji Platform.

In the New Hebrides Arc three distinct island belts formed in direct response to late Tertiary and Quaternary tectonic processes - the Western Belt, Eastern Belt and Central Chain. The Western Belt of islands grew from igneous accumulation and basinal sedimentation associated with westward subduction. The growth continued until late middle Miocene, and was followed by a shift of arc volcanism to the Eastern Belt, suggesting fragmentation of the older arc and subduction reversal. Major regional unconformities observed in the seismic-reflection profiles from the Central Basin are correlated with these tectonic events. A regional unconformity at about 14 Ma appears to correspond to the start of backarc rifting and is seen in the narrow-rift half-graben, island-shelf basins along the eastern edge of the Western Belt. Another unconformity dated at about 8 Ma, corresponds to breakup of the arc and reversal of subduction, and is correlated with elevation of the Eastern Belt islands. A final unconformity, dated at about 2 Ma, preceded elevation of the Western and Eastern Belts of islands that resulted from the collision of the D'Entrecasteaux zone with the New Hebrides Arc. Steepening of the subducting slab during 1.8-0.4 Ma caused volcanic activity to migrate westward from the Eastern Belt to the still-active Central Chain.

The evolution of the arc and its sedimentary basin sequences can be explained by an explicit model for the pre-Miocene reconstruction of the outer Melanesian composite arc, based on seafloor spreading. The formation of microplates within the North Fiji Basin and the growth of the New Hebrides Arc and Tonga-Lau region were the result of migrating ridge-ridge-ridge and ridge-trench-trench triple junctions within the North Fiji Basin and the Lau Basin in Late Miocene and Pliocene time. The first event to affect the composite arc was the collision of the Ontong Java Plateau in the Solomon Islands region at 10 Ma. This collision was followed by arc reversal, rotation of the Fiji platform, and emergence of the island of Vanua Levu to enclose Bligh Water. The New Hebrides Arc formed by arc reversal and emergence of the outermost part of the original forearc region (Vitiaz forearc of the outer Melanesian arc) caused by ridge-arc collision and compression. Rifting in the Lau Basin separated the Tonga platform from its old arc complex at about 3 Ma.

Ten sedimentary basins have been identified along the summit platform of the New Hebrides Arc. Several basins contain thick (>5 km) sedimentary deposits and have structures that suggest the potential for hydrocarbon accumulation if a source is present. Organic geochemistry shows that the rocks onshore are immature and contain mainly terrestrial types of kerogen. Onshore rocks, therefore, would be sources mainly for carbon dioxide and methane gas, except for one Miocene unit of unknown extent which contains possible source rocks for condensate and gas. No organic-geochemical data from offshore rocks are available. Fine-grained rocks, possibly distal-fan or overbank deposits, probably lie within the offshore basins. These rocks may be sources for hydrocarbons. Onshore, rocks of late Miocene and younger age are the most likely reservoirs for hydrocarbons. A large anticline along the western flank of the South Aoba basin is the most obvious target for further exploration for hydrocarbons.

Oil and/or gas seeps are present in Tonga, and possibly in Fiji and Vanuatu. Oil wells have been drilled on Fiji and Tonga, so far without success. However, we expect that the most promising prospects for hydrocarbons lie along the old traces of the now-fragmented outer Melanesian arc. We conclude that the prospects for hydrocarbons in the Central Basin of Vanuatu are comparable to those of Bligh Water in Fiji, because both basins cover once-contiguous geologic provinces and experienced similar types of tectonic deformation.

FOUQUET, Y. and SHIPBOARD PARTY

High Temperature Polymetallic Sulfides Deposits in Backarc Environments: Diving with 'Nautile' in the Lau Basin

During the French-German NAUTILAU cruise (April/May 1989) a total of 22 dives were completed to investigate the southern Lau Basin near the Kingdom of TONGA. The objectives of the scientific team from France, Germany, and Tonga was to understand the processes of seafloor ore formation associated with hydrothrmal circulation in a back arc basin close to an island arc. Many of the sulfide deposits now onland have been formed in a similar geotectonic situation as found at the Valu Fa Ridge.

The four diving sites in water depths of about 2000 m are located between 21°25'S and 22°40'S, selected from preliminary studies carried out by R/V Jean Charcot and R/V Sonne. In order to better understand the hydrothermal discharge we have sampled the water near the sea bottom and measured physical parameters using a minirosette and a bathysonde on the submersible. We have also measured the heat flow in sedimented basins between the Valu Fa Ridge and the island arc.

Three types of hydrothermal deposits were discovered during the cruise:

1. Low temperature (40°C) deposits are related to discharge through highly vesicular andesite. They are characterized by extensive deposits of Mn and Fe oxides. They are discussed in another contribution.

2. Medium to high temperature barite/sulfide mineralizations were observed in many places along the ridge; they constitute a new type of hydrothermal deposit in the ocean. The most important field, a few hundred meters in diameter and 20 m high, is constituted by barite chimneys and massive barite boulders mixed with massive sulfides.

3. Very high temperature black and white smokers were discovered. The temperature measured on the vents (400°C) and the general anomalies of the bottom seawater (up to 25°C) indicate that the area is one of the most active known in the oceans at the present time. A complete cross section was sampled through a massive sulfide deposit including the stockwork. The hydrothermal fluid is the most acid ever found in the oceans (pH 2.5).

The overall scientific results allow a better understanding of the tectonic and volcanic activity, the hydrothermal processes, and the genesis of sulfide ores in a backarc environment.

GREENE, H.G.

Exploration for Mineral and Hydrocarbon Resources a long Plate Boundaries in the Southwest Pacific

Some of the world's most complex and dynamic geologic processes occur in the southwest Pacific, a region of plate convergence, collisions, and sea-floor spreading. This is also a region of limited natural resources and severe potential geohazards. Recent geologic and geophysical invstigations in the region indicate the presence of hydrocarbons and mineral resources that someday may prove economic. Data collected there during the past 5 years have improved our understanding of the tectonic processes and further defined resources and geohazards potential.

The volcanic island arcs of the southwest Pacific share a common origin and evolution. Parts of Papua New Guinea, the Solomon Islands, Vanuatu (New Hebrides arc), Fiji, and Tonga were all once part of the older (middle Miocene) outer Melanesian composite arc. Sediment eroded from this arc filled forearc basins that later (late Miocene) were broken, rotated, and displaced along faults to form intra-arc and arc summit-platform basins. Late Miocene collision of the Ontong-Java Plateau resulted in subduction reversal and fragmentation of the outer Melanesian arc. This fragmentation of the arc, along with arc fragment rotation and separation, led to isolation and subsidence, with further sediment deposition in the basins. Continuing (Pliocene-Holocene) fragmentation of the Solomon Islands, New Hebrides, and Tonga arcs resulted from ridge collision with subduction beneath the older arc fragments and newly (Pliocene-Holocene) formed arcs. About 4 to 7 km of sediment has been deposited in the intra-arc summit-platform basins; these basins are considered the most likely targets for petroleum exploration.

In addition to basin formation, active volcanism resulting from subduction and collisional processes have carried mineral-rich melts from depth to form islands and seamounts of the arcs. Many recently formed and old island volcanoes contain finely disseminated gold that may eventually be of economic importance. Present-day formation of new spreading centers with associated hydrothermal activity, such as those found in the vicinity of the North Fiji Basin triple junction and in the Woodlark Basin, and incipient backarc spreading areas, such as those found in Vanuatu and the Lau Basin, may contain polymetallic sulfides that someday will be economic to mine.

Along with resource-oriented studies and tectonic investigations, geohazard analyses have also been made. Island arcs are regulary subjected to earthquakes, volcanism, and tsunamis. Sea-floor mapping, tectonic investigations, and seismic studies have produced data that can be used to properly plan for offshore and coastal development and to mitigate plate-margin geohazards. Marine geologic and geophysical data is used to define offhshore areas of mass wasting and topography (bathymetry) that can generate and focus tsunamis. Mapping of offshore faults and fractures commonly indicates where future earthquakes and fault ruptures may occur, as well as suggesting probable sites of new sea-floor volcanic centers.

Although significant geologic investigations have been completed along the plate margins of the southwest Pacific, much work still needs to be done. The region is large, and generally only the most dynamic areas have been investigated. With the now-available new mapping tools (i.e., GLORIA, SeaMARK, SeaBeam) that more economically define the morphology and structure of the sea floor in greater detail than previously used tool, a new phase of exploration should begin.

As a result of past investigations, two sites in the southwest Pacific have been selected for drilling by the Ocean Drilling Program (ODP): (1) Leg 134 (Vanuatu), where drilling will be done in the zone of collision between then D'Entrecausteaux Ridges and the arc and within the intra-arc basin; and (2) Leg 135 (Lau Basin), where drilling will be done in the vicinity of a newly discovered magma chamber. This drilling program will contribute considerable new data and should initiate a new and productive phase of regional exploration.

POSTER

GREENE, H.G.

Multiple Beam Echo Sounding Systems - A New Tool for Geologic Mapping

Sea Beam and Bathymetrics Swath Survey System (BS^3) are wide-swath, multiple-beam echo-sounding systems that produce more accurate bathymetry at 100% coverage than is obtainable with a conventional single-beam fathometer. Sea Beam is normally operated at a frequency of 12 kHz and obtains data from 600 m to deeper depths, whereas the middepth BS^3 operates at a frequency of 36 kHz and obtains data between 150 and 600 m. Multiple-beam echo-sounding systems are characterized by narrow fore and aft transmit pulses that are directed through relatively large angular zones athwartships. Hydrophone arrays receive the incoming echoes and algebraically resolve these echoes into multiple beams extending outward from vertical in a fan-shaped pattern. Sea Beam can obtain a total potential swath of 42.66°, and BS^3 can obtain a 105° potential total swath width. As water depth increases, geometric spreading of the beam pattern occurs; thus, resolution is inversely proportional to water depth. Efficiency of areas coverage, however, is directly proportional to water depth. Sea Beam and BS^3 are measoscale tools. Sea Beam, for example, cannot unambiguously identify features that have horizontal dimensions less than 5% to 10% of water depth; small conical features appear relatively smeared out and truncated.

Recently declassified multiple-beam wide-swath echo-sounding data collected along the offshore margins of the United States by the National Oceanic and Atmospheric Administration (NOAA) show many geomorphologic features that lead to significant new geologic conclusions. For example, a 1:50,000 and 1:100,000 scale gridded data set produced from swath mapping in the Monterey Bay region of California indicate that the sea-floor topography is influenced by sedimentary and tectonic processes, which are both active along the outer parts of the central California margin. The sedimentary morphology in and adjacent to the Ascension-Monterey Submarine Canyon system are well defined in the data set and lead to new interpretations of the canyon-forming processes. Mass wasting along the lower canyons' walls appear to be the dominant modifying process along the continental slope and contributes significant sediment to the lower fan valleys and the fan. On the shelf, Monterey Canyon intercepts sediment transported by longshore currents, but this sediment appears to be trapped and ponded behind slump dams in the narrow upper canyon.

All the canyons and fan valleys (Soquel and Carmel Canyons and Ascension Fan Valley) tributary to Monterey Canyon and Fan Valley are hanging valleys, indicating Monterey Canyon to be the dominant erosional channel of the system.

Retrogressive slumping, slump structural meanders, point and median bars, braided channels, fall and plunge pools, abandoned and partly filled channels, and many other sedimentary morphologic features are identified in the data set. A distinct change in sedimentary processes can also be correlated with a major tectonic boundary.

Interpretation of multiple-beam swath-mapping bathymetric data can produce new and significant ideas helpful in the understanding of sedimentary processes and tectonic framework. Swath mapping data can be combined with GLORIA and other wide-swath side scan-sonar data to justify and improve interpretations. Three-dimensional, net-mesh diagrams generated from gridded data sets are useful in refining morphology and give the added dimension of viewing sea-floor topography from various directions. Geophysical data, such as high-resolution 3.5 kHz seismic-reflection profiles, are commonly collected along with the bathymetric data; and incorporation of these data allow construction of an excellent geologic map.

RESERVE PAPER

GREENE, G.H. and JOHNSON, P.

Geology of the Central Basin Region of the New Hebrides Arc Inferred from Single Channel Seismic Reflection Data

Single-channel seismic-reflection profiles collected in the Central Basin Region of Vanuatu, which includes the intra-arc basin of the central New Hebrides Arc, were used to define offshore structure and stratigraphy. Twelve stratigraphic units forming five age groups are identified. Interpreted ages range from Oligocene to Holocene, with hiatuses in early middle Miocene, middle Miocene, and early Pleistocene times. Interpreted lithologies include volcanic rocks, calcarenite, calcilutite, other carbonate rocks, graywacke, and unconsolidated pelagic ash, skeletal mud, and fluviomarine deposits. Most of the stratigraphic units identified acoustically offshore are correlated with onshore sections.

The three hiatuses are marked by regional unconformities and correspond to three episodes of uplift and erosion along the western and eastern margins of the intra-arc basin since early middle Miocene time. More conformable relations in the axial parts of the basin indicate that it remained below sea level throughout Neogene and Quaternary times. The middle Miocene unconformity attests to a period of erosion on the major horst blocks that host the islands of Espiritu Santo and Malakula. This erosional episode was succeeded by a north to south marine transgression. The basal Quaternary unconformity is recorded on the island by elevated terraces and reefs.

Seven sedimentary basins have been identified that underlie an aggregate area of 26,000 km^2. The basins have all formed in response to complex development of horst and grabens. These basins (in decreasing order of size) are North Aoba, South Aoba, Malakula, East Santo, Big Bay, Cumberland, and Queiros. The North Aoba basin contains the thickest sedimentary sequence (5-6km).

HILL, P.J., and COULBOURN, W.T.

Geophysical Expression, Distribution and Origin of Manihiki Plateau Mud Volcanoes

Introduction

In 1986, during the Tripartite II research cruise of HMNZS 'Tui', an unusual piercement structure was recorded by seismic in the 900 m thick sedimentary section at the northeast edge of Manihiki Plateau. This feature and the adjacent area were investigated in more detail in the following year as part of the program of the R/V 'Moana Wave' expedition (MW87-02). In addition to being well-equipped geophysically (airgun seismic, magnetics and gravity), the 'Moana Wave' carried the seafloor imaging SeaMARC II system which has a bathymetry/side-scan sonar swath width of up to 10 km. The seafloor images showed the feature to be a conical mound about 150m high and 500 m in diameter, surrounded by a shallow depression or moat. It was but one in a field of about 100 such cones subsequently found distributed about and culminating in a central composite edifice, 1900 m high and 25 km across, located just to the north. The complex is centred at 10° 18.5'S, 161° 27.5'W, about 50 km southwest of Rakahanga Atoll. The composite edifice rises from a plateau depth of about 3200 m to a summit at 1310 m below sea-level.

Though the observed structures are clearly manifestation of active, or recently active, volcanism on the plateau, there is still no conclusive evidence as to their origin - are they sedimentary (i.e. mud volcanoes) or igneous intrusions and flows?

Morphology and seismic expression

Individual cones appear as acoustically transparent piercements on single channel seismic reflection profiles. 'Wipe-out' zones are also present at depth within the seismic sections.,

SeaMARC II side-scan images of piercement structures which intersect the seafloor typically reveal nearly conical, steep-sided peaks of about 1 km diameter rising several hundred metres above the smooth and featureless plateau surface. Many of the cones are formed by multiple flow units. A few appear to have summit depressions, and moats partially surround some of the cones. Patterns in the SeaMARC II images suggest fluid sediment flow radiating from the centre of the main edifice, then trending toward the northeast via a submarine outwash plain incised by channels transporting the sediment to abyssal depths.

Local structure and stratigraphy

The seismic data in the vicinity of the composite edifice has been interpreted by correlating to the DSDP 317 drill site at the centre of the high plateau. On the plateau side of the edifice (to the southwest), the sedimentary section above basalt basement is seen to comprise two main units - (i) a mid-Late Cretaceous unit intense alteration haloes consequent on widespread feldspar and ferromagnesian mineral destructive reactions, silicification and pyritisation. Other characteristics of epithermal systems are the transfer of potassium into the upper few hundred meters of the system and, due to the presence of reduced sulphur, the widespread demagnetisation of host rocks. These features allow that airborne magnetic, radiometric and resistivity surveys are very useful in locating epithermal systems. The former have been very successful in epithermal exploration throughout eastern Australia. Such surveys also provide basic geologic information and, depending on correct flight line orientation, may locate major regional and related structures which canprovide a fundamental control on the location of ore districts. The recognition of possible regional structures is also aided by satellite thematic mapper and SLAR radar imagery.

Recent discoveries in the young volcanic regions of the Pacific Rim demonstrate the effectiveness of modern exploration concepts and methods, and also emphasize the potential for further major ore discoveries but discoveries of epithermal gold deposits are not confined to young volcanic terranes. In Eastern Australia, epithermal veins, eg. Pajingo and Wirralie (12.5 Mt at 8.7g/t and 3.65 Mt at 2.75 g/t gold respectively) have been discovered during systematic exploration of upper Paleozoic felsic volcanics in northern Queensland and a deformed, alunite-kaolinite type deposit has been found at Temora, NSW. Similar Paleozoic deposits are in production in South Carolina, USA.

RESERVE PAPER

HAWKINS, W. J.

Backarc Basins - Their Evolution/Geolgical Characteristics and Importance in Crustal Evolution

Backarc basins (BAB) are sites of generation of new oceanic crust due to upwelling of mantle material, fractional melting of these mantle diapirs and emplacement of broadly tholeitic basalt into linear zones of extension, or at seamounts. Tectonic-magmatic processes, and the chemistry of crustal rocks generated, resemble those at mid-ocean ridge spreading centers. The basins are situated in regions of lithosphere dilation between remnant and active volcanic arcs adjacent to oceanic trenches, and many overlie the trace of the seismic zone interpreted as the trace of the subducted plate of oceanic lithosphere. There is no mechanical coupling between the convergent plates and the zone of extension, but mantle counterflow may help drive the diapirs and cause the opening of the basin. The geometric configuration of the subduction vectors, seismic zone trace and fabric of the backarc basin, may be highly variable, ranging from subparallel (e.g. Mariana Trough) to nearly orthogonal (e.g. Andaman Sea). This history of opening of some basins suggests continual reorganization of spreading centers and extension vectors, plus propagation of spreading rifts into older forearc crust (e.g. Lau Basin). Most BAB appear to have had life spans of $<$7-10 Ma, suggesting that they may be tectonically unstable and subject to deformation during reconfiguration of lithospheric plate motions.

