ABSTRACTS OF PAPERS PRESENTED AT THE STAR* SESSION 2001

John Collen & Peter Rodda
Editors

SOPAC Miscellaneous Report 445

*** Science, Technology and Resources Network**

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FOREWORD

STAR (SOPAC's Science, Technology and Resources network) was founded in 1985 in collaboration with IOC. The first Chairman of STAR, Dr Charles Helsley, then Director of the Hawaii Institute of Geophysics, guided STAR until 1992. He was succeeded by Keith Crook from the Hawaii Undersea Research Laboratory. Keith served until the end of 1999 when John Collen from Victoria University became Chairman. STAR was formed as a vehicle to assist the international geoscience community to provide advice to SOPAC, particularly during the intervals between SOPAC International Workshops, the most recent of which was the ENSO Workshop, held in Nadi from 19 to 23 October, 1999.

STAR meetings are not simply technical conferences at which individuals present scientific papers and discuss their results and implications. Participants have the additional responsibility to formulate advice to SOPAC about its work program and to highlight technical and scientific issues of particular importance or urgency. This advice, in the form of reports and recommendations from STAR Working Groups and reports on highlights of STAR technical presentations, is tendered to Council by way of an address in Plenary by the Chairman of STAR and during the Governing Council/Technical Advisory Group (GC/TAG) segment of the Annual Session. All STAR participants are invited and urged to participate in this phase of the meeting.

One of the great strengths of SOPAC is its ability to mobilize excellent and multidisciplinary science and bring it to bear so as to address the national needs of SOPAC's island member countries. The long-established working relationship between SOPAC and the international research community is a vital element in this endeavor, which STAR is charged to nurture. This relationship stimulated an order-of-magnitude change in the geoscience database in the SOPAC region during the 1980s. During the 1990s it supported the changes in SOPAC's scope and focus which are still continuing.

In earlier years STAR was primarily concerned with "blue-water" marine geoscience, tectonics and resources. However, as national needs and priorities have changed, the scope of STAR has altered so as to ensure that SOPAC's Work Program and its forward planning are influenced by international science that is both excellent and relevant.

SOPAC's 2002 Work Program, which all participants should examine, encompasses a broad spectrum of geoscience and related activities which are focused on three areas in particular: Resource Development, Environmental Science and National Capacity Development. SOPAC's past record demonstrates that this approach to program development is synergistic, advancing both the national needs of island nations and fundamental research.

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STAR Presentations at SOPAC Annual Session, 2001