Although most BAB are floored by hypersthene and olivine normative basalt, broadly similar to mid-ocean ridge basalt (MORB), we find a range in composition both within some BAB and between them. For example, the Mariana Trough is formed largely of MORB-type basalt with MORB-like Pb, Sr, Nd and He isotope ratios. However, the Mariana Trough basalts are distinctive in having higher concentrations of alkalis, alkaline earths, light REE and H_20 than MORB with comparable Mg levels. Enrichment of the mantle source with these elements is implied. The axial ridge of the Mariana Trough is capped by pinnacles of andesitic composition pillow lavas (54-56% $Si0_2$) that were derived by fractional crystallization of the basalt; these are not arc lavas.

The Lau Basin has a regional zonation in which older crust resembles the Mariana Trough while the younger crust, including the axial neo-volcanic zone, is more like MORB in alkalis, etc. However, all Lau Basin samples have more radiogenic Sr for a given Nd ratios Nd ratio are like MORB. The Lau Basin is also characterized by a seamount province, formed of E (enriched)-type MORB, and a major spreading ridge that is largely andesite-dacite (e.g. 54-72% $Si0_2$); isotope evidence shows that this is not island arc rock but is derived from the same mantle source as the basalt. An origin due to fractionation of tholeiite and mixing with early fractional melts of amphibole-rich (altered) older crust is suggested.

Backarc basin magma chemistry does not require any direct chemical contribution from the subducted lithosphere slab or from the mantle sources feeding the volcanic arc. Mixing of old, subducted lithosphere into the mantle may provide the selective enrichment in Pb and Sr seen in parts of some basins.

Backarc basins, together with island arcs, are an important locus of generation of new crust in oceanic environments. They are also likely sources for many, if not most, of the ophiolite suites. Ophiolite "obduction" may be due to collision between arcs and BAB when subduction is blocked but plate convergence continues.

HAWKINS, W.J.

Intra-plate Volcanism - Louisville and Samoan Linear Volcanic Chains as Possible Hotspot Traces

Intra-plate volcanoes give important insights to the nature of the sub-lithosphere mantle and its temporal evolution. Linear volcanic chains also serve as tracers of large scale relative motions of oceanic plates. The Samoan Island chain, and the seamounts and guyots of the Louisville Seamount Chain, have trends and age distributions suggesting that both formed by progressive injection of mantle-derived melts into Pacific Plate lithosphere as the plate moved across a relatively fixed magma source - e.g. a "hotspot". Their chemistry indicates that each tapped a distinct mantle source. The youngest volcanism in the Samoan Chain although petrologically equivalent to "final" stages of hotspot volcanic series, may be related to stresses in the lithosphere plate distorted by the Tonga Trench subduction zone. This volcanism has been offset from the southeastern end of the chain to Savaii, Upolu and Tutuila where plate distortion has developed fracture systems that have controlled the youngest eruptions.

The Louisville Seamount Chain (LSC) intersects the Tonga-Kermadec Trench systems at 26°S where it causes the trench axis to shoal to 6000 meters. The LSC extends southeastward 4300 km to the Pacific-Antarctic ridge and is marked by more than 75 seamounts. The chain youngs from about 66 Ma (Osborn Smt) at the trench to 0.5 Ma at the SE end. Modern volcanism on Savaii, and Holocene volcanism in Samoa masks an age progression for shield volcanoes there that appears to young to the SE from middle Miocene submarine banks on the west to 1 Ma at Tutuila. The Samoan Chain shows part of the classic Hawaiian magma sequence youngest lavas that form the domelike carapace of Savaii and flows/cones on Upolu and Tutuila are basanitoids like the Hawaiian post-erosional lavas. These overlie fractionate and alkalic basalts and hawaiites that fill calderas or form radial dikes; trachytes form plugs on caldera rims. The main mass of each island is formed of alkali-olivine basalt with varied extent of fractionation. The Samoan chain is characterized by OIB Sr and Nd isotope ratios; younger lavas reflect a less depleted source than older (e.g. post-erosional series has $^{87}Sr/^{86}Sr$ 0.7.50-0.7062, $^{143}Nd/^{144}Nd$ 0.51266-0.51269; shield lavas have 0.7-045-0.7055, 0.51275-0.51295). This is the opposite from the Hawaiian series.

Seamounts of LSC followed a parallel magmatic evolution with less voluminous eruptions even though numerous volcanoes were formed. Dredged rocks include basanitoids, alkali basalt and differentiates. DSDP site 204, north of Osborn Smt., recovered K age gravels with clinopyroxene-bearing phyric basalt. The CPX has Si:Al indicating a tholeiitic source; thus, oldest lavas of LSC may include tholeiitic basalt and the complete Hawaiian progression may be present.

The LSC isotope data contrasts with both Samoan and Hawaiian. There is little variation for Nd or Sr between rock types or throughout the length of the chain. Mixing of mantle sources and a change in ratios through time is implied for Samoa, but the LSC tapped a homogeneous source throughout its history.

HENLEY, R.W.

Epithermal Gold Mineralisation and Epithermal Exploration in the Circum-Pacific Rim

The close association of epithermal precious metal ore deposits and volcanic rocks has been recognized for a long time but it is only recently that new steps have been taken in understanding these relationships. These steps have come from a series of integrated geoscience studies on active geothermal systems in the volcanic terranes of the Pacific Rim during their exploration. In some case of these systems (eg. Waiotapu and Broadlands, New Zealand and Osarazen, Japan) gold deposition is known to be occurring and the mechanisms for gold deposition are now well understood.

Combined with the increase in the world price of gold in the early 1980's and lower cost extraction methods, this high confidence understanding of the relation between gold deposits and high level magmatism focused recent exploration on the young volcanic terranes of the circum-Pacific region resulting in a number of major new discoveries, eg. Lihir Island, Papua New Guinea (167 Mt at 3.4g/t), Hishikari, Japan (1.4 Mt at 70g/t), progressive exploration of earlier developed prospects, eg. Kelian, Indonesia (>40 Mt at 2g/t) and Porgera, Papua New Guinea (80 Mt at 3.7g/t + 5.2 Mt at 25.5g/t in Zone 7), and redevelopment of epithermal deposits mined earlier this century, eg. Waihi (14 Mt at 3.5g/t) and Golden Cross (5 Mt at 4.4g/t), New Zealand. Gold deposits in deeper but related volcanic environments are also important, including porphyry deposits such as Bougainville (625 Mt at 0.46g/t) and associated skarn deposits, OK Tedi (351 Mt at 0.59g/t).

Present reserve estimates for epithermal and porphyry type gold deposits in the S.W. Pacific alone are around 2100 tonnes of gold compared with total past production of about 600 tonnes. Such reserves are as important in the socio-political evolution of nations in these regions as were the epithermal districts of northern Greece and Romania to the establishment of ancient Greece and Rome.

Epithermal precious metal deposits form in the upper few hundred meters of large hydrothermal convection systems in volcanic terrane. Most commonly vein and disseminated deposits are hosted by rocks altered to sericite/clay-K-feldspar assemblages. Gold deposition is frequently the result of boiling and is accompanied by abundant silica and adularia. Examples are Round Mountain, Nevada, McLaughlin, California and Hishikari, Japan. A second common association is between gold-copper (often as enargite) ores and zones of high temperature advanced argillic alteration. In this case the advanced argillic alteration has been produced by volcanic gases but later mineral assemblage acts as a chemical trap for metals subsequently introduced by a long lived convective system. Examples of such alunite kaolinite (or acid sulfate type deposits) are Goldfield, Nevada, Iwato, Japan and El Indio, Chile.

Modern exploration for epithermal deposits follows the methodology developed in the 1960's and 1970's for porphyry deposits and volcanogenic massive sulphide deposits. The majority of large epithermal systems are characterised by large

400 m thick, predominantly of vocaniclastic sediments, but grading to limestones and chalks near the top of the sequence (at least at DSDP 317), and (ii) an overlying 500 m thick Tertiary sequence of cherty chalks, nanno-foram chalks and oozes.

The section is completely obscured beneath the edifice because of the diapirism and rugged topography. However, mapping of basement structural contours adjacent to it suggests that the edifice is located on a local basement high.

The plateau margin to the northeast of the edifice is formed by a major zone of normal faults which step the plateau down to abyssal depths. To the north, the fault zone is fairly narrow and well defined with a NNW trend, however immediately northeast of the edifice the fault zone broadens and appears to swing to a more NW-SE trend. Erosion (by ? ocean currents) has severely truncated much of the sedimentary section at the edge of the plateau.

Gravity and magnetic expression - potential field modelling

The free-air gravity field over the area mainly reflects the combination of crustal thickening across the margin of the plateau and local seafloor topography - large gravity highs are centred over nearby Rakahanga and Manihiki atolls, while a 61 mgal positive anomaly is located directly over the complete edifice. Three-dimensional modelling of the feature indicates a density of 2.4-2.5 t/m^3 for the upper part of the structure, and a probable higher density at depth. Such densities are greater than would be expected for unconsolidated sediment.

The magnetic field over the general area is moderately anomalous. Both Manihiki and Rakahanga atolls have strong magnetic signatures associated with their volcanic pedestals. Field variations trending northward along the plateau margin are in the order of 300 nT. Much of the magnetic variation is believed to result from structural relief on the basaltic basement and possible infra-basement magnetic heterogeneities. The size and nature of anomalies in the vicinity of the composite edifice are not significantly different to those present farther north where no such seafloor features exist. It is difficult to establish exactly how much of the anomalous field can be attributed directly to the edifice or to any internal magnetization it may possess. The seismic data indicate that the feature is located adjacent to a major fault zone, so part or all of the anomalous field may be due to faulted basement at the plateau edge. The possibility of an underlying igneous volcanic body cannot be ruled out, however. Magnetic profile data from a long SW-NE line crossing the edifice just to the north of its summit were processed by Werner deconvolution. Clusters of magnetic source estimates at depths of about 2.0 to 3.5 km below sea level directly beneath the feature, indicate an internal igneous component.

Three-dimensional magnetic modelling of the composite structure (assuming uniform magnetization) yields a reasonable, though not precise fit to the observed anomalous field. The mismatch could be due to non-uniform magnetization. An improved fit is obtained by assuming that the edifice is non-magnetic down to a depth of 2.4 km below sea-level.

Modelling has produced best-fit values for density of 2.4-2.5 t/m^3 and effective magnetization of about 3.0 A/m. Such values are typical of basaltic seamounts in the Pacific and this tends to argue against a sedimentary origin for the edifice.

Seafloor sampling

Though time constraints limited the sampling program aboard 'Moana Wave' in the area, some seafloor samples were recovered.

Free-fall corers released over one satellite cone returned with Recent foraminiferal ooze. Burrowed limestone dredged from the summit of the composite edifice contained embedded mid-Eocene planktonic foraminifera. Some of the limestone cobbles were manganese encrusted; coralline fragments were also recovered in the same dredge. No igneous rocks were recovered.

The recovery of mid-Eocene limestone near the summit of the edifice suggests that this material must have been transported vertically upwards by about 1.4 km, assuming it originated from the Manihiki Plateau sedimentary section. It provides strong evidence for possible fluid-driven mud volcano formation.

Distribution of volcanic cones and diapirs

Most of the mapped cones and diapiric structures on Manihiki Plateau lie within 25 km of the composite edifice, which is clearly a major focal point of activity. This area is however, not the only part of the plateau affected. A number of diapir-like structures can be seen in the 'Tui' and 'Moana Wave' seismic profiles recorded over other areas of the High plateau, and also the western Manihiki Plateau, though some may be narrow fault blocks.

An isolated cone, about 200 m high and clearly resolved in the SeaMARC II images, is located on the plateau about 20 km west of the eastern marginal ridge at about 12°S. A similar cone, also imaged by SeaMARC II, projects above the flat and relatively featureless surface of the central High plateau. It was discovered on investigating a diapiric structure in the 'Glomar Challenger' seismic profile recorded near the DSDP 317 drill-site; the structure overlies a prominent basement ridge.

Possible sedimentary origin

The satellite cones seen in the SeaMARC II mosaics are very similar in form to the subaerial mud volcanoes of the Makran, Caspian Sea, area and Timor in Indonesia. Those mud volcanoes range in size from a few tens of metres to about 400 m high.

Methane overpressuring is commonplace in marine sediments and generally represents the driving mechanism in the formation of subaerial shale diapirs and mud volcanoes. Methane may therefore be a likely agent for the formation of the Manihiki Plateau cones, especially because a small portion of the Cretaceous section drilled at DSDP 317 is sapropelic. High organic carbon content (28.7%) was measured in a thin interval within volcaniclastic sandstones of high porosity, overlain by limestone and calcareous claystones of significantly lower porosity and permeability. Such a source/seal configuration provides an ideal setting for overpressuring to occur.

The composite seamount is a large scale structure that could conceivably only be created by a vigorous, localized geodynamic process. A magmatic heat source may be a driving force. Such a heat source could accelerate hydrocarbon generation in the sapropelic Cretaceous beds and could mobilize pore fluids by convection. Magma emplacement may have produced local uplift and fracturing of ovrlying formations, facilitating upward movement of fluids and fluidized sediment. Explosive emission of magmatic water vapour and carbon dioxide through a sediment pile may contribute to mud volcano formation.

Conclusions

The discovery of a large, apparently active, field of volcanoes on Manihiki Plateau has surprised many marine scientists. Such mid-ocean plateaus have previouly been regarded as relatively passive environments, lacking powerful geodynamic systems such as those associated with active plate boundaries.

The interest generated has led to the programming of a follow-up research cruise dedicated to investigate the volcanic complex more fully. This cruise is planned for early 1990 and will be conducted by R/V 'Sonne' of the Bundesanstalt fur Geowissenschaften und Rohstoffe, Hannover. The investigation will include Seabeam bathymetric mapping, piston coring, video and conventional bottom photography, hydrographic and geochemical sampling, as well as heat flow measurements. It is hoped that such a comprehensive investigation will answer some of the questions raised by the discovery of this enigmatic field of volcanoes.

POSTER

HILL, P.J., COULBOURN, W.T., GLASBY, P.G., MEYLAN, A.M. and SHIPBOARD SCIENTISTS

Manihiki Plateau: Results of Recent SeaMARC II Geophysical and Seafloor Sampling Investigations

The investigations

Resource oriented geological and geophysical investigations were conducted over Manihiki Plateau and its margins during research cruises by HMNZS 'Tui' in 1986 and R/V 'Moana Wave' in 1987. These cruises were part of the Tripartite II Program undertaken by the government of Australia, New Zealand and the United States of America, in co-operation with the Committee for Co-ordination of Joint Prospecting for Mineral Resources in South Pacific Offshore Areas (CCOP/SOPAC) to carry out joint marine geoscientific research and mineral resource studies in the South Pacific region.

The investigation of Manihiki Plateau, and its eastern margin in particular, was aimed at multiple objectives - (i) to map the structure and stratigraphy of the submarine geology to extend our knowledge of the area's geological framework and tectonic evolution, (ii) to locate and sample submarine exposures of Early Cretaceous volcaniclastic sediments correlative with a Copper bearing interval intersected at Site 317 of the Deep Sea Drilling Project (DSDP) in order to learn more about the nature of mineralization and to establish its lateral extent, and (iii) to dredge for manganese nodules and FeMn-oxide crusts, map their distribution, study the depositional environments and assess their mineral resource potential, particularly in relation to cobalt content.

The 'Tui' and 'Moana Wave' surveys included seismic profiling (single channel with 120 cu. inch airgun source), gravity and magnetic profiling, plus 3.5 kHz and 12kHz bathymetry. Seafloor sampling was mainly by dredge (rock and pipe), but also by corer. The 'Moana Wave' was equipped with a SeaMARC II bathymetric and side-scan seafloor mapping system. This system has a swath width of 10 km in deep water, and was operated at a speed of 8 knots in conjunction with the other geophysical methods. Extensive areas of northern, eastern and central parts of the plateau were surveyed in this way. Total SeaMARC II coverage amounted to about 8000 km^2. Navigation aboard 'Tui' was by the TRANSIT and GPS satellite systems.

Geological background

Manihiki Plateau is a large, anomalously shallow area of seafloor about 500,000 km^2 in size, located in the central Pacific Ocean. It is one of a number of such features in the Pacific that total about 2% of the ocean basin - other similar plateaus being Ontong Java Plateau, and Shatsky, Hess and Magellan Rises. The most elevated part of the plateau, the south-east sector, is known as the Manihiki high Plateau. It rises from adjacement ocean basins, which are about 5500 m deep, to a relatively smooth, dome-shaped upper surface lying mainly 2400-3000 m below sea-level. The high Plateau is bounded by Danger Islands and Suwarrow Trough to the west, Samoan Basin to the south, Central Pacific Basin to the north and Penrhyn Basin to the east. The margins of Manihiki Plateau all appear to be structurally controlled with structural development most spectacularly expressed along the eastern margin of the plateau where the High Plateau plunges 3500 m into the depths of the Penryhn Basin along a descending series of high-relief ridges and troughs.

Manihiki Plateau is capped by a thick section of sediment with a well developed internal acoustic stratigrapy. DSDP drilling in 1973 at Site 317 located near the centre of the High Plateau penetrated the entire section and entered basement. Three holes (317, 371A & 317B) were drilled in a water depth of 2622 m and reached 943.5 m sub-bottom depth. The section was found to consist of (i) 424.5 m of late Pleistocene-early Eocene nannofossil and foraminiferal oozes, chalks and cherts, (ii) an uncored gap of 129.5 m probably occupied by Palaeocene pelagic sediment, (iii) Maestrichtian through Aptian-Barremian (?) chalk, chert, limestone and siltstone in the interval 554-677.5 m, (iv) volcaniclastic sandstones and siltstones (mollusc-bearing in the uppermost part, but otherwise barren of fossils) between 677.5-910 m, and (v) tholeiitic, MORB-type basalt flows with intercalated thin volcanogenic siltstone/sandstone beds from 910 m to the bottom of the hole at 943.5 m sub-bottom. The age of the basalts is probably 110-112 Ma.