PROGRAMME

Time	Theme	Authors & Speaker	Title
Wednesday October 17th			
09:00-09:20	OPENING		
09:20-09:40	Energy	Enet, F., Chavez, M.A., Hopfe, H.H. & Grilli, S.T.	The Wave Energy Module (WEM). A U.S. wave energy project.
09:40-10:00		Huttrer, G.W.	Geothermal small power generation opportunities in SOPAC-member countries.
10:00-10:20		LaFoy, I., Smith, R., Pratt, C.	Gas hydrates – a potential natural resource in the Pacific Island region.
10:20-10:50	**Refreshment break**		
10:50-11:10	Energy	Tareti, T.	The Regional Energy Database.
11:10-11:30	Water & Sanitation	Carpenter, C.	Water, sanitation and hygiene strategies for SOPAC (2001-2004).
11:30-11:50		Overmars, M. & Carpenter, C.	Pacific Strategic Action Plan on Wastewater.
11:50-12:10		Dawe, P.	An integrated approach to rainwater harvesting using GIS: technical evaluation of roof catchment legislation for Tuvalu.
12:10-13:30	**Lunch break**		
13:30-13:50	Minerals	Nion, S.	The mineral resource sector in Papua New Guinea.
13:50-14:10	Hazards	Anton, L. & McKee, C.	Damaging tsunamis of Papua New Guinea.
14:10-14:30		Crook, K.A.W. & Liu, K.	Life on a plate edge: The Lae Urban Area, Papua New Guinea, during the Holocene.
14:30-14:50		Shorten, G. & Oliver, S.	Impact of tele-storm waves from Cyclone Paula on Tonga and Fiji islands.
14:50-1510		Tappin, D.R., McMurtry, G.M. & Matsumoto, T.	Relationships between chemosynthetic faunas, fluid flow and sediment slumping in the source area of the 1998 Papua New Guinea tsunami.
15:10-15:30	**Refreshment break**		
15:30-15:50	Hazards	Shorten, G.	Low-frequency earthquake resonance in Suva from ML4.7 Event in the Fiji Fracturee Zone.
15:50-16:10		Shorten, G.	Modelling for earthquake, tsunami and storm surge and cyclonic wind effects in Mele Bay and Port Villa Harbour, Vanuatu
16:10-16:30		Mearns, A.	Managing unacceptable risks – a model for the Pacific.
16:30-16:50	Tectonics & Geology	Kroenke, L.W., Wessel, P. & Sterling, A.	Initiation of subduction, force changes in absolute plate motion, and the development of rifting: a Pacific perspective.
16:50-17:10		Kilmer, F.	Eocene-Oligocene geology of Guam.
17:10-17:30	STAR Business Meeting		
Evening	Meetings or working groups		
Thursday October 18th			
09:00-09:20	Habitats & Coastal	Pratt, C., Clarke, A. & Simpson, A.	Key outcomes of the Regional Workshop on the issues and challenges of marine scientific research in the Pacific – Papua New Guinea, February 2001.
09:20-09:40		Greene, H.G. & Bizzarro, J.J.	Advances in deep-water marine habitat characterization: a combined geological and biological approach to habitat mapping.

09:40-10:00	Habitats & Coastal	Harris, P.T., Heap, A.D., Bryce, S.M., Porter-Smith, R., Ryan, D.A. & Heggie, D.T.	Classification of coastal depositional environments based upon a quantitative analysis of wave, tidal and fluvial power: relevance for environmental management.
10:00-10:20		Howorth, R. & Chungting, X.	Coastal geology of Majuro: development and planning implications
10:20-10:40	**Refreshment break**		
10:40-11:00	Habitats & Coastal	Salm, R.V & Smith, A.J.	Climate change-induced coral bleaching and the implications for marine protected areas design and coastal management.
11:00-11:20		Garton, D. & Collen, J.D.	Contributions of molluscan shell material to marine coastal sediments.
11:20-11:40		Levy, N.M. & Greene, H.G.	Causeways – solution or problem: a proposal to study and mitigate the effects on atolls by causeway construction.
11:40-12:00		Smith, R. & McMurtry, G.	Tarawa Atoll: a reclamation concept to bridge the gap between land and water resources.
12:00-12:20		Collen, J.D., Eagar, S.H. & McCulloch, M.	Dating the "Royal Society core" for the Quaternary history of Funafuti Atoll, Tuvalu.
12:20-13:30	**Lunch break**		
13:30-13:50	Technology	Allinson, L.	Outcomes of Pacific ICT Needs Assessment and Strategy Planning Workshop.
13:50-14:10		Martin, F.	INET/ICANN Conference.
14:10-14:30		Forstreiter, W.	Latest developments in remote sensing.
14:30-14:50		Smith, R. & Forstreiter, W.	Island system management: Manihiki Lagoon – the application of remotely-sensed mapping technology in support of coastal and lagoon marine resources management.
14:50-15:10		Forstreiter, W.	Quantification of change through rectifying historical aerial photographs by high resolution satellite images.
15:20-15:40	**Refreshment break**		
15:40-16:00	Technology	Martin, F.	PPA Conference – GIS opportunities.
16:00-16:20	Oceans	Roemmich, D.	The Argo Project in the Pacific – Global Ocean Observations for understanding and prediction of climate variability
16:20-16:30		Kaluwin, C.	The challenge of measuring absolute sea level rise and climate change in the Pacific Islands.
16:30-18:00		Gautier, M., Pratt, C., Simpson, A., Erb, W.	A strategy for PacificGOOS.
Evening	Meetings of Working Groups		