The basalt flows and overlying volcaniclastic sediments appear to have been deposited in relative shallow water (several hundred metres depth to (?) subaerial). This is evidenced by the extreme vesicularity of the basalt, the presence of hyaloclastics and the occurrence of bivalves and gastropods of shallow shelf (<200 m water depth) aspect in the uppermost section of the volcaniclastics. The absence of fossils in all but the upper part of the volcaniclastics suggests an initial rapid accumulation rate as large volumes of basaltic lavas erupted explosively in shallow water. Then, as volcanism waned, the deposits were reworked by currents and colonized by benth fauna. According to Winterer et al (1974) the volcanic foundation of Manihiki Plateau evolved at a seafloor spreading centre near the Pacific/Antarctic/Farallon plate triple junction in the Early Cretaceous. The early evolutionary history of Manihiki Plateau could be likened to the modern development of Iceland.

The volcaniclastic sequence overlying the basalts is about 235 m thick and is of considerable interest because of its native copper content. The native copper, which occurs as disseminated blobs and strands, is distributed in zones throughout most of the volcaniclastic section. The average copper content of the sediment is not remarkably high-150 ppm from 6 analyses, though one analysis yielded a value of several thousand ppm Cu. Chalcopyrite is present in the underlying basalts. Jenkyns (1976) attributes the native copper to precipitation from cupriferous fluids driven through the sediment column by a convective hydrothermal system. Clay seams observed to traverse the volcaniclastic sediments may have acted as conduits for the mineralized solutions. Relatively large hydrothermal mineral deposits have been discovered along the presently active seafloor spreading centres - similar deposits may exist within the Manihiki Plateau volcaniclastic unit.

Cu-bearing volcaniclastics

Seismic lines obtained previously over Manihiki Plateau by a number of scientific expeditions and by our own surveys show strata correlative with the volcaniclastics at DSDP 317 outcrop on fault scarps on the margin of the plateau as well as on the walls of fault-bounded troughs cutting across the plateau. Dredging of such exposures could provide valuable information on the nature and extent of mineralization within the Manihiki Plateau volcaniclastics. Dredges attempted on the northeast margin of Manihiki Plateau during the 1984 R/V 'Sonne' research cruise (SO 35-1), native copper was not recovered. We were successful in dredging volcanic sandstones, siltstones and claystones, stratigraphically equivalent to the Cu-bearing units at DSDP Site 317, from several areas of the plateau, including its eastern and northeastern margins as well as Suwarrow Trough. However, our preliminary examinations of the volcaniclastic samples in both thin and slab sections revealed no evidence of native copper particles. Either copper mineralization never developed locally within the intervals sampled, or quite possibly, was leached out by circulation of seawater through the submarine exposures.

Mn nodules and crusts

All our sampling stations located on the crest of the High Plateau indicate a surface of light brown nanno-foraminiferal ooze devoid of manganese nodules. Areas adjacent to the northern part of the eastern marginal ridge are shown in the seismic profiles as being severely affected by erosional truncation. The recovery of unconsolidated ooze even from these areas may indicate a recent return to tranquil bottom water conditions and renewed deposition. This is supported by bottom photographs which show a tracked and burrowed surface without any sign of strong current activity.

The absence of Mn nodules on the plateau contrasts with the situation on the marginal slopes where nodules are abundant both on ridges and in troughs. Red clays and nodules blanket the adjacent Penrhyn and Samoan Basins at abyssal depths. It is not uncommon for nodule coverage of the seafloor there to be as high as 50-70%. In addition, all exposed rock surfaces on the marginal slopes are FeMn-oxide coated or encrusted - this is observed in bottom photographs and seen on dredged rock specimens. Thickest FeMn-oxide crusts (35-45 mm) were dredged from the eastern marginal slope. Bottom photographs taken on the upper part of this slope show foraminiferal sand surfaces to be rippled and current lineated, as well as scoured around nodules and boulders embedded in the sands. This evidence of vigorous bottom water movement suggests conditions of low sedimentation or even erosion. Such conditions are known to be conducive to manganese nodule development which probably explains the abundance of nodules and the well-developed FeMn-oxide crusts on the marginal slope.

Structure stratigraphy and evolution of the eastern margin

Three major reflecting horizons are indicated in the sections shot over the eastern plateau: horizons b, m and k. From seismic reflection and drilling data correlations made at DSDP Site 317 we interpret these horizons as representing the following lithostratigraphic boundaries.

Reflector		Unit Description	Depth below seafloor at DSDP 317 (m)
Seafloor (s)	------------------------------------		0
		Foraminiferal/nannofossil ooze, chalk & chert. ?Maestrichtian/Palaeocene - Quaternary	
k	------------------------------------		576
		Nannofossil chalk, claystones and limestone - very minor interbedded volcanogenic sandstone to siltstone (near base) ?Barremian/Aptian- Maestrichtian	
m	------------------------------------		675
		Volcanogenic sandstone to siltstone, containing mineralized zones. ?Barremian/Aptian (oldest fossil date 107 Ma)	
b	------------------------------------		910
		Tholeiitic basalt flows. 110-112 Ma (106 +/- 3.5 Ma K/Ar minimum age).	

Two main phases of tectonism postdating construction of the Manihiki volcanic edifice are evident in our seismic data. Phase 1 is represented by normal faulting that affects basement and extends partly or completely through the overlying basal volcaniclastic sequence (m-b). These structures were probably created in response to late stage oceanic rifting in the area and to differential subsidence as the volcanic pile began to cool and sink. The time of this episode of deformation would be late Barremian-early Aptian, about 112-107 Ma. Phase 2 is expressed as (i) normal faulting that extends through the chalk/nannofossil claystone/limestone sequence (k-m), (ii) tilting of the sub-k units at the plateau margin, and (iii) angular unconformity (k). The onset of Phase 2 probably occurred during the late Maestrichtian-Palaeocene about 65 Ma. Minor deformation affecting the Tertiary section is also seen on the High Plateau, but is mainly restricted to small scale, local, normal faulting, slumping, and compaction structures. A 500 m thick pile of pelagic carbonate has accumulate on the plateau since the beginning of the Tertiary. Adjustment of basement to the additional load and internal soft-sediment deformation are likely causes of many of the observed structures.

The extraordinary length (up to 1200 km) and linearity of the prominent ridge along the eastern margin of the plateau and its structural extensions to the north and south, as well as the extensive set of side-scan lineations trending parallel to the marginal ridge, strongly suggest transform faulting as the primary structural mechanism. The apparent lateral truncation of sequences m-b and k-m is consistent with their being offset by transform movement. Thus the linear eastern margin of the High Plateau is tentatively interpreted as a fracture zone active at the time of Phase 2 tectonism, i.e. from about 65 Ma.

Crustal structure

The difference in free-air anomaly between that in the Penrhyn Basin (-15 to 0 mgal) and that over the Manihiki Plateau (about 15 mgal) is relatively small considering the tremendous change in seafloor elevation, amounting to about 3000 m. The relatively subdued gravity expression of the plateau (see also Haxby, 1987) suggests that the mass of Manihiki Plateau is isostatically compensated. In addition, the absence of a well defined gravity 'moat', such as surrounds the islands of Hawaii, beyond the plateau margin implies that compensation is local, signifying that the plateau was emplaced on relatively young oceanic crust of low flexural rigidity, i.e. close to a spreading centre. The fact that the plateau appears to be isostatically compensated, coupled with its considerable 3000 m relief above the adjacent ocean basins, indicates that the crustal thickness of Manihiki Plateau is substantially greater than that of normal oceanic crust.

Sonobuoy seismic refraction soundings have been made at a number of locations on and adjacent to Manihiki Plateau. Sounding 68 in the Penryhn Basin indicates a typical ocean basin crust with a mantle depth of about 11.5 km, while beneath Manihiki Plateau the average structure derived from a number of soundings suggests a velocity structure similar to that of typical oceanic crustal layers 2A-3A, but beneath Manihiki Plateau each of these layers is about 3.1 times thicker than normal. The average crustal model for Manihiki Plateau puts the deepest recorded layer of 6.8 km/s at a depth of 10.7 km. No refraction data with deeper penetration to the lower crust and mantle are available. On the basis of the similarity of the shallow crustal structure between the Ontong Java and the Manihiki plateaus, Hussong et al. (1979) extrapolate a mantle depth of about 25-30 km beneath Manihiki Plateau.

Our gravity data and seismic profiles allow us, we believe, to make an improved estimate of the crustal thickness beneath the plateau and to construct an approximate crustal model of the eastern margin of the plateau. From gravity modelling, depth to mantle beneath Manihiki Plateau is interpreted as 19.5 km - at least 5.5. km shallower than predicted by Hussong et al. (1979). The zone of crustal thinning beneath the plateau margin is modelled as being 75 km wide. Crustal thickness changes across this zone from 17 km beneath the plateau to 6.3 km in the Penrhyn Basin. The gravity modelling cannot resolve with certainty whether the margin represents a rift or transform structure.

Diapirism and volcanic edifices

The 'Tui' and 'Moana Wave' expeditions led to the discovery of a field of active, or recently active, volcanoes on Manihiki Plateau. Though a number of submarine cones (100-200 m high) and diapiric stuctures within the sedimentary section were recorded at scattered locations on the High Plateau, the volcanism is concentrated at the northeastern adge of the plateau, about 50 km southwest of Rakahanga Atoll. Here about 100 cones appear to coalesce to form a composite edifice 1900 m high and 25 km across. It is not yet clear at this stage whether the volcansim is of sedimentary (i.e. mud volcanoes) or igneous origin. The subject of the Manihiki Plateau volcanism is discussed in more detail in an accomanying abstract (Hill & Coulbourn).

POSTER

HILL, P.J., COULBOURN, W.T., GLASBY, P.G., MEYLAN, A.M. and SHIPBOARD SCIENTISTS

Subduction of Capricorn and Machias Guyots Structural and Sedimentological Processes

Capricorn and Machias guyots are both large, flat-topped seamounts of basal diameter 100 km and 60 km respectively, located at the northern end of the Tonga Trench. They are perched on the outer trench wall in a highly dynamic tectonic environment: their lower trench-facing flanks have already reached the trench axis and subduction of the edifices is imminent. The Pacific plate on which the guyots lie is subducting beneath the Tonga Ridge in an approximately E-W direction at a rate of 9^+ cm/year. This convergence is the product of back-arc spreading in the Lau Basin and large scale relative motion of the Indo-Australian and Pacific plates. At the present convergence rate, the summit of each of the seamounts will reach the trench axis in about 0.5 Ma. Subduction in the vicinity of Machias is oblique, rather than normal as at Capricorn, because of the sharp westward bend of the Tonga Trench at its extreme northern end.

Both Machias and Capricorn were the subject of investigation as part of the CCOP/SOPAC Tripartite II program. During the 1986 HMNZS 'Tui' research cruise, two long geophysical lines (magnetics, gravity and bathymetry) were surveyed across Machias seamount, and a number of sites on the flanks and summit of the feature were dredged to recover a representative suite of FeMn-oxide crusts and rock samples. Capricorn guyot was investigated in a similar fashion, but there, the investigation included single-channel airgun seismic profiling along an E-W line over the summit and across the trench as well as a N-S line over the summit parallel to the trench axis. In early 1987, the entire Machias seamount was surveyed by a bathymetry/side-scan sonar SeaMARC II swath mapping system during the RV 'Moana Wave' cruise. Seismic, gravity and magnetic data were recorded concurrently with the SeaMARC II imagery and bathymetry.

Seismicity and fault mechanisms

Very high seismicity west of the Tonga Trench axis is associated with underthrusting of the Pacific plate beneath the Tonga Ridge. Earthquakes are shallow (0-70 km) along the trench, but deepen to the west in conformity with a Wadati-Benioff zone that dips to the west at about 45° for focii in the shallow-intermediate depth range.

Though less intense than to the west, seismic activity east of the trench axis is still moderately high within about 150 km of the axis. Capricorn and Machias seamounts are located within this zone. Earthquakes to the east of the trench axis are all shallow (less than 70 km deep) and result from internal deformation of the Pacific plate. Focal mechanism studies indicate two main types of focal mechanism solution, (i) normal faulting on fault planes striking approximately N-S, and (ii) thrust faulting, also on northerly striking planes, but dipping steeply to the west.

Bending of the Pacific plate as it enters the trench and longitudinal compressive stress within the plate are believed responsible for these styles of structural deformation.

A third type of earthquake mechanism relevant to the Machias area, is one associated with hinge faulting - a phenomenon localized at the trench bend and produced as the Pacific plate 'tears' along a vertical plane to accommondate subduction of the southern part of the plate beneath the Tonga arc and continued horizontal westward drift of the northern part.

Capricorn

The trench adjacent to Capricorn seamount is about 9 km deep with local shallowing of the trench floor by several hundred metres immediately west of the seamount. This shallowing is probably due to the combined effect of (i) the lower seamount flank starting to subduct, and (ii) a build-up of talus derived from the disintegrating slopes of the seamount.

The lower trench is V-shaped in cross-section adjacent to Capricorn Seamount, with both insular and seaward slopes inclined at about 9.5°. To the north and south of the seamount the insular slope remains much the same, while the seaward slope decreases markedly to about 4.5°. The upper flanks of the seamount are relatively steep with gradients generally in the range 15°-35°. The slopes become more gentle towards the base of the seamount, particularly on the western and southern sides where the lower slopes have gradients in the order of only 3° - 4°. At least several local topographic highs with 100-300 m relief exist on the trench-facing flank of Capricorn.

The summit area of the seamount is flat-topped at two levels. Both surfaces dip gently towards the trench. The larger surface lies at a depth of about 800-1000 m and is inclined at approximately 1.7° towards the trench. The smaller (22 km^2) but higher surface lies to the east of the summit area at about 540 m depth. Our shallowest depth recorded for Capricorn Seamount (440 m) was over a point on the southern margin of this elevated area.

The seismic profiles show that the summit area is underlain by a well-stratified sedimentary section 0.5 sec thick (500 m assuming a sediment velocity of 2.0 km/sec). On the basis of the sampling data, it appears that the sediments comprise coralline limestones, while seismic basement corresponds to basaltic rocks of the volcanic substructure.

A system of closely-spaced, steeply-dipping faults intersects both volcanic basement and sedimentary section. The faults strike predominantly in a N-S direction, parallel to the trench axis. Beneath the planar summit area, fault throws are typically 20-100 m, but beyond this area (on the upper flanks of the seamount) the magnitude of throw appears to increase to several hundred metres or more. The faults are interpreted as normal faults produced by brittle fracture of the upper crust in response to tensional stress created by flexure of the Pacific plate as it enters the trench. Such fault systems have been recorded seaward of other trenches in the Pacific. Seabeam and seismic mapping of an area over the southern Tonga Trench by the 1986 SEAPSO V expedition revealed classic horst and graben structures trending N-S which are attributed to bending of the Pacific plate at the trench.

The 1.7° westward tilt of the summit area is replicated by the bedding within the sedimentary capping and also by the basement surface. This tilt is believed to be due to movement of the seamount down the inclined outer wall of the trench. The parallelism of basement, bedding and seamount suggests typical atoll evolution followed by 'drowning' - involving sub-aerial planation of an oceanic volcano, subsidence and upward growth of coral reef forming a limestone platform, and finally rapid subsidence below the photic zone preventing further coral development.

The bedding within the sedimentary capping is best seen in the S-N seismic section which has not suffered major disruption by faulting. The section is well stratified, with beds sub-parallel and mainly gently undulating. Many of the reflectors can be followed almost right across the width of the summit area. The general continuity of reflectors indicates that much of the section may comprise lagoonal sediments. Fringing reef buildups may have largely been faulted off the sides of the summit area. Strong hummocky reflectors near the base of the section may represent early reef development.

Seismic data over the inner (insular) trench wall show no evidence of a substantial sediment thickness, small sediment ponds in local depressions on the insular slope can be seen. These contains up to several hundreds of recent sediment which appears to dip gently (0.5°-1°) away from the trench axis, suggesting possible uplift of the lower trench wall to accommodate subduction of the lower western flank of Capricorn. Such back-tilting of the inner trench wall has been observed at the southern end of the Tonga Trench where seamounts of the Louisville Ridge are being subducted (Herzer, 1986).

A total of seven sites were dredged on Capricorn Seamount. Water depths at these sites ranged from about 940-4685 m. Basalt and coralline limestone were recovered; no Mn crusts were obtained.

The dredging results indicate that Capricorn Seamount is a volcanic edifice of basaltic composition, capped by a Miocene limestone platform. Unconsolidated sediments of foraminiferal sand, shell & coral fragments and pumice mantles the relatively flat-lying limestone platform. The lower slopes of the seamount are covered by abyssal clays and sediment fans containing limestone and volcanic erosional products transported from higher levels on the seamount by debris flows. The shallowest recovery of basalt was from a water-depth of about 1850 m. This implies a maximum thickness of about 1000 m for the limestone platform, and is consistent with the seismically determined thickness of approximately 500 m. The brecciated nature of the basalt from this site may be an example of the extensive normal faulting seen in the seismic sections.

Machias

The summit area of the seamount undulates slightly but is roughly flat-topped at a depth of about 750 m. This area is elongate in shape, with its long axis aligned sub-parallel to the local trend of the Tonga Trench axis, and is about 8 km in length and 2.5 km wide. It was mapped in detail during the 1985 RAN 'Cape Pillar' bathymetric survey. The shallowest point is a local high located close to the centre of the summit area at a water depth of 636 m.

SeaMARC II bathymetry and side-scan images of Machias Seamount reveal extensive fracturing of the seamount by normal faults striking sub-parallel with the local trench axis, and considerable remobilization of the sediment cover produced by the tectonism (Coulbourn et al., in press). Tensional fracturing of the convexly flexed Pacific lithosphere as it descends into the trench is believed to be the cause of much of the observed structural deformation. The normal faults are seen as an extensive system of NW-SE trending curvilinear escarpments generally several hundred metres in height and up to about 20 km long.

The trench-facing flank of the seamount is most affected by the faulting. all flanks are incised by gullies and canyons, and are partly covered by large debris flows. Slopes are mainly 10°-35°.

The slopes of the upper part of the seamount are broken at various levels by a series of prominent terraces. The most notable terrace development occurs on the southern flank of Machias, where the slope flattens out onto large platforms 5-25 km^2 in area. Fault scarps usually bound the terraces on the up-slope side. The terraces are believed to be sections of a flat-topped summit area that was once several times larger than at present. Substantial portions of the summit area were apparently down-faulted as the southern part of the seamount deformed in descending into the trench. The terraces on the SW flank tilt roughly 2-4° towards the trench, whereas the summit area is close to horizontal suggesting that this part of the guyot has, as yet, been little influenced by the descent and concomitant fracturing.

The trench floor SW of Machias lies at an average depth of about 7.5 km. A maximum depth of 7.7 km is attained in a local depression directly down-slope from the seamount. The Tonga fore-arc side of the trench is characterized by hummocky terrain with local ridges and troughs.

The 'Moana Wave' seismic data indicate an extensive blanket of well-stratified sediment several hundred metres thick to the north of the seamount. These sediments lie in water depth of about 4500 m and probably comprise hemipelagic silts/clays bearing radiolaria and tuffaceous material from volcanic ash falls. Up to several hundred metres of sediment is ponded in local depressions on the trench floor and lower insular slope. The thickness of the sedimentary capping on thick sediment acculations are evident in the vicinity of Machias.

The survey data portray Machias as a large (4 km high) volcanic edifice capped by a relatively thin (?500 m) carbonate platform. The platform is composed of partially recrystallized, reefal limestones mantled by a veneer of unconsolidated foraminiferal sand and coral/carbonate debris. Samples dredged from the flanks show that the volcanic pedestal is composed mainly of basalt. Both vesicular and massive types are present (in about 1:1 ration); some contain ultramafic inclusions. Tuffs are represented in the dredge samples and so appear to be a minor lithological component of the volcanic edifice. The high mobility of the debris flows is indicated by the recovery of mixtures of vry well rounded to angular pebbles and cobbles in dredge hauls.

The presence of dunite inclusions within fresh basalt (K/Ar age of 1.4 Ma) recovered in two dredge hauls suggest that this late volcanic activity is party sourced directly from the mantle. This is in keeping with the major lithospheric deformation taking place close to Machias.The 'hinge' faulting, in particular, may cut right through the entire lithosphere potentially allowing access of mantle magmas to fractures and other conduits at higher levels in the crust.

RESERVE PAPER

HODKINSON, R.A. and CRONAN, D.S.

Regional Variability in Cobalt-Rich Ferromanganese Crusts from the Central Pacific

Two hundred and ten Co-rich samples, with data comprising Mn, Fe, Co, Ni and Cu concentrations, water depth, crust thickness and crust substrate type, have been used to assess factors controlling the variability of crusts in the central Pacific over an area from 20°S to 20°N and 150°W to 175°E. Analysis of variance techniques, along with mean data for differing latitudinal provinces, have been used to assess crust variation with water depth, longitude, substrate type and latitude.

The two predominant factors controlling crust composition are latitude and water depth, with longitude and substrate type being of little importance in this regard. The model of crust composition variation with water depth related to 0_2 minimum zone proposed by Aplin and Cronan (1985) for the Line Islands region appears to be applicable to crust compostion variation over a wider area. This model, however, does not explain the observed variation in the data set with latitude. Variation in biological productivity about the equator, in addition to the 0_2 minimum zone model, can account for such observed crust compositional variations.

Models to explain crust variability are, however, based on present day oceanographic conditions. Hence, a slightly asymmetric variation in crust composition and a more pronounced asymmetric variation in crust thickness about the equator may be a reflection of plate movements and changes in conditions for crust formation over time.

JARVIS, P. A.

The Central North Fiji Basin Triple Junction

Changes in spreading direction and formation of new tectonic elements have recently occurred in the North Fiji Basin. Co-registered SeaMARC II imagery and swath bathymetry reveal a new triple junction at 17° S, 174° E. The southern limb of this triple junction is the extant Central North Fiji Basin Ridge (CNFBR), whereas the eastern and northern limbs comprise newly formed rift structures. Active ridge volcanism along the realigned ridge axis of the southern limb is clearly evident in SeaMARC II imagery. This limb is also marked by both bathymetric and gravity highs. Extension along the northern limb has produced numerous flanking normal faults and a pronounced central graben, but volcanic activity is sparse, limited to a few isolated locations along the graben floor. Free air and Bouguer anomalies indicate the northern limb is only slightly under compensated. The eastern limb is a single broad graben bounded by two large normal faults. SeaMARC II imagery reveals that young volcanic flows cover most of the graben floor. Recent changes in the stress field across the North Fiji Basin are believed to be responsible for the reorientation of spreading directions along the CNFBR and the formation of new tectonic elements.

POSTER

JOHNSON, H.

Petroleum Geology of Fiji

Most petroleum exploration in Fiji has been directed towards the shallow water sedimentary basins offshore and extending onshore Viti Levu - the Bligh Water and Bau Waters Basins.

The Bligh Water Basin is a Late Miocene and younger intra-arc basin and overlies a more extensive Late Oligocene to Late Miocene forearc basin. Total sedimentary thickness in the Bligh Water area is unproven, but about 3 km of Late Miocene and younger strata locally occur. An episode of folding and faulting which shaped the basin relates to the breakup of the Outer Melanesian Arc in the Late Miocene. Since the Pliocene, extensional tectonism has been dominant.

Total sedimentary thickness in the Bau Waters Basin is also unproven, but about 2 km of Late Miocene to Recent strata locally occur, associated with northwest trending Late Pliocene extensional half grabens. These possibly overlie a Late Oligocene to Late Miocene forearc basin.

Other basins include the deep water Suva and Baravi Basins, and basins in Vanua Levu and the Lau Ridge.

Five deep petroleum exploration wells were drilled between 1980 and 1982, but all missed their limestone targets and were dry. However there are indications that thermogenic hydrocarbons have been generated and potential traps include buried reefs. Doubts remain with regard to the quality and quantity of source rocks and possible hydrocarbons generated.

POSTER

JOHNSON, H. and PFLUEGER, J

Potential Pliocene Reef Traps in Iron Bottom Basin, Solomon Islands

Seismic mound-like anomalies in the nearshore area (water depth 550-650 m) of Iron Bottom Sound, north of Honiara, Guadalcanal, Solomon Islands, display many of the characteristics of buried reefs. They occur at two stratigraphic levels, and are interpreted to be Pliocene shelf-edge reefs with dimensions more than 6 km by 3 km and up to about 200 m thick, and a patch reef. They are overlain by about 1 km of stratified sediments and form potential traps for hydrocarbons which may have been generated in the deeper part of the Iron Bottom Basin to the north.

RESERVE PAPER

KEATING, B. H.

Island Arc Rotations in Review

Paleomagnetic studies of major island arc systems around the world have shown that the island arcs are characterize by large scale tectonic rotations. The rotations are documented in the island arcs of the western Pacific, the Caribbean, and the Southern Atlantic Ocean (Scotia Arc). The magnitudes of the rotations observed are large. For example, 140° of clockwise rotation has been documented over 40 million years in the Bonin Islands. Also, the rates of rotation are high; for example, 15° of clockwise rotation over the past few million years has been documented in Papua New Guinea.

The large scale rotations observed in island arcs are generally associated with poles of rotation on, or adjacent to, the plates. The islands of a group can be observed to move as coherent blocks showing consistent amounts of rotation (e.g., the Caribbean); others show relative motion within an island. In the Bonin Islands, rotations of large stratigraphic terranes are evident. In other island arcs, stratigraphic relationships are disturbed and numerous rotations of varying degree occur in domains of a few kms to tens of kms in size.

Structural fabric observed in the back arc basin in some cases can be traced from the seafloor onto the islands. Faults within the Manus Basin and seamounts and fault traces in the Mariana Basin appear to mark zones of weakness where rotations are most easily accommodated. The size of the rotated blocks and the nature of rotation vary, reflecting plate boundary conditions.

KEATING, B. H.

Seamount Morphology and Manganese Crust Resources in the Central Pacific Basin

The mining of cobalt-rich manganese crusts on the upper slopes and summits of seamounts is likely to take place in the Central Pacific Basin because (1) the crusts are richer in metal content and more extensively distributed than previously recognized, (2) many deposits are situated within the Exclusive Economic Zones of island nations desiring economic development, (3) the deposits occur at relatively shallow depths compared to manganese nodules and (4) these deposits provide important alternate sources of strategic minerals and rare earth metals.

The proposed sale of marine mineral leases in the Hawaiian Archipelago and the Johnston Island Exclusive Economic Zone raises the possibility of Mn-crust mining on seamounts in the Hawaiian and Line Island seamount chains. The distribution, abundance and mineralogy of the crusts are strongly influenced by their geolgic setting, thus it is important that we gain a clear understanding of the geologic setting of these crusts. Geological and geophysical studies have been conducted in the Hawaiian, Line, Gilbert and Phoenix Islands groups in the Central Pacific Ocean. A bathymetric study has included analyses of seismic reflection profiles to determine characteristic shapes, depths to slope break, depths of reef platforms and sea level benches, and slope analysis based on digital bathymetry. A total of 470 seismic reflection profiles were examined. SeaMARC side-scan sonar mapping images and detailed bathymetry are available for several seamount within the Line Islands, Geologist, Musician and Hawaiian seamounts chains and were used to compare the acoustic character of substrates and to examine details of seamount morhology. Dredging and coring records from these areas were compiled in order to examine distribution of substrates.

Thick Mn-crust deposits are commonly dredged from seamounts of Cretaceous age within the Central Pacific Basin. The relative abundance of economic minerals varies significantly both within and between seamount provinces. The studies summarised here suggest that the geologic environment associated with the seamount provinces under study is variable.

The mineral deposits are generally thickest on the most stable (least mobile) substrates, but they will be most readily mined on friable substrates. Characteristics conducive to mining include: minimum slope angle, relative absence of bathymetric obstacles (benches, fault scarps, and volcanic features), absence of poorly consolidated sediments (which minimize Mn-crust growth), and presence of amenable substrates.

Resource potential in the Line Islands Seamount chain and the Necker Ridge portion of the Hawaiian Exclusive Economic Zone is greater than that associated with the Hawaiian Islands Seamount chain, reflecting the greater ages and crust thicknesses. The Line Island chain however is characterized by rough topography which would make mining, using conventional dredge-type apparatus, difficult.

POSTER

KISIMOTO, K., JOSHIMA, M. and LAFOY, Y.

Geophysical Structure of the North Fiji Basin

Marine geophysical surveys conducted in North Fiji Basin by RV 'KAIYO' in 1987 and 1988 have revealed several characteristic features related to the rift system in this region. Compiled geomagnetic anomaly data from the KAIYO and SEAPSO cruises show the change of strike of the rift axis from N-S trend in the southern part of NFB to N15° in the northern part of the basin up to the triple junction. Reduced half spreading rate of the southern spreading axis, from magnetic anomaly data is about 3 cm/year during the late Quaternary, decreasing to 2 cm/year or less near the triple junction.

Results of heat flow measurements at stations where the sediment layer is visible on seismic records show that this basin is rather hot, in conformity with its young age.

Seismic refraction surveys have been carried out in the axial area along multi channel seismic lines. Two sets of OBSH (Ocean Bottom Seismometer and Hydrophone) were deployed around station No.14 (18°50'S, 173° 30') where the most active hydrothermalism was implied from chemical analyses of water samples. Four sonobuoy stations were also selected and data integrated with that from the OBSH. Thinning of the oceanic crust in the axial region is suggested from the data obtained, i.e., the depth to Moho from the sea bottom is less than 3 km, deduced by the apparent refraction velocity of 7.7-7.9 km/sec.

KROENKE, L.W.

Tectonic Setting of the Southwest Pacific.

The tectonic setting of the Southwest Pacific is one of complex interaction along the boundary between two large, obliquely converging, lithospheric plates: the Indo-Australia (IA) and Pacific (P) plates. The history of the tectonic development of the Southwest Pacific during the Cenozoic is the history of successive relocation of that boundary in response to shifting stress patterns resulting from changing directions of motion of the major plates, episodic marginal basin formation, and recurrent collisional tectonism. Successive periods of convergence along four different paleo-subduction zones that formed concommitantly with changes in I-A and P plate motions from the Eocene to the late Miocene occurred along: Aure-Moresby-Rennell-New Caledonia (55-40 Ma), Manus-North Solomon-Vitiaz (40-25), Wewak-Trobriand and Lau (25-10 Ma), New Britain-San Cristobol-New Hebrides (10-0 Ma) and Tonga-Kermadec (5-0 Ma) trenches. At least seven hot spot trails, five down the eastern margin of Australia and two down the Tasman Basin, suggest that changes in Indo-Australia plate motion occurred at times when new convergence zones were developing. Collision tectonism has occurred repeatedly, resulting in: obduction of ultramafic belts in Papua New Guinea (43-37 Ma), New Caledonia (39-36 Ma), and the Solomon Islands (5-0 Ma); and sporadic reactivation of older subduction zones, briefly rejuvenating arc volcanism. Arc rotation, fragmentation, and severe dislocation also have contributed to the complex morphologies of the region.

KURNOSOV, V.B.

Hydrothermal Processes at Oceanic and Back-Arc Rifts and Seamounts; and Associated Metals and Phosphates

Many investigators consider the interaction between sea water and basalts to be basic to the circulation of elements in the crust-ocean system. The study of this reaction sheds light upon the formation of underwater mineral deposits and can promote further understanding of the relation between crustal and mantle sources of hydrothermal material in the ocean.

Up to this day there are many problems still to be solved. We attempted to answer the following questions, most important to our point of view:1. Under what conditions do basalts alter? 2. What masses of chemical elements are removed from basalts under these conditions? 3. What is the real contribution of chemical elements removed from basalts for supplying the ocean with sedimentary and ore-forming materials?

1. Basalts moving from the axis of the ridge go through two distinct periods of alteration. The first period of basalt alteration takes place in axial zones under "non-oxidative" conditions at increased temperature, where water flow is mainly upward. The second period of alteration takes place during the shift of basalts to the flanks of convection cells under conditions of descending flow of sea water into the crust. In this period the conditions of the first period are still preserved, largely in lower levels of the basalt blocks. The upper part of the basaltic basement is oxidized. During the second period an oxidative type of alteration is superimposed on a "non-oxidative" one. The maximum depth of oxidation was observed in DSDP Hole 504B. It is about 300 m. At the East Pacific Rise oxidative alterations appeared in basalts 0.5 Ma after their origin. At the Mid-Atlantic Ridge, where the spreading rate is lower, they appeared not earlier than 2 Ma after their origin. The study of any block of the basaltic layer of the oceanic crust clearly shows that major alterations of rocks occur during the hydrothermal stage under "non-oxidative" conditions.

   Unlike basalts from mid-oceanic ridges, basalts from volcanic seamounts do not alter in superimposed stages. Zonal alteration of basalts is observed there under "non-oxidative" conditions at increased temperatures in the central parts, and under oxidative low-temperature conditions at the flanks. The main newly formed mineral, replacing the principal mineral constitutents of basalts, is trioctahedral smectite. This circumstance allows us to distinguish a smectite facies of basaltic alteration in the oceanic crust from a zeolite facies.

2. To calculate material balance we used the method of atomic-volume recalculation of chemical analyses, using porosity of rocks. We calculated material losses for mid-oceanic crust by assuming that an average half-velocity of the accretion of the basaltic layer of the oceanic crust in axial zones was 3 cm a year and every annual portion of basalts would be altered

sooner or later till the level observed in nature is reached. At the assumed average spreading rate, a total length of mid-oceanic ridges of 60,000 km and a basaltic layer 2.5 km thick, 9 km^3 are generated in axial zones annually. These data, obtained for extrusive basalts, were extrapolated to sheet- like complexes, for which we have very limited data.

To estimate an annual loss of material by magmatic rocks of the volcanic seamounts is more difficult. We obtained very approximate data.

We obtained following data for annual losses of chemical elements by basalts (mid-oceanic ridges, seamounts and guyots, in $tx10^6$): Si-577; Ca-314; Fe-118; Al-138(?); Na-54; Mn-4.8; P-0.6; Zn-0.5; Cu-0.3; Co-0.6.

3. To estimate the influence of material extracted from basalts on ore formation and sedimentation in the ocean, we should know what masses of chemical elements are delivered into the ocean by underwater hot springs. There are two ways to know this. The first way is to compare the masses of material delivered from land with those accumulated on the ocean floor. Comparison of the mobile forms of chemical elements is the most promising. Another way is a direct estimation of the amount of elements delivered into the ocean by underwater hot springs.

At present, data on the supply to the ocean of many chemical elements from hydrothermal sources are scarce. Approximate estimations of the hydrothermal supply to the ocean of Mn, Al, Ca, Fe, P, Si and Ti were made. Hydrothermal flows of matter are fully able to provide all the supply to the ocean for a majority of chemical elements, in excess - in some cases with considerable excess. This excess is spent in the formation of veined and impregnated mineralization, including ore mineralization.

Thus, the results obtained suggest that the formation of sulfide deposits, metal-bearing sediments and Fe-Mn nodules on the sea floor, as well as the origin of sulfide veins within the basaltic basement, are due mainly to the material removed from magmatic rocks during hydrothermal circulation in the oceanic crust.

Underwater hot springs, which accompany tectonic and magmatic processes on plate boundaries and within plates, influence Pacific Ocean resources and resources of ophiolite complexes of West and Southwest Pacific islands.

LARUE, B.M.

Biological Resources Associated with Seamounts

Estimations of the number of seamounts on the entire Pacific basin vary between 10,000 and 1 million, depending on the knowledge of the bathymetry and the size the structures.

Apart from the geological resources associated with their origin, seamounts appear to be a place of flourishing marine life, whereas the surrounding waters are almost deserted. Some of this life such as corals or fish might become an economic resource. A test of fishing made on a seamount of the Norfolk Ridge, south of New Caledonia, for 200 days caught an average of 2.4 tons of Beryx splendens per day.

A large number of unresolved questions result from the scarcity of available data. Where are the seamounts located? Are they all equally rich? How does this life develop? Where are the nutrients coming from? How do they reach the surface? Are they linked with the nature of the seamount? With its structural position? With its origin? How and how fast are newly formed seamounts colonized by species?

The endo-upwelling concept, a hypothesis that the nutrients come from the 400 m deep layer, driven to the surface by heat flow due to the volcanic origin of the seamounts, can provide a framework to answer to some of the questions. During the past year, 35-40m holes have been drilled on the atoll of Tikeau, French Polynesia. Water sampling at the bottom of the holes shows that the nitrate content is intermediate between deep and superficial waters. Analysis of fluoride and helium currently under progress will allow discrimination between deep and shallow origins of the water.