Poster Presentations	Kennedy, D.M., Woodroffe, C.D. & Jones, B.G.	Morphology and evolution of the southernmost atolls, Middleton and Elizabeth reefs, southwestern Pacific.
	Kim, S.-P., Lee, S.-R., Kim, J.-H., Talia, L., Smith, R.	Mapping the coastal morphology of Savai'I Island, Samoa (Pu'apu'a to Sasina)
	Lobegeier, M.	Foraminiferal assemblages and their contribution to carbonate sediment, Green Island Reef, Great Barrier Reef Province.
	Mario, R.	Results of an energy audit of the SOPAC Secretariat premises.
	Mario, R.	Pacific Island Countries mark Earth Day 2001.
(Title in – no abstract)	Rufin, C.	Fongafale island (Tuvalu) between insular development and preservation of these environments. Which are the directions for minimising the impacts ?
Others to be confirmed		

ABSTRACTS OF PAPERS

Outcomes of Pacific ICT Needs Assessment and Strategy Planning Workshop

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A one-week workshop was held at SPC Noumea, from Monday 27 to Friday 31 August 2001. This was a joint SOPAC/SPC/PIF initiative and two participants had been invited from each member country of these regional organisations. The purpose of the workshop was to enable member countries to address both policy and technical issues on ICT at the regional level, to explore individual country needs, and to formulate an ICT Policy and Strategy Plan for the next five years that will be the foundation for developing ICT within the PICT's where the outcomes will be summarised.

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Damaging Tsunamis of Papua New Guinea

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Introduction

Historically, most damaging tsunamis in Papua New Guinea (PNG) were related to seismicity. Papua New Guinea (PNG) lies in one of the most seismically active regions of the world. Large earthquakes having magnitude greater than 7 are relatively frequent, 197 having occurred in the period 1900-2000. A large number of these earthquakes were tsunamigenic. Less commonly, tsunamis were caused by volcano-related activities.

Significant events

Ritter Island, 1888: A major tsunami was generated by rapid, large-scale slope failure at Ritter Island Volcano on March 13th 1888 (Johnson, 1987). Tsunami wave heights reached 15 metres along eastern New Guinea and western New Britain coastlines where native coastal villages disappeared, and 3 metres at Rabaul 480 km away.

North coast PNG mainland, 1930: A severe earthquake shook the northern mainland coastal area on December 24th 1930 and was followed by a 7-8-metre tsunami on part of the northern mainland coast, and a 9-12-metre tsunami on Mal Island (Everingham, 1977).

Madang, 1970: On November 01st 1970 a magnitude-7.0 earthquake occurred on-shore beneath the Adelbert Range, about 30 km north-northwest of Madang, and was followed by a tsunami 3 metres high near Madang. The Madang-Guam and Madang-Cairns SEACOM cables, on the seafloor east of Madang, were severed at the same time.

Solomon Sea, 1971: On July 14th 1971 a magnitude-8.0 earthquake occurred beneath the northern Solomon Sea and was followed by a tsunami which was observed at areas of Bougainville (1-2 metres), Wide Bay (6-8 metres), Rabaul (2.4 metres) and at Pomio (1-2 metres). Twelve days later on July 26th, another magnitude-8.0 earthquake occurred in a different part of the Solomon Sea. An apparently related tsunami was observed at Rabaul Harbour (7 metres), southern New Ireland (4-5 metres), Pomio (3 metres), areas of Kavieng (1 metre) and western New Britain (1 metre) (Everingham, 1977; Ripper and Letz, 1991).

Rabaul, 1994: Two metre high tsunami waves were generated during the September 1994 Rabaul volcanic eruptions. Tsunamis swept across the northern part of Matupit Island near the centre of Simpson Harbour damaging many houses, and affected near-shore properties at Rabaul Town in the northern part of the harbour.

Aitape, 1998: The Aitape Tsunami of July 17th 1998 closely followed a magnitude-7.1 earthquake. The tsunami killed more than 2500 people and injured 1000, and left thousands homeless.