The abundance of life associated with seamounts in a wide range of situations shows large variability. Among the influencing factors, are:

The age of structures: The age determinations of young structures such as those found on the North Fiji basin boundary are rather poor compared thosee on the Indo-Australian plate.

The stability of the slopes: The role of falling debris seems important on the slopes of Loyalty Islands and of Ile of Pines, New Caledonia, observed between 100 to 2900 m during dives of the submersible 'Cyana', where extremely poor fauna life was observed.

The remoteness of the structure: The seamounts of the Tasmantid guyots are much richer than those south of Chesterfield Islands.

The influence of the hydrothermal regime, sedimentation, growth of metallogenic crusts, and morphology have also to be taken into account.

The economic prospects can be achieved in short or mid term for halieutic resources. For such a development, there will be a need for detailed morphological maps, and for a better understanding of the processes involved, by heat flow measurements, sampling, diving etc. Though the resources will not be geological, the tools will be those of basic marine geology, therefore cooperation between scientists from different disciplines will be necessary to develop our knowledge.

LENOBLE, J.P.

Deep Seabed Mining for Polymetallic Nodules

A comprehensive revue of the French deep sea bed mining project is given.

The French mining site was explored by many methods including free-fall grabs and photo-cameras, corers, multibeam echo-sounder, deep-towed or self propelled continuous bottom photopgraphy equipment, deep-towed side-scan sonar and manned submersible. From the acquired data a simulation of the detailed topography and the nodule distribution of a possible mining area has been done. By further considerations on the future bottom collector efficiency, one can define the shape and size of elementary nodule fields that could be mined with the first generation of mining equipment.

The full system proposed for mining is presented, including the bottom collector, the flexible hose and the rigid pipe string, the lifting systems, and the surface platform. The transportation of the nodules to the treatment plant and the processing is briefly explained.

The economy of exploitation of polymetallic nodules is discussed, showing that a satisfactory internal rate of return can be expected with metal prices that seem realistic for the beginning of the next century and are considerably lower than the present very high prices. A comparison with land-based deposits, mainly manganese oxides and lateritic nickel, concludes slightly in favor of the nodules. However, the deep-sea technology has to be confirmed by testing its many components at a representative scale. It implies the realization of a pilot test of the full system at a one to ten scale.

LE SUAVE, R., PAUTOT, G. and HOFFERT, M.

French Exploration of Cobalt-rich Crusts in Tuamotu Archipelago, French Polynesia

The Tuamotou archipelago, one of the most important midplate volcanic structures, has been identified for many years as a potential area for the occurence of cobalt rich crusts.

In 1986 and 1987, IFREMER conducted two cruises with the R/V Jean Charcot using Seabeam, French deep side-scan sonar SAR and free vehicle EPAULARD. The objective of the first cruise, NODCO 1, was to survey in detail and sample two sites identified by CNEXO in the early seventies as potential cobalt-bearing sites. The second cruise, NODCO 2, in March 1987 was devoted for the main part, to a large geophysical survey from the western end of the archipelago to the southeastern part 1000 km away. During this second cruise, three additional sites were identified and studied in detail and polymetallic crusts have been sampled at different water depths.

The main conclusions of this work are:

1. The occurence of polymetallic crust deposits is closely bound to the existence of topographic highs and to the lack of sedimentation during the last ten million years:

2. The average cobalt content is comparable, for the same depth, in the different samples collected along a northwest to southeast axis:

3. The average cobalt contens increses as a function of decreasing water depth, and enrichment of cobalt in the external layers of deposits is well identified:

4. Relatively high values of platinium have been determined (up to 3.8 g per ton with an average of 0.75 g per ton). This has a possible relationship with meteoritic material.

These results, which confirm the existence of the "cobalt-rich crusts province" in the South Pacific, raise the question of the southern limit of the phenomenon.

LISITSYN, A.P., BOGDANOV, Y.A., ZONENSHAIN, L.P., KUZ'MIN, M.I. and SAGALEVICH, A.M.

Soviet Research from Submersibles of Hydrothermal Ore Occurrences Oceanic Rifts

Systematic studies of geological structure, volcanism and hydrothermal activity began in the USSR in 1972 with investigations of some areas of occurrences of metalliferrous sediments in the Pacific and Indian oceans. In 1979-1980 the Soviet studies of rift metallogeny and sulphide structures on the ocean floor began to be based on a wide use of unmanned and manned vehicles. The accepted procedure of studies includes a preliminary geophysical mapping of the axial part of a rift aimed at tectonic prediction of the most promising areas, three-dimensional mapping of the geochemical field of the bottom water aimed at localizing hydrothermal sources, lithologic/geochemical sampling of sediments with mapping of the fields in sediments and interstitial water, studies of the seafloor with unmanned vehicles (television, photography, side-scan sonar location of the surface, thermohaline measurements, and determination of concentration of some ions with geochemical sensors), discrete sampling of water, suspended matter, and gas with the "Rosette" bathometers, and studies of hydrothermal fields from manned subersibles. Also, sediment cores are taken from a close vicinity of the source to study their specific geological history, and sedimentary traps are deployed to determine flows of chemical elements.

The Soviet manned submersibles have made possible detailed studies of different parts of the global rift system: the Red Sea rift, the Tajura rift (Gulf of Aden rift), the Reykjanes rift, the Osevoy Seamount (Juan de Fuca Ridge rift), the Guaymas Deep (Bay of California). More than 200 dives of the PISCES submersible were made. The work has yielded information on hydrothermal manifestations of rifts at different stages of development and in different geodynamic environments. These studies are carried out by the USSR Academy of Sciences and are aimed at finding out the fundamental regularities of present hydrothermal processes in order to know ore formation in the geologic past. They are not aimed at economic evaluati f present ore formation or at the possibility of getting mineral resource from the ocean floor.

In winter 1990 an international four month expedition is planned for the southwestern part of the Pacific using R/V "Akademik Mistislav Keldysh" with two MIR submersibles. The main task of the expedition is to study hydrothermal activity in representative and well studied areas of island arc spreading. Scientists from USA, Great Britain, FGR, France, New Zealand, Australia and island countries are invited to participate. Scientific material obtained during the expedition will be analysed in laboratories of countries involved, and will be available for all scientists concerned. A joint publication of the expedition material is planned, and all data will be available for those countries in whose economic zones the work is to be carried out. Scientists from these countries are also invited to take part in the expedition.

The scientific community should now make use of this unique opportunity to choose and agree upon areas to study, and to provide necessary equipment to process the collected material. We propose the joint work should start from the planning stage and conclude with monographs and maps.

The paper gives also a short description of investigations to be done on R/V "Akademik Mistislav Keldysh", as well as about MIR submersibles, a preliminary expedition route, and alternative areas for studying. An international commission of scientists is planned to be organized for preparation and carrying out this expedition. The cruise is to start in Singapore in late February-early March, 1990.

LUM, J.

An Overview of Gold Mining and Exploration in the Southwest Pacific

Gold mining has taken place commercially in the Southwest Pacific for over 100 years but it attracted little international attention until the development of Bougainville Mine in Papua New Guinea in 1972. During the 1970s, the Southwest Pacific became the center for porphyry copper deposits. As a result, the Ok Tedi and Frieda River deposits were discovered in PNG and the Namosi deposits in Fiji.

The Ok Tedi deposit was developed in 1984 at a cost of approximately US$1.5 billion. The development of Ok Tedi made PNG a significant world gold producer, ranking the country tenth among the world's leading producers.

Exploration of porphyry copper in the late 1970s shifted to exploration for epithermal gold, primarily due to the increase in the price of gold. The Pacific 'rim of fire', the boundary of the earth's tectonic plates in the South Pacific where PNG, the Solomon Islands, Vanuatu and Fiji lay, were inundated by exploration companies based mainly in Australia.

Numerous large gold deposits were soon discovered. In PNG, the Lihir deposit (reportedly the largest gold deposit discovered outside of South Africa, with gold estimated at some 25 million oz at a cutoff grade of 1.5 g/t), the Porgera deposit (containing some 9 million oz of recoverable gold), and the Hidden Valley deposit (containing some 2 million oz of gold) were discovered. These deposits are undergoing final feasibility studies for mine development. In the Solomon Islands, Gold Ridge was re-evaluated for gold and is undergoing feasibility studies. In Fiji, the Namosi deposit was discovered near the existing Emperor Gold Mine. The deposit is now being mined. In Vanuatu, where gold exploration did not take place until the early 1980s, several gold occurrences have been located. Today, the Southwest Pacific is being vigorously explored for gold. The region contains the largest number of mining companies per square kilometer in the world. Gold production for PNG is expected to reach some 3.0 million oz of gold per year during the early 1990s, ranking the country sixth amongst the world gold producers.

MAILLET, P., MONZIER, M., EISSEN, J.P. and LOUAT, R.

Geodynamics of an Arc-Ridge Junction: The Case of the New Hebrides Arc/North Fiji Basin

Detailed surveys (bathymetry, magnetism, seismicity and focal mechanism solutions) on the junction between the southern New Hebrides Arc and the North Fiji Basin show the geodynamic complexity of the area. The presently active circa N-S oriented spreading structures of the North Fiji Basin are superimposed on ancient ones constructed during a N135° E spreading episode active before 3 Ma. A recent southward extension of the New Hebrides Arc occurred circa 2 Ma ago.

Structural and geophysical consequences of both events partly obscure the present arc-ridge junction. For example, backarc troughs do not exist to the south of the former arc termination. N45° E structural directions, present all over the studied area, are interpreted as older transform faults related to the N135° E spreading axis, which also left recognizable NW-SE magnetic anomalies.

The New Hebrides Arc/North Fiji Basin junction remains geodynamically unstable due to the concommitance of convergent, strike-slip and divergent movements. Their respective crustal expressions, i.e. arc volcanism, lateral displacement and sea-floor spreading, are examined and considered in their regional environment. A provisional model of the arc-ridge junction that accounts for most of the parameters analysed above is presented.

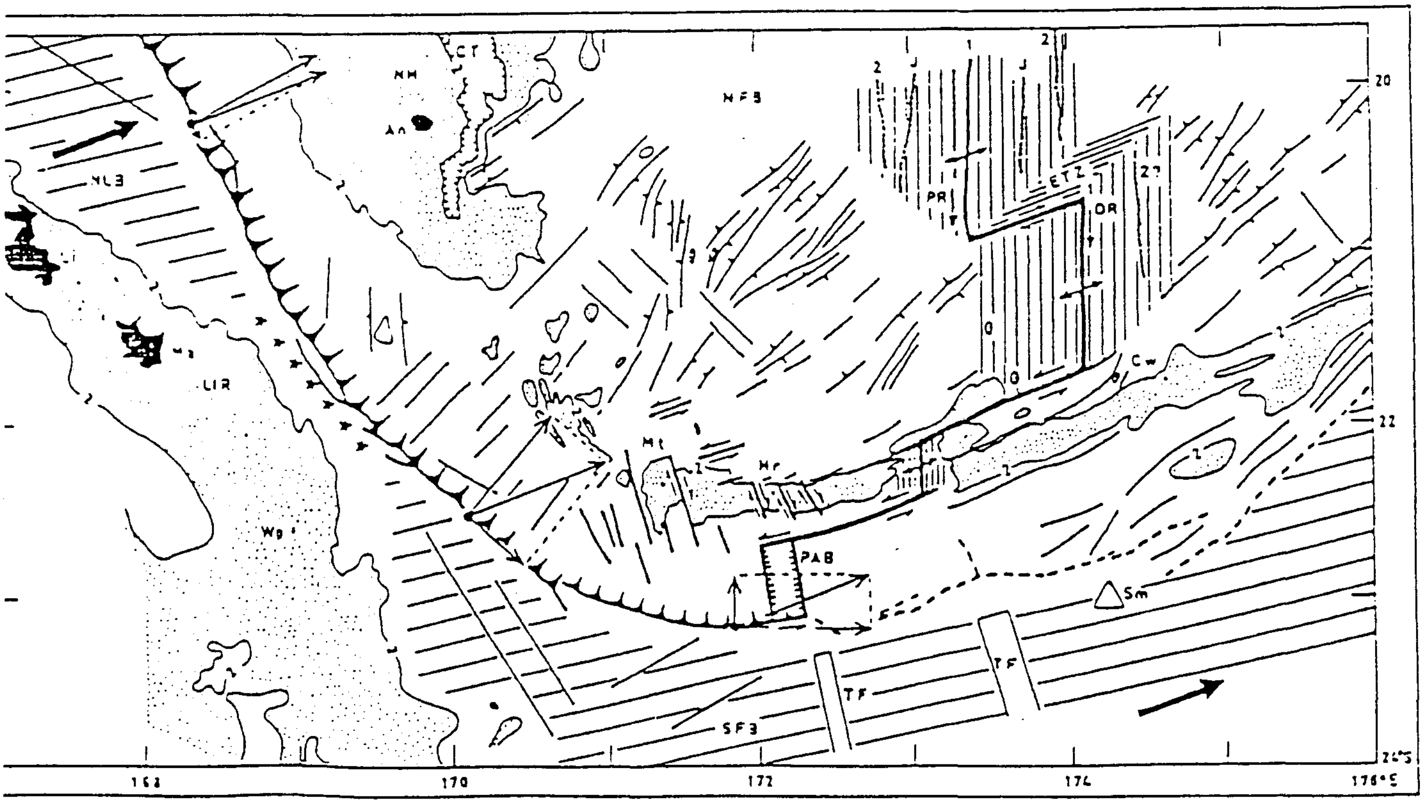


Figure 1: Proposed geodynamic configuration of the southern junction between the New Hebrides Arc and the North Fiji Basin. Bathymetry in km. Stippled areas correspond to 0-2 km deep ridges. Toponyms: LIR - Loyalty Islands Ridge; Li-Lifou; Ma-Mare; Wp-Walpole; NLB-North Loyalty Basin; NH-New Hebrides island arc; An-Anatom, CT-Coriolis back-arc troughs; Mt-Mathew volcano; Hr-Hunter volcano; Cw-Conway; NFB-North Fiji Basin; SFB-South Fiji Basin; TF-old transform faults on the South Fiji Basin; Sm-seamount Geodynamic key: large black arrows show the general N70° E movement of the Australia-India Plate relative to the New Hebrides. The convergence vector in three different trench locations is deduced according to its two normal components. Stars point out the collision zone between LIR and NH. The active plate boundary is marked by a heavy line on NFB, and by a heavy line with tick marks along the New Hebrides trench. Identified magnetic anomalies are shown along the southern NFB spreading zones (hatched area). PAB-pull-apart basin; PR-propagating rift; DR-dying rift; ETZ-evolutionary zone.

RESERVE PAPER

MALAHOFF, A.

Magnetic Fabric and Contemporary Rifting Patterns in the North Fiji Basin and Lau Basin

Detailed airborne and shipboard magnetic studies conducted over the North Fiji and Lau Basins suggest that seafloor spreading in the North Fiji and Lau Basins, which began in latest Miocene, continues today. The North Fiji Basin is marked by at least two triple junctions, located in the central (15° S, 174° E) and northeastern (14° 30'E) parts of the basin. Both were apparently formed during the past five million years in response to continuing adjustments in the strike of the active spreading centers in the North Fiji Basin. Two additional contemporary spreading centers appear to have formed within the last one million years to the north and immediately to the west of Viti Levu. Although magnetic anomalies from 1 to 3 (0-5 Ma) are seen to form a clearly defined lineation pattern over the North Fiji Basin, earthquake foci suggest that only portions of the present North Fiji/Lau Basin spreading center system are currently active.

Analysis of the magnetic anomalies suggest that spreading began in the North Fiji Basin about 8 Ma (shortly before anomaly 4). At about 6 Ma (shortly before anomaly 3), the New Hebrides/Fiji island arc began to fragment through the development of an active spreading center (calculated half-spreading rate of 3.5 cm/yr) located between the New Hebrides and Fiji portions of the island arc. Subsequently portions of the northeastern sector of the South Fiji Basin Plain were subducted beneath the North Fiji Basin. Between 4.5 Ma and 3.5 Ma (anomalies 3 and 2'), spreading in the North Fiji Basin extended into the Lau Basin and Havre Trough, thus separating the Tonga and Lau Ridges. As a result, a distinct series of active spreading centers developed southward along the axis of the Havre Trough.

Spreading from the North Fiji Basin into the Lau Basin and Havre Trough has been accomplished through the formation of triple junctions located in the North Fiji and northern Lau Basin. The data suggests that rifting at any given point in time is discontinuous in the North Fiji/Lau Basin region. Episodic spreading throughout the system is the process by which the inverted U-shaped backarc basin system developed.

The ages of the basins in this system, based on the magnetic anomaly data, are as follows:

North Fiji Basin	8 Ma to the present (magnetic anomaly 4-1)
Lau Basin	4.8 Ma to the present (magnetic anomaly 3'-1)
Havre Trough	2.8 Ma to the present (magnetic anomaly 2-1)

The North Fiji Basin commenced development during the Late Miocene about 8 Ma, shortly before the time of anomaly 4. At about 4.8 Ma, shortly before the time of magnetic anomaly 3', spreading migrated into the Lau Basin, and at about 2.0 Ma (at the time of magnetic anomaly 2), into the Havre Trough and the central volcanic zone of New Zealand. These complex patterns of overlapping ridges, triple junctions and propagating ridges located over the North Fiji and Lau Basins appear to be unstable through time, and thus, reflect a non-steady state of magmatic convection beneath the ocean floor of the inverted U-shaped North Fiji/Lau Basin spreading center complex. Contemporary spreading and hydrothermal activity is therefore located along discrete but separate, currently active, spreading segments of the U-shaped backarc system. On the basis of the Fiji/Lau backarc basin magnetic studies, we suggest an unstable spreading regime through time in the development of this backarc basin.

MCMURTRY, G.M., SEDGWICK, P., MURPHY, E., KARL, D., GAMO, T., STOFFERS, P. and CHEMINEE, J.L.

International Cooperative Investigations of Hydrothermal Systems in Backarc Basins and on Intraplate Hotspots in the South Pacific

The focus of our international cooperative investigations of submarine hydrothermal systems in backarc basins has been on active spreading ridges in the Lau and North Fiji Basins. Our Lau Basin studies identified lowtemperature (22° C) hydrothermal nontronite deposits on the Valu Fa Ridge where later surveys found high temperature massive sulfide deposits. In the North Fiji Basin, geochemical studies of pelagic sediments in the north central basin revealed a major hydrothermal source associated with the South Pandora Ridge, a feature previously thought to be a fracture zone. Two smaller hydrothermal source areas were also identified which are not associated with any known tectonic feature. A sediment core at one of these sites suggests a sequence of initial volcanism followed by high temperature and then low temperature hydrothermal mineralization lasting continuously from 128 kyr ago until the present.