Southern New Ireland, 2000: On November 16th 2000, a tsunami was generated soon after a magnitude-8.0 earthquake which occurred immediately offshore northwest of southern New Ireland. Tsunami waves damaged houses and property on southern New Ireland, Gazelle Peninsula, eastern New Britain, Trobriand Islands and Bougainville.

Tsunami generation mechanisms

Volcano-associated activity

The Ritter Island event of 1888 produced one of the most damaging tsunamis in PNG's recorded history. It appeared that no earthquakes or eruptive activity accompanied the event, and that tsunami waves were generated by the collapse of part of the volcano. The volume of the displaced part of the cone is estimated to be 4-5 km^3 (Johnson, 1987).

Pyroclastic flows from Vulcan cone are the probable cause of the tsunamis generated during the Rabaul volcanic eruption in 1994. The formation of the tsunamis was closely linked to the onset of the initial plinian phase of Vulcan's eruption when voluminous pyroclastic flows were formed and entered the sea in an arc on the northern to eastern flank of Vulcan.

Submarine slumping

Earthquake-induced submarine slumping is considered to be a common cause of tsunamis in PNG. This mechanism is illustrated by the events of Madang 1970, Solomon Sea 1971 and Aitape 1998.

Submarine sediment slumping was indicated as the causative mechanism for the Madang 1970 tsunami on the basis of the coincidental breakages of the seafloor telecommunications cables immediately east of Madang (Everingham, 1971). The on-shore location of the earthquake linked to the Madang tsunami of 1970 would tend to rule out seafloor surface rupture as a possible cause of this tsunami.

In 1971, the two magnitude-8.0 northern Solomon Sea earthquakes were typical subduction earthquakes. Occuring at depths of 50 km, these earthquakes were too deep to cause surface rupture. Thus the most probable mechanism for the tsunamis associated with these earthquakes is sediment slumping.

The 1998 Aitape Tsunami was generated by slumping which was induced by a magnitude-7.1 earthquake. The focal mechanism and aftershock distribution indicate that the fault plane was near horizontal, strike 147° and dip 14°. Motion on the fault plane was bottom side movement landwards orthogonal to the coastline and plate boundary.

Surface rupture (?)