Hydrographic studies over the North Fiji Basin spreading center between 15° and 17° S revealed near bottom anomalies in methane and total dissolvable Mn (TDM) over the triple junction. A surprising feature of this work was the observation of a mid-depth anomaly in TDM with no corresponding methane anomaly between 2250 and 2500 m depth at four stations over the northwest portion of the spreading center. The TDM anomaly intensifies from north to south and probably originated as a pulse from near 18° S on the spreading center.

Hydrographic and CYANA submersible investigations of two hotspot submarine volcanos, Teahitia and Macdonald seamounts, were conducted in January-February, 1989. "Nontronite" assemblage hydrothermal deposits were recovered from the summits of both volcanos and, on Teahitia, were observed to form large active low temperature (<40° C) chimney fields. Hydrocasts taken over the summit of Macdonald during an eruptive cycle revealed extremely concentrated hydrothermal effluent at 125-150 m depth, showing large anomalies in methane, pH, H^2S, Mn and S. Surface explosions, green water, and a slick composed of elemental sulfur, iron oxides and volcanic ash, were also observed, along with several specimens of expired medusa fish Centrolophidae.

MONJARET, M.C., BELLON, H. and MAILLET, P.

Magmatism of the Troughs at the Rear of the New Hebrides Island Arc: K-AR Geochronology, Petrology, and Relationships with Arc Volcanism

A petrological/geochemical study and detailed K-Ar geochronological analysis of dredge samples from the 1985 SEAPSO 2 cruise of the R/V Jean Charcot over the New Hebrides backarc troughs allows comparison with the nature and timing of volcanic activity in the backarc troughs and on the island arc.

Geochemical affinities of the dredged lavas -

Basic lavas (basalts and basaltic andesites) can be classified into six groups, according to their contents in K_20, Rb, Ba, Sr, MgO, Cr, Ni, $Ti0_2$.

- a) MORB with low K_20, Rb, Ba and Sr; relatively high $Ti0_2$, MgO, Cr and Ni.
- b) Island Arc Tholeiites (IAT), with medium K_20, Rb, Ba,Sr, $Ti0_2$, MgO, Cr and Ni.
- c) $Ti0_2$-enriched IAT.
- d) Ankaramitic IAT, i.e. enriched in MgO, Cr and Ni.
- e) Calc-alkali Basalts (CAB), enriched in K_20, Rb, Ba and Sr.
- f) Basalts with geochemical characteristics intermediate between MORB and IAT.

Three groups of acids lavas (acid andesites and dacites) have been dredged in the New Hebrides backarc troughs.

- g) Low-K acid lavas, with high $Ti0_2$, which resemble primitive island arc (PIA) tholeiitic volcanics.
- h) K-dacites, and
- i) High-K dacites.

Geochronological and geochemical evolution of the backarc troughs volcanism -

Three specific groups of volcanics occur in the New Hebrides backarc troughs: MORB, (a) intermediate basalts (f) and low-K acid lavas (g). All other groups correspond to orogenic lavas, either tholeiitic -(b), (c), (d) - or calc-alkaline -(e), (h), (i)-, which are found in the troughs as well as on the islands. However, lavas from the troughs are preferentially enriched in $Ti0_2$, and/or Mg, Cr, Ni, and the proportion of tholeiitic versus calc-alkaline lavas is greater in the troughs than on the islands.

MORB's are limited to the northern troughs (Vanikoro and Hazel Holme areas), and show quite old K-Ar ages (13-12 Ma and 6-5 Ma). They presumably correspond to remnants of the North Fiji Basin crust.

Basalts with chemical characteristics intermediate between MORB and IAT only occur in the Vanikoro area between 2.6 and 1.25 Ma. They are followed by a low-K acidic volcanism, resembling PIA tholeiites, between 1.75 and 0.3 Ma, which may mark the onset of the island arc volcanic line in this area. K- and high-K dacites are found in the central and southern areas (Hazel Holme, Vate and Erromango Troughs; Vate and Tanna islands), and particularly in the Vate Zone. Their K-Ar ages range between 3.5 and 2.25 Ma. Younger volcanics are usually less-K enriched. However high-K dacites have been dated at 1.5 Ma on Vate Island, and at 0.5 Ma in the Vate Trough.

Evolutionary scheme of the New Hebrides backarc troughs -

The formation of the northern New Hebrides backarc troughs began at least at 2.75 Ma in the Vot Tande area, and at 2.6 Ma in the Vanikoro area. The opening of the southern troughs is earlier, i.e. older than 4 Ma in the Erromango Trough, and perhaps a little more recent in the Vate Trough. This fact agrees with the greater structural maturity of the Coriolis (southern) troughs, where a multistage opening is probable.

Most of the volcanics dredged in the New Hebrides backarc troughs present chemical similarities with the volcanic rocks of the islands. K-Ar ages of 6.5-6 Ma in the southern troughs, and of 4.8 Ma in the northern ones correspond to the first phases of the arc building. A second volcanic phase began around 4 Ma.

The Vanikoro Trough (the northernmost one) corresponds to a unique feature of the New Hebrides backarc area, i.e. a possible initiation of a volcanic arc building phase

However, the New Hebrides back-arc troughs must be considered as **intra-arc troughs,** in spite of their location at the rear of the active emerging arc. The great variety of K-Ar ages and geochemical affinities of their volcanics reflects their volcano-tectonic unstability, still effective today.

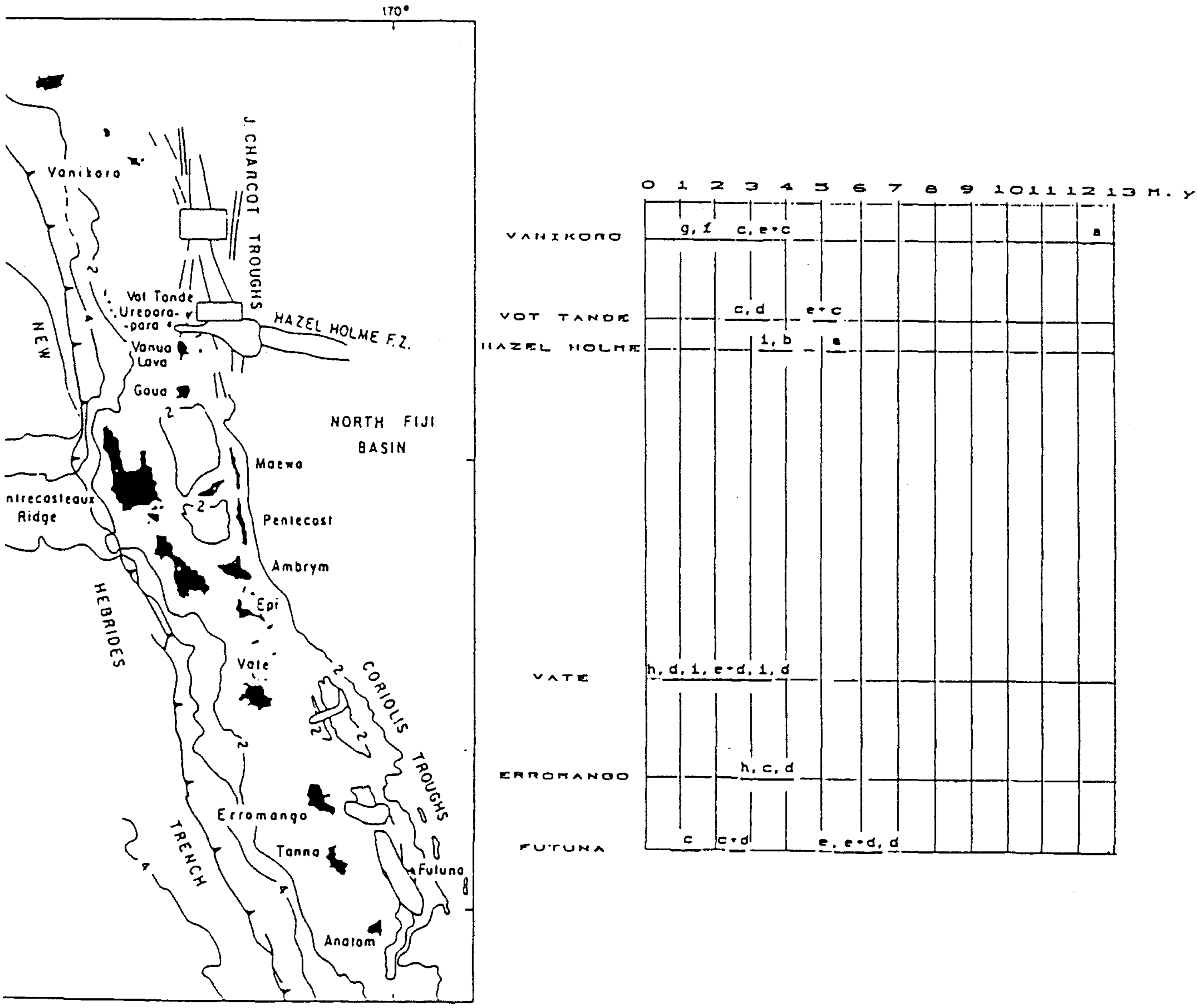


Figure 1: K-Ar ages and geochemical affinities of dredged samples from the New Hebrides back-arc trough.

-a:	MORB
-b, c, d:	IAT
-e:	CAB
-f:	basalts intermediate between MORB and IAT
-g:	low-K acid lavas
-h:	K-dacites
-i:	high-K dacites

MUSGRAVE, R.J.

Inter-and Intra-arc Rotations and Palaeomagnetism in the Southwest Pacific

Initial palaeomagnetic work in the southwest Pacific established the magnitude and timing of large angular rotations of whole arcs, e.g., New Britain, the Huon Peninsula, the New Hebrides arc, and Fiji. There is now a shift in focus of palaeomagnetic studies in the region to resolution of intra-arc rotations. This shift reflects a growing interest within palaeomagnetism in the resolution of tectonic events, particularly transcurrent faulting, by the analysis of rotations of small scale blocks. After correction of magnetization directions for local structure assuming simple cylindrical folding, such rotations show themselves as displacement of the palaeomagnetic pole away from the local apparent polar wander path around a vertical axis through the sampling locality.

Rotations of island sized blocks relative to the rest of the arc may be related to processes which disrupt the lateral continuity of the arc, such as the subduction of seamounts. Blocks with dimensions of about 10-20 km or less may be rotated within or on the margins of systems of shear related to transcurrent faulting within arcs. Shear systems within arcs marked by such rotations include "medial" transcurrent faults. These fault systems take up part of the arc-parallel component of highly oblique convergence, and have been proposed as the mechanism for the emplacement and entrainment of belts of ultramafics in Sumatra. Similar mechanisms may have emplaced the ultramafic bodies strung through the Solomon Islands arc; the activity of such a fault system is indicated by Late Oligocene - Early Miocene anticlockwise rotation of a palaeomagnetic pole from Guadalcanal. Ultramafic bodies on Pentecost in Vanuatu may also have been emplaced by this mechanism when the Solomon Islands and New Hebrides arcs formed a single, linear system during the Late Oligocene.

Terrane analysis has also been a field of major expansion of palaeomagnetic studies in recent years. While most of the arc systems of the Southwest Pacific consits of just one terrane, two suspect terranes have been identified in the Solomon Islands arc, and several in Papua New Guinea. Palaeomagnetism in the Solomon Islands has demonstrated the absence of significant past displacement between the two suspect terranes there. Palaeomagnetic terrane analysis in Papua New Guinea has only just begun.

NOHARA, M., URABE, T., JOSHIMA, M. and HONZA H.

REE and Isotope Constraints on the Origin of Backarc Basalts in the North Fiji Basin

Rocks from the spreading center or nearby areas in the North Fiji Basin are mainly classified into two types. One, a highly porphyric glassy pillow basalt with 30-40% of plagioclase pheno- to megacrysts and about 5% of olivine phenocrysts is found at the triple junction in the northern part of the spreading centre. Another, an aphyric to subaphyric glassy pillow basalt, is generally distributed in the central part of the basin.

The rare earth element (REE) patterns suggest that these basalts originated from different magma types: (1) light REE-depleted type (La/Yb: 0.4-0.7), (2) Ce- and Pr-enriched, but decrease to heavy REE, (3) T-type (La/Yb: 1.6) with Eu anomaly.

Its isotope ratios, $^{87}Sr/^{86}Sr$ and $^{143}Nd/^{144}Nd$, range between 0.70289-0.70319 and 0.51303-0.51310, respectively, similar to those of spreading center basalts from EPR, MAR and the Indian Ocean.

PELLETIER, B. and LOUAT, R.

Present-Day Relative Plate Motion in the Southwest Pacific

In the SW Pacific, convergence between the Pacific and Indo-Australian plates is accomodated by two subduction zones of opposite polarity behind which active backarc extensions occur. The model RM-2 of Minister and Jordan (1978) quantifies the consumption rates along the New Hebrides (NH) and Tonga-Kermadec (TK) trenches, assuming no backarc opening. We studied 754 focal mechanism solutions from shallow earthquakes over the entire area, including 732 Centroid Moment Tensor Solutions for the period 1977-1987 and 22 addtitional solutions within backarc domains for the period 1965-1976. Spreading rates in the North Fiji Basin (NFB) and the Lau Basin given by the youngest magnetic anomalies, and tectonic features identified by recent studies, have also been considered.

Highest consumption rates occur along the northern parts of the NH (16 cm/y) and TK (18 cm/y) trenches. Lowest rates are found where ridges are subducting: respectively 9 and 8 cm/y at the d'Entrecasteaux and the Louisville ridges. There, the observed direction of convergence motion is as predicted by the model RM-2, and backarc extension either does not exist (Louisville) or is replaced by compression (segment east of NH central islands from 13° 30 to 16° 30'S). Within the TK backarc domain, extensional tectonics changes trend from N135°E in the south to N93° E in the north. Extension rate is 1 to 2 cm/y in the Havre Trough and reaches 8 cm/y in the Lau Basin. Conjointly, consumption rates jump from 7-9 cm/y along the Kermadec Trench to 16-18 cm/y along the Tonga Trench. Vector diagrams in Tonga between 24° and 19°S require a left-lateral strike-slip motion (0.3 to 1.7 cm/y) somewhere between the arc up to and including the Lau Basin spreading center.

The NH backarc domain is composed of a central compressive belt flanked southward and northward by zones of extension. Rate of extension is especially high in the north (7 cm/y). A N72°E opening tectonics is inferred along the N-S trending NFB spreading center. Two additional zones with smaller rate of extension are proposed within the NFB: the 176°EZ feature (3 cm/y) and the Hazel Holme zone. Near the central triple junction, the model is not in full agreement with the data. Improvement of the model would require motion along additional boundaries.

A valid approximation of the boundary P-IA is given by the following structures: the TK trench, the Fiji Fracture Zone, the NFB spreading axis, the southern NFB Fracture Zone (SNFBFZ) connecting across the NFB from the southern tip of the spreading center to the NH trench at 21° - 22° S, and the NH trench north of 21° - 22° S. Progressive rotation of slip motion along the southern part of the NH trench suggests that the SNFB microplate is almost attached to the IA plate, and that the major plate boundary is not the southern NH trench but is the SNFBFZ, trending N70° E, located north of the Matthew Hunter arc. The tectonic style of the southern NH subduction zone differs from the Northern Tonga subduction zone where direction of converging motion does not change up to the large left-lateral strike-slip Fiji Fracture Zone. A valid approximation of the boundary P-IA is given.

POSTER

PFLUEGER, J.

Structure and Stratigraphy of the Tonga Ridge from 19.5°S to 21.5°S

A strong basement anticlinal trend, detected both seismically and magnetically, strikes due north from 'Eua Island. From 'Eua Island it passes through the small island of 'Eua Iki and then continues northward until terminated by a fault forty kilometers north of Tongatapu. The trend is significant in that it strikes obliquely across the Tonga Ridge which has a gross topographic strike of N15°E.

In 'Eua Channel several seismic anomalies built upon basement "highs" have been interpreted as buried Eocene reefs. Between the "reefs" persistent channels exist which may be fossil conduits for lagoonal drainage. These channels became plugged during the depositional hiatus which occurred between the Lower and Upper Oligocene. Mounds believed to be piles of channel outfall debris occur at the seaward mouths of several of the inter-reef channels.

POSTER

PFLUEGER, J., HAVARD, K., GATLIFF, R. and HELU, S.

Structural Style and Petroleum Prospects of the Tonga Ridge

Recent reprocessing of seismic data from the Tonga Ridge has provided a clearer picture of the tectonic style of a forearc basin. Sediments along the ridge achieve a maximum thickness of more than 4 km. Many faults have been observed, almost all of which are normal. The presence of scarps on the seafloor show that a significant percentage are active today. Although seismic traverses are not spaced closely enough to allow unambiguous definition of fault orientations, it is believed that most of the tensional faults are parallel to the ridge axis. A second set of near vertical faults, with apparent transcurrent movement, exist at a high angle to the ridge axis. Bathymetry has played a major role in defining the strikes of the second set of faults.

The tensional failures are due to flexing of the ridge as the leading edge of the Indo-Australian Plate is pulled down and under by frictional coupling to the subducting Pacific Plate. The development of major fault blocks is related to the subduction of Pacific Plate seamounts.

Fault-bounded closures and reefs of Eocene to Miocene age could form excellent traps for hydrocarbons. Oil seeps of biodegraded but thermally mature crude oil on Tongatapu encouraged the drilling of five exploratory test wells, but the source rock feeding the seeps was not discovered. Burial history and geothermal modelling indicate that mature source rocks could occur at greater depths than those penetrated by the test wells.

PRICE, R.C., KROENKE, L.W. and JOHNSON, L.E.

Geochemistry of Basalts from the North Fiji Basin: Tectonic Implications

The North Fiji Basin is a complex backarc basin in which active seafloor spreading is occurring along two complex, north-south ridge systems. Lithospheric extension is also taking place along segments of the Fiji Fracture Zone and South Pandora Ridge. Both of these structures trend approximately east-west.

At its northern end, the central ridge of the North Fiji Basin has a bathymetric profile normally associated with fast spreading, steady state, mid-ocean ridges, and the basalts recovered on this part of the ridge are moderately evolved normal MORB'S. In contrast, the northern end of the ridge has a complex topography dominated by a series of deep linear troughs and grabens, and basalts recovered from the floors of these troughs vary widely in chemistry from normal MORB's to transitional alkalic basalts unusually enriched in large ion lithophile and high field strength elements. The central ridge appears to be propogating northwards into old North Fiji Basin crust and the northern extension of the ridge is an incipient spreading locus in the very earliest stages of development.

Basalts recovered on the South Pandora Ridge are enriched in high field strength and large ion lithophile elements and many of them resemble ocean island tholeiites or transitional alkalic basalts. The South Pandora Ridge is an enigmatic tectonic feature and the geochemistry, morphology and seismicity are best explained in terms of a model involving slow spreading ridge segments within a broad transform domain.

ROGERSON, R. J. and HILYARD, D.

Scrapland: A Suspect Composite Terrane in Papua New Guinea

A suspect composite tectonostratigraphic terrane informally named Scrapland has been recognized in Papua New Guinea. Scrapland stretches from at least Milne Bay in the east along the southern foothills of the Owen Stanley Ranges through the Aure Trough zone and eventually into the Highlands, passing through Kainantu and Goroka. Identification of the belt northwest of the Bismarck Intrusive Complex is difficult. Although Late Miocene to Pliocene deformation has modified original terrane boundaries, we recognise that the Owen Stanley Metamorphics are in fault (probably thrust) contact with Scrapland in the east and north, and the Tauri and Puburamba Faults bound it in the west and southwest. The belt varies from 50 to 100 km in width and consists of at least two groups of tectonostratigraphic blocks, Palaeozoic and Mesozoic crystalline basement blocks, and numerous Paleogene marine tholeiitic complexes.

We suggest that Scrapland originated by dominantly transform faulting along the Australia/Pacific Plates' boundary both prior to and following Coral Sea opening. Late Oligeocene to late Early Miocene Aure Group/Omaura Formation volcanolithic sediment is the oldest confirmed overlap assemblage suggesting amalgamation of tectonic-floored Papuan Fold Belt and Scrapland. Final accretion occurred prior to N17 (middle Late Miocene) when collision of the Papuan Ultramafic Belt caused foreland thrusting in the region.

RESERVE PAPER

ROGERSON, R.J., FINLAYSON, E.J., HILYARD, D. and HEKEL, H.

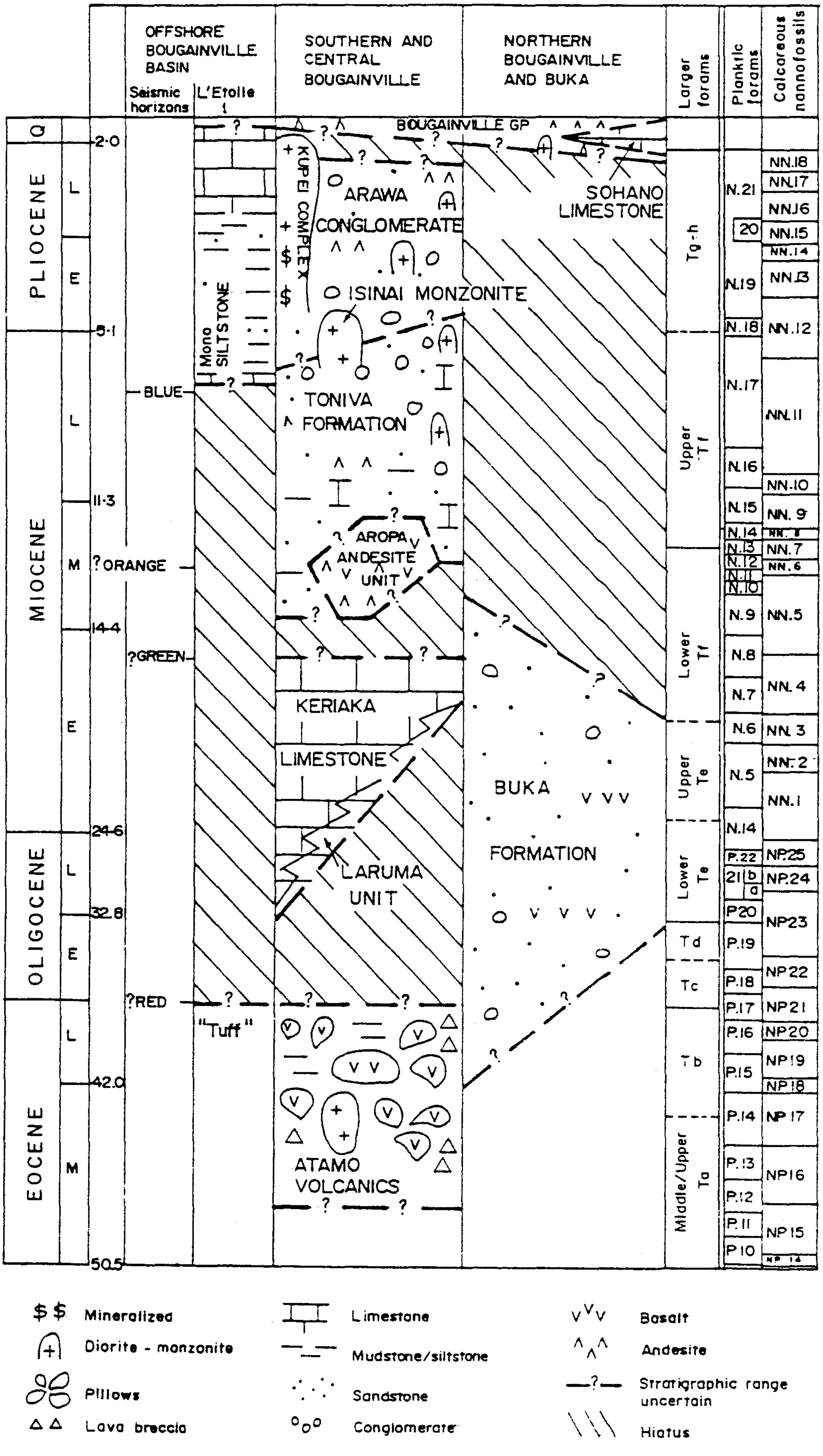
Revised Stratigraphic Framework for Bougainville and Buka Islands, Papua New Guinea: Mineral Deposit Models and Petroleum Prospectivity

Geological mapping and a revised stratigraphic framework for Bougainville and Buka Island (Figure 1) have allowed definition of probable mineral deposit models for each stratigraphic unit and have generated new data bearing on the petroleum potential of the Bougainville Basin.

Only epigenetic mineralisation was found associated with the small areas of basement Eocene Atamo Volcanics on Bougainville. However, potential exists for epigenetic as well as syngenetic volcanic and/or sediment hosted mineralisation in Atamo Volcanics masked by veneers of younger units. No mineralisation was found associated with medium-coarse volcanolithic sediments of the Late Eocene-Middle Miocene Buka Formation and the unit apparently lacks intrustive phases. In central Bougainville, gold-bearing skarns were discovered in some areas where Late Miocene-Pliocene diorites intrude Keriaka Limestone. Epigenetic deposit models are common in Late Miocene-Quaternary units. Porphyry Cu, porphyry Cu-Au (eg Panguna deposit) commonly occur and are associated in some places with peripheral epithermal vein systems.

In northern Bougainville, topographically elevated Quaternary volcanics are marked by nested calderas associated with intersecting northwesterly and northeasterly trending normal faults which localise extensive areas of acid sulphate argillic alteration. Reconnaissance isotopic studies on spring waters and precipitates in northern Bougainville suggest that acid SO_4-$HC_{03}Cl$ meteoric waters (and their derivative near-neutral equivalents) dominate topographically elevated areas while neutral chloride waters debouch at lower elevations.

Palynological studies have yielded the only spore maturity data for the onshore part of the Bougainville Basin. Poor spore recoveries from the volcanolithic Late Eocene-Middle Miocene (?) Buka Formation prevented assessment of its maturity. However, marginally mature spores were recovered from a calcareous mudstone-sandstone-coal lens sub-unit at the base of the Late Oligocene-Early Miocene Keriaka Limestone. D.W. Haig (pers. comm.) recognised lagoonal foraminiferids from this sub-unit, which bears a remarkable similarity to the Matakan unit at the base of the Early-Late Miocene Lelet Limestone on New Ireland. Mainly immature spores were recovered from Late Miocene Toniva Formation volcanolithic siltstones. As this unit occurs near the locus of Late Miocene-present igneous activity on Bougainville, distal offshore equivalent of the Toniva Formation, and the Mono siltstone (=Arawa Conglomerate onshore) should be immature given the apparent lack of volcanism in the forearc Bougainville Basin and the relatively low heat flow in the central Solomon Islands.


OFFSHORE BOUGAINVILLE BASIN
Seismic horizons
L'Etolle
SOUTHERN AND CENTRAL BOUGAINVILLE
NORTHERN BOUGAINVILLE AND BUKA
Larger forams
Planktic forams
Calcareous nannofossils
Q
PLIOCENE
MIOCENE
OLIGOCENE
EOCENE
2·0
5·1
11·3
14·4
24·6
32.8
42.0
50.5
BLUE
?ORANGE
?GREEN
?RED
Mono SILTSTONE
"Tuff"
BOUGAINVILLE GP
KUPEI COMPLEX
ARAWA CONGLOMERATE
SOHANO LIMESTONE
ISINAI MONZONITE
TONIVA FORMATION
AROPA ANDESITE UNIT
KERIAKA LIMESTONE
LARUMA UNIT
BUKA FORMATION
ATAMO VOLCANICS
Tg-h
Upper Tf
Lower Tf
Upper Te
Lower Te
Td
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Tb
Middle/Upper Ta
N.21
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NN.13
NN.12
NN.11
NN.10
NN.9
NN.8
NN.7
NN.6
NN.5
NN.4
NN.3
NN.2
NN.1
NP25
NP.24
NP23
NP22
NP21
NP20
NP19
NP18
NP 17
NP16
NP 15
NP 14
$$ Mineralized
Diorite - monzonite
Pillows
Lava breccia
Limestone
Mudstone/siltstone
Sandstone
Conglomerate
Basalt
Andesite
Stratigraphic range uncertain
Hiatus

SCHOLL, D.W., HERZER, R. and VALLIER, T.L.

Tonga and Lau Ridges: Implications of Tectonism and Submergence Histories for Petroleum Resources in the Southwestern Pacific

In 1982 and 1984, offshore regional geophysical and geologial studies were conductred over the southern Tonga and Lau Ridges to more fully assess the petroleum resource potentials of southwestern Pacific island nations. These investigations were carried out jointly by the U.S. Geological Survey, the New Zealand Geological Survey, and the Bureau of Mineral Resources, Australia, in cooperation with CCOP/SOPAC.

The Tonga Ridge is a northeast-trending and mostly submerged mountain range bordered to the east by the abyssal (8-10 km depth) Tonga Trench. The much shallower (2-3 km) Lau Basin separates the Tonga Ridge from the north-striking Lau Ridge, which is 100-200 km to the west.

The basement rock sequences of both ridges were formerly part of a single massif of Eocene arc-igneous rocks. In conjunction with episodes of backarc spreading, rifting and low angle detachment faulting deformed both parts of the arc massif, first in latest Eocene-earliest Oligocene time, then, as Lau Basin opened, in latest Miocene-Pliocene time. Late Cenozoic deformation of the Tonga Ridge may also ahave been complicated by its collision with the Louisville Ridge along the landward trench slope.

During the Paleogene rifting event, grabens and rotated fault blocks (half grabens) formed along both ridges. Many of these basins have since been filled with and overlapped by relatively thick (2-4 km) sequences of volcaniclastic and calcareous beds mostly of Neogene age. Shallow-water limestone deposited on igneous basement rocks in middle and late Eocene time may underline the basin fills.

Along Lau Ridge, the basinal and younger overlapping sedimentary sections underlie a 50-75 km wide deep-water (2-3 km) terrace, the Lau Terrace, bordering the western side of the ridge. During Miocene time, the axis of arc volcanism lay along the crest and eastern flank of Lau Ridge; basins in these areas were flooded by intrusive and eruptive masses. Relative to this magmatic front, Lau Terrace sedimentation took place in a backarc setting, although the terrace is presently part of the drowned massif of a remnant Miocene arc.

Contrastingly, along the Tonga Ridge thick and laterally extensive basinal and overlapping sedimentary deposits underline a relatively shallowly submerged (generally less than 1 km) summit platform. In Miocene time, the Tonga massif was still structurally attached to that of the Lau Ridge, but east or trenchward of its cresting volcanic axis. Arc rifting and backarc spreading subsequently separated the two massifs. The axis of active arc volcanism presently lies immediately west of the Tonga Ridge. Thus, relative to an arc-magmatic front, since Eocene time or earlier the sedimentary sequence underlying the Tonga platform has accumulated entirely within a differentially subsiding forearc region.

Owing to a paucity of subsurface stratigraphic information, the petroleum resource potentials of the Lau and Tonga sedimentary sequences are troublesome to assess. But the dominance of volcaniclastic debris in Paleogene and Neogene deposits implies that reefal or carbonate accumulations are the most likely reservoirs for petroleum deposits. Shallow-water platform limestone may have accumulated in Paleogene time, but during the Neogene the Lau Terrace sediment accumulated in waters much too deep for reef formation. This factor, together with a relatively thin (2 km) basinal and overlapping sedimentary column, downplays the petroleum potential of the southern Lau Ridge. In contrast, large regions of the Tonga platform are underlain by thick (4 km) sedimentary sequences that since middle Eocene time have accumulated in relatively shallow shoal environments. The Tonga platform section is therefore apt to contain reefal accumulations. In fact, subsurface mound-like bodies of Miocene age have been imaged acoustically on seismic reflection records.

See page of thermally mature oil through the exposed Plio-Pleistocene reef of Tongatapu Island implies that source rocks exist at depth. However, exploratory drilling encountered neither source beds nor reservoir rocks in the underlying dominantly volcaniclastic section. This outcome lowers the petroleum resource potential of the Tonga Ridge, but the lower Neogene and underlying beds of the platform section were not adequately explored at the Tongatapu holes.

If reefal masses are the only likely petroleum reservoirs, then the submergence history of the Tonga Ridge has played a special role in determining its resource potential. Because reef growth is stimulated by submergence, both eustatic sea level rise and tectonically linked subsidence are complementary factors favoring reef buildup. Major subsidence episodes are associated with arc rifting and possibly also with large-scale collision events at the Tonga Trench. Long-term subsidence of the ridge probably reflect cooling and subduction processes. A combination of subduction-related tectonism and a rising sea level may have especially favoured reefal buildups in early and middle Miocene time. Accordingly,if they exist, large-volume petroleum accumulations are most likely to occur in early Neogene biothermal units that are associated with older graben-filling sequences that potentially contain nourishing source beds.

SCHOLL, D.W., STEVENSON, A.J., VALLIER, T.L., RYAN, H.H. and GEIST, E.L.

Arc-massif shearing, block rotation and transportation - a consequence of oblique convergence along the Aleutian Ridge

Arc magmatic rocks of the Aleutian Ridge form most of the length of the northern Pacific rim. Pacific lithosphere underthrusts the ridge to the northwest, a direction that from east to west is increasingly oblique to the ridge's arcuate plan. The regional plate convergent setting is therefore that of a right-lateral shear couple that increases in magnitude westward.

Bathymetric and insular geologic mapping, paleomagnetic, offshore seismic reflection and geopotential data, and earthquake seismicity establish that the ridge consists of separately moving terranes. Roughly equidimensional blocks of torn arc massif, common along the ridge's central sector, are rotating clockwise. Farther west, more elongate terranes are bounded by right-lateral shear zones that roughly parallel the direction of relative plate movement.

GLORIA side-scan imagery documents the tectonic fabric of the terrane boundaries, revealing complex structures along them and the astonishing linearity of major shear zones, some of which are effectively transform plate boundaries.

From a large-scale tectonic perspective, application of right-lateral plate boundary shear stresses has not only fragmented and splintered the ridge's arc massif, but caused the lateral dispersal of the resulting tectonostratigraphic terranes to the west, some rotating as they move. Some of these translating terranes have collided with the Kamchatka Peninsula at the inner wall of the Kamchatka Trench. If processes of terrane creation and movement persist, much of the mass of the existing Aleutian Ridge will be removed sideways from the north Pacific rim, and, in piecemeal fashion, sutured to or subducted beneath the Kamchatka sector of the adjacent Eurasian plate.

STOFFERS, P., BOTZ, R., DEVEY, C.W., HARTMANN, R., KOGLER, F., MUHE, R.K. and PUTEANUS, D.

Geology and Petrology of Active Hotspot Volcanism in the Austral Islands: The Macdonald Region

The southeastern extension of the Austral Islands volcanic chain terminates near 29° S - 140° W at the active Macdonald seamount. Scattered around Macdonald are at least five other volcanic edifices each more than 500m high and all standing on anomalously shallow sea-floor included in an area about 50 - 100km in diameter. The region is thought to represent the present day surface expression of the Austral hotspot. On the basis of the sea-floor topography, the southeastern limit of the hotspot area is located about 20km east of the base of Macdonald, where it is defined by the 3950m isobath. At the edge of the hotspot area, there is a marked deepening of the seafloor from c.3900 m down to 4000-4300 m. The deeper sea-floor is faulted and heavily sedimented. The Macdonald volcano itself stands 3760 m above the surrounding sea-floor, and has a basal diameter of 45 km. Its summit in January, 1987 was 39 m below sea level.

Recent (March and November, 1986) phreatic explosions on Macdonald seamount erupted fragments of ultramafic and mafic plutonic blocks together with basaltic lapilli. The plutonic blocks have been variably altered and metamorphosed, and in some cases contain disseminated sulphides. The blocks presumably come from deeper levels in the volcanic system. The volcanics so far dredged from Macdonald consist of olivine and clinopyroxene cumulus-enriched basalts, evolved basalts, and mugearite. On the basis of incompatible element variations, simple crystal fractionation seems to be controlling the chemical evolution of Macdonald magmas. The extreme Sr and Nd isotopic homogeneity of the Macdonald volcanics further suggests that only one source is involved in their formation.

STOFFERS, P., PUTEANUS, D., GLASBY, G.P. and KUNZENDORF, H.

Hydrothermal Iron-rich Deposits from the Teahitia-Mehetia and Macdonald Hot Spot Areas, S.W. Pacific

During cruise SO-47 of R.V. Sonne, iron oxyhydroxide crusts of restricted extent were recovered from Teahitia and Moua Pihaa seamounts at the Teahitia-Mehetia hot spot area, and Macdonald Seamount at the Macdonald hot spot area. The crusts show complex layering and incorporate volcanic ash layers. They consist of geothite, feldspar and pyroxene and display low contents of transition elements apart from Fe. It is believed that the crusts were deposited from relatively low temperature hydrothermal fluids. These low temperatures preclude the formation of sulphide deposits. The type of hydrothermal mineral recovered may be a function of the thermal regime of the system and the elevation which controls the pressure of the venting fluids. The shallower depths of these seamounts compared to the axes of mid-ocean ridges may therefore be responsible for the style of mineralization encountered. The finding of hydrothermal iron oxyhydroxide crusts at these two hot spot seamounts is only the second such finding after Loihi Seamount, S.E. of Hawaii.

TANAHASHI, M., KISIMOTO, K., JOSHIMA, M., LAFOY, Y., HONZA, E. and AUZENDE, J-M.

Geological Structure of the North Fiji Basin

SeaBeam mapping, single channel and multichannel seismic profiles, sonobuoy-OBSH refraction measurements and geomagnetic anomaly observations, heaf flow measurements which were obtained from KAIYO87 and 88 cruises in the North Fiji Basin revealed the detailed structures and the history of jumps of spreading systems. Current active spreading systems NNW and SSW of a triple junction at about 17°S, 174°, where the active hydrothermal activity was discovered during KAIYO88, jumped from the other places to the current positions possibly in late Quaternary.

The spreading ridge SSW of the triple junction is oriented N15 to 20 and has a 0.7 to 3.5 km wide axial graben and trapezoidal morphological profile with 11 km width. It cut in a N40 to 60 oriented graben whose side walls sharply cut previous structures, that is NW trending sediment covered horst and graben and a high seamount which was separated into probably three highs.

A sharply cut and separated volcanic cone on either side of the spreading ridge shows the spreading direction of the plates relative to the ridge. The estimated spreading direction is normal to the ridge direction about N110 and N290.

The spreading system NNW of the triple junction is oriented N340 and is characterized by the development of a deep valley in the middle of a 70 km wide sediment free basement high zone which cuts into a sediment covered old seafloor. The current spreading system is inferred as an oblique volcanic starved spreading system.

Seismic refraction survey revealed thin oceanic crust under the spreading ridge at 18°50'S, 173°30'E where the most active hydrothermalism was implied from the water chemistry. The depth of Moho from the sea bottom is less than 3 km, deduced by the refraction waves of apparent velocity 7.7-7.0 km/s South Carolina, USA.

POSTER

TAYLOR, B., LIU, L., MALLONEE, R., SINTON, J. and CROOK, K.A.W.

Transtension in the Manus Backarc Basin

Extension in the Manus backarc basin of PNG is occurring in a transtentionsl environment. Three fast-slipping sinistral transform faults bound four major extensional zones. The SE basin, between New Ireland and the Gazelle Peninsula, is a pull-apart basin between the Weitin and Djaul transforms. Extension is accommodated by crustal stretching along normal faults as well as by intrusions feeding seven en-echelon volcanic ridges. The SE ridges extrude calc alkaline lavas similar to, or more fractioned than, New Britain arc lavas.

West of the Djaul Transform, two extensional segments bound a sinistral shear zone which is rotating the intervening crust anticlockwise. In the south, two overlapping grabens with axial extrusions of backarc basin basalts and calc alkaline basaltic andesites occur in the middle of a NE-widening wedge of stretched crust. To the north, the 120 km-long sigmoidally-shaped Manus Spreading Center (MSC) occurs at the center of a SW-widening wedge of Brunhes normally-magnetised crust. The spreading is transform parallel, but oblique to the ridge axis, with spreading rates of 118 mm/yr in the SW decreasing to zero in the NE. The ridge morphology varies along strike from an axial high in the SW to an axial graben in the NE. The lavas are depleted N-MORB ferrobasalts as well as backarc basin basalts.

Branching due west off the SW end is an Extensional Transform Zone which links the MSC (044°) with the Willaumez Transform (117°). The 90 km-long ETZ is characterised by overlapping, right-stepping, en-echelon spreading ridges (072°) cut by a Riedel shear (150°) synthetic to the Willaumez Transform. The highly oblique spreading has generated Brunhes normal crust at 118mm/yr, erupting both depleted N-MORB basalts and backarc basin basalts.

Backarc spreading in the Manus Basin began 3.5 Ma, but the spreading axis jumped to the south inaugurating the current spreading configuration 0.68 Ma. Methane and helium anomalies in the water column above all the volcanic segments, as well as bottom photographs of vent fauna and chimneys on the MSC, attest the presence of active hydrothermal systems. The SeaMARC II sidescan has been reprocessed to provide higher resolution images of the basin floor than was previously available.

URABE, T.

An Overview of the Seafloor Hydrothermal Mineralization In Northwestern Pacific Basin

Favourable conditions for the initiation and continuation of seafloor hydrothermal activity include: (i) heat source eg. magma reservoir, (ii) permeable layer or fractures, which enable seawater to penetrate to depth, (iii) an orifice to focus hydrothermal fluid outflow and (iv) a proper mechanism to precipitate metals. These conditions can be achieved not only along the mid-oceanic ridge, but also at back-arc basin spreading centers, back-arc rifting centers, and at submarine volcanoes. This is why exploration on seafloor hydrothermal activity hs been carried out in the Western Pacific where many back-arc basins are known to exist.

Recently, several examples of hydrothermal deposits have been discovered near Japan which occur in these three tectonic settings. Barite-rich sulfide chimneys were first found during Alvin dives to the summit of the ridge seamounts of the Mariana Trough back-arc spreading center at 18°N. Other sulfide occurrences have been found in similar settings in the S.W. Pacific back-arc basins including Lau, North Fiji, Woodlark, and Manus Basins. In the Sumisu Rift and Okinawa Trough, hydrothermal activity has been observed in back-arc rifting crust, the nature of volcanism and associated mineralization is quite different from that at mid-oceanic ridges. The Sumisu Rift, Izu-Ogasawara (Bonin) arc, is characterized by bimodal volcanism along the rifting axis. Several chimneys consisting of barite and silica were found on flanks of the rhyolite lava domes. Chemical and isotopic compositions of the chimneys are very similar to that of hydrothermal chert which covers the Kuroko deposits in Japan. Large massive sulfide-barite deposits were located in a submarine depression called Izena Cauldron, Okinawa Trough.

Small veinlets of base metal sulfides were found in altered andesite in the wall of a submarine caldera of the Kaikata Seamount, one of the frontal volcanoes of the Izu-Ogasawara arc. Geochemical anomalies of gold and silver suggest that the network of veinlets is analogous to disseminated epithermal gold deposits commonly observed in association with subaerial andesitic volcanoes.

From the viewpoint of metallogeny of onshore island - arc deposits, these three types of mineral deposits correlate to Besshi-type deposits, Kuroko deposits, and epithermal deposits, respectively. The striking similarity in the tectonics, geology, occurrence, mineralogy, and chemical composition, suggest that the hydrothermal mineralization observed on land is not a unique episode through the evolution of the island arc, but is a common phenomenon which is closely related to the activity of island-arc volcanism.

USAMI, T.

Research And Development of Marine Mining Technology in Japan

The Agency of Industrial Science and Technology, the Ministry of International Trade and industry, Japan, has conducted a National Project entitled "The Research and Development Project of Manganese Nodule Mining System" since 1981. The mining system being researched and developed in the Project is a hydraulic air-lift and pump-lift mining system in which manganese nodules are collected by a towed vehicle on the sea floor and transported in a slurry of seawater and nodules through the lift system onto the mining ship. In the last stage of the Project, a pilot scale mining test is scheduled in the Pacific Ocean. This paper describes the outline of this Project and the current level of research and development achieved at the National Research Institute for Pollution and Resources, MITI.

VEDDER, J.G., BRUNS, T.R. and COLWELL, J.B.

Geologic Setting and Petroleum Prospects of Basin Sequences, Offshore Solomon Island and Eastern Papua New Guinea

Late Cenozoic intra-arc basins in the New Ireland-Guadalcanal segment of the Melanesian arc system developed in response to complex interaction along the boundary between the Pacific and Australia-India plates. Among the associated tectonic events were arc-polarity reversal, and subduction of the Woodlark spreading-ridge system. Back-arc depositional aprons derived from the ancestral arc were transformed into intra-arc depositional basins by uplift along the newly active arc after reversal. Sequences of chiefly volcaniclastic strata as much as 6 to 8 km thick accumulated in these basins may have the ingredients necessary for generation and entrapment of hydrocarbons.

The Central Solomons Trough under New Georgia Sound is a composite intra-arc basin that contains faulted and folded late Oligocene and younger strata as much as 7 km thick. Deformed Oligocene and younger strata about 8 km thick underlies the deep-water basin west of Buka Island between Bougainville and New Ireland. A down-faulted basin beneath Indispensable Strait locally contains as much as 4.5 km of Miocene (?) and younger strata, and an offshore extension of the Mbokokimbo basin on eastern Guadalcanal may include 6 km or more of late Miocene and younger strata. At least 2 km of slightly deformed late Oligocene (?) and younger strata underlie parts of both Manning and Bougainville Straits.

Offshore areas that may be favorable targets for future petroleum exploration in the central and western Solomon Islands and in eastern Papua New Guinea include New Georgia Sound, Indispensable Strait, Manning Strait, Bougainville Strait, the shallow-water platform southwest of Bougainville, and the open-water expanse between New Ireland and Buka Island. The only exploratory well in the entire region was drilled in 1975 on the island platform southwest of Bougainville where 1,682 m of strata, chiefly Miocene and Pliocene volcaniclastic beds, were penetrated in Oceanic Exploration company's L'Etoile No. 1 well.

Potential reservoir rocks as well as structural and stratigraphic traps may occur in the Central Solomons Trough and the adjoining straits. Also, the areas southwest of Bougainville and west of Buka Island contain underlying structures and sedimentary sequences that may incorporate reservoir rocks and traps. Source rocks, however, have not been positively identified, either onshore or offshore, and the thermal history of the basins is uncertain.

VON STACKELBERG, U.

Growth History of Manganese Nodules of the Equatorial North Pacific Ocean

The origin of manganese nodule fields is due to "seeding" of coarse particles at distinct horizons. Such seeding occurred at hiatuses which were formed by the erosional capacity of the Antarctic Bottom Water Currents, especially during the Neogene. Two kinds of nodules are prevelant, one of which owes its existence to these hiatuses. This is the main type of the equatorial North Pacific. The other nodule type originated at the surface of consolidated ash layers.

A steady process of biogenic lifting has prevented most of the nodules from being buried. Occasionally encountered buried nodules prove, however, that nodules formed at a distinct horizon, as well as revealing their progressive growth stages.

Pelagic accumulation rates are negatively related to the rate of decay of organic matter within near-surface sediments. This decay correlates positively with the Mn-flux within the interstitial water. The Mn-flux, in turn, is responsible for the diagenetic growth of nodules. The amount of organic matter available in the sediments positively influences the activity of burrowing organisms. Due to this activity nodules are kept at the sedimentary surface. Sediment accumulation rates are mainly determined by the velocity of bottom currents which, in turn, are strongly influenced by bottom morphology.

Manganese nodules in the equatorial North Pacific Ocean represent the sedimentary history of at least the last 15 million years. From site to site, however, sedimentary conditions differ, which may explain the great variability in manganese nodule facies.

VON STACKELBERG, U. and SHIPBOARD PARTY.

Extensive Low-temperature Hydrothermal Activity in the Southern Lau Basin

During a French-German diving cruise with the submersible NAUTILE in April/May 1989, high and low-temperature hydrothermal activity was found in the southern Lau Basin. Low-temperature discharge (up to 40°C) was observed and measured at various locations, especially along the southern Valu Fa Ridge, an active back-arc spreading ridge which is mainly composed of highly vesicular, brecciated andesitic rocks. Near the hydrothermal discharge a great number of vent organisms were observed. Due to the acid character of the solutions, the volcanic rocks are strongly altered and corroded, sometimes altered into white fine-grained debris. Most of the near-surface rocks show a strong impregnation, or vein-like stockwork mineralization, by metal sulfides. Mn- and Fe-oxide crusts and dead clams were observed at the Valu Fa Ridge extending for a few kilometers, which indicates the widespread occurrence of low-temperature hydrothermal products. A mineral assemblage suggestive of higher temperatures is found in the stockwork deposits and in mineralized xenoliths. According to our model, the extensive occurrence of low-temperature surface mineralization and of high-temperature subsurface mineralization is explained by the high permeability of the fragmented andesites depressing the hydrothermal front to deeper levels within the spreading ridge. High temperature activity is discussed in another contribution.

WRIGHT, I.

Tectonics of the Havre Trough - Taupo Volcanic Zone, Bay of Plenty: Evidence from GLORIA Side-Scan

The Taupo Volcanic zone - Havre Trough marginal basin, northeast New Zealand, provides a unique opportunity to study the tectonic and volcanic evolution of an active and contiguous oceanic - continental back-arc system. A GLORIA side-scan sonar survey over a 23,000 km^2 area in the Bay of Plenty, off North Island, New Zealand, provides the first complete plan view imagery of this oceanic - continental transition. The regional physiography is a direct response to extensional tectonism and volcanism. A diffuse 50-65 km wide zone of basaltic volcanism, comprises a series of multiple and overlapping, but laterally discontinuous, "spreading centres". At least two, and probably three, active "spreading centres" bound the 300 m deep Ngatoro Basin, and mark the southern extremity of Havre Trough oceanic accretion. The multiple "spreading centres" and the Ngatoro Basin are tentatively interpreted to represent examples of, respectively, spreading segmentation and an overlap basin.

Volcanic basement trends are aligned N045° to N051° en echelon to the flanking Colville and Kermadec Ridges. A further distinct clockwise en echelon trend results from synthetic shear between the 45 km dextrally offset, but overlapping, active rifts of the southern Havre Trough and the northern Taupo Volcanic Zone. Evidence for a linking transform fault is not seen and basement trends aligned north to northwest along the suggested offshore extension of the North Island Shear Belt to the Ngatoro Basin are also not observed.

At least twenty seamounts, of varying physical dimensions and unknown composition, are newly mapped. The pristine appearance of seamounts, some with craters, and the large areas of exposed volcanic basement, indicate that active volcanism persists on the southern Colville Ridge.

ZONENSHAIN, L.P.

Mussau Ridge SW Pacific: Geology, Origin and Plate Tectonic Setting

The Mussau Ridge lies near the boundary of the Mesozoic crust of the Pacific plate and the Paleogene crust formed from a spreading center of the Caroline Basin. It runs nearly 400 km N-S, its summit is 1500-2200 m below sea level being elevated up to 2.5 km above the surrounding floor of the Caroline Basin. The Mussau Ridge is accompanied to the west by the Mussau Trench which floor is 6500 m below sea level. The Ridge has asymmetric morphology with a steeper western and more gently eastern slopes. The eastern slope is covered by sediments no less than 500 m thick. It is merged with the Lyra Basin which follows the Lyra Fault a previous (Paleogene?) plate boundary. The steeper western slope is a younger feature lacking thick sediments. The Mussau Trench which floor is 6500 m below sea level. The Ridge has asymmetric morphology with a steeper western and more gently eastern slopes. The eastern slope is covered by sediments no less than 500 m thick. It is merged with the Lyra Basin which follows the Lyra Fault a previous (Paleogene?) plate boundary. The steeper western slope is a younger feature lacking thick sediments. The Mussau Trench axis is no more than 30 km westwards from the crest of the Mussau Ridge. The Trench is commonly believe to be a former convergent plate boundary separating the Caroline plate from the Mussau microplate. Available data show that the Caroline Basin floor was formed from a spreading center which was active from 40 to 28 Ma.

The crust of the Mussau Ridge was studied with "Pisces" subersibles during the 9th cruise of the Soviet R/V "Akademik Mstislav Keldysh" in December 1984. These studies, especially two submersible dives, revealed that the Mussau Ridge is an uplifted oceanic block back tilted eastwards. The full section of the oceanic crust was found. Troctolites and mafic gabbro outcrop on the steeper western slope in the interval 1900-1550 m. More recent dredging results obtained by Soviet expeditions show that ultramafics are developed in the lower part of the western slope. On more gently eastern slope, gabbro-norites were found in its lower part at 1800 m level. They give way upslope to dolerites which are interpreted as sheeted dikes and to MORB-type basalts incluing hyaloclastic layers. The igneous crust is overlain with a sharp unconformity by conglomerates and other sedimentary rocks which contain numerous pebbles of gabbro, dolerites and basalts so indicating that the Ridge was above sea level and was undergone to erosion.

Sedimentary layers include rich benthic foraminifera assemblage which was studied by Kh. Saidova. According to her conclusion the assemblage belong to the Late Oligocene zone P22 equal to 27-23 Ma. All the rock surfaces are covered by Co-rich manganese crust which contain Late Miocene-Pliocene planktonic foraminifera. That means that almost immdiately after uplifting and erosion the Mussau Ridge subsided very quickly no less than 15 km since 23 Ma.

The history of the Mussau Ridge seems to be well correlated with subduction of the Caroline Basin floor in the Late Oligocene. It included three stages: (1) cessation of spreading in the Caroline Basin 28 Ma and the change of extension to compression; (2) as a result, very short time interval from 28 to 25 Ma when a subduction under the Mussau Ridge occurred and when the oceanic basement was deformed and broken in several tectonic slices which were forced above sea level and were partly eroded; (3) as subduction stopped the Ridge isostatically subsided very quickly.

The sharp changes in plate interactions in the eastern part of the Caroline Basin and in the Mussau Ridge can be related to cardinal reorganization of plate motion in the SW Pacific region in the Late Oligocene (28 Ma) when the Melanesian arc collided with the Australian passive margin and compression was spread over a wide nearby territory including the Caroline Basin and Mussau Ridge.

AUTHOR INDEX

DEPARTMENT OF GEOLOGY - ANU

GROUND FLOOR

L: Lectures (Plenary Sessions)
P: Posters
W: Working Group meetings