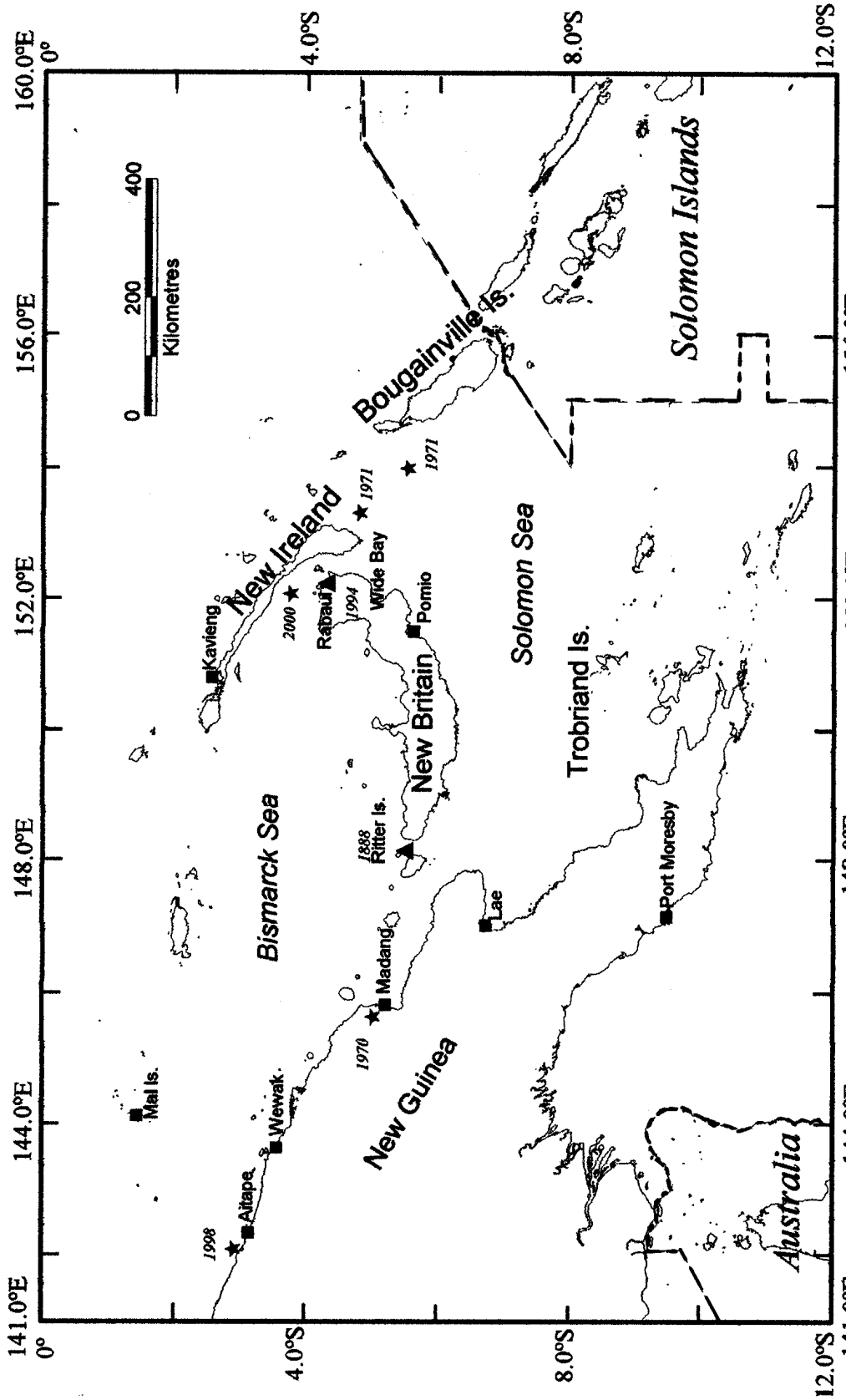
The tsunami of November 16th 2000 may have been caused by large-scale surface rupture on a well-defined left-lateral strike-slip fault. There is on-shore evidence of both vertical and horizontal ground displacements of several metres along the fault. The length of rupture was several hundred kilometres, including offshore northwest and southeast of southern New Ireland.

Discussion

There appear to have been several mechanisms of tsunami generation in PNG. While earthquake induced slumping seems to be the most common mechanism, the largest tsunamis probably are caused by large-scale slope failure at volcanic islands.

Earthquake focal mechanisms, major earthquake locations and aftershock patterns are important factors to consider when evaluating mechanisms for tsunamis caused by seismic activity.

Results from the Aitape Tsunami offshore surveys will enhance regional and local tsunami studies which, hopefully, will help minimise losses that will result from future events. An immediate lesson from the 1998 Aitape Tsunami is that other coastlines of PNG may be considered highly vulnerable to tsunamis generated from offshore sediment slumping caused by earthquake shaking.



Sources of historically damaging tsunamis in Papua New Guinea. Stars denote earthquake sources and triangles denote volcanic sources.

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Ripper, I.D., Letz, H., 1991. Distribution and origin of large earthquakes in the Papua New Guinea region, 1900-1989. *Papua New Guinea Geological Survey Report 91/5*.

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Implications of Sea-Level Rise for Malta

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Malta is a small-island developing state consisting of three islands with an area of about 320 km^2. The population (370,000) has a very high density of about 1200 persons per square kilometre. The economy depends heavily on manufacturing and tourism. Tourism generates about 20% of GDP, represents about 30% of national employment and earns 25% of the foreign exchange. The coasts are extensively used for production, including ship repair and building, fishing and quarrying as well as tourism, and even inland production affects on the coast.

The climate is typically Mediterranean with hot dry summers, warm and showery autumns, and short, cool winters. The islands have a large coast-to-total-landmass ratio, with a 200 km-long shoreline characterised by cliffs, clay slopes and boulder rocks. About 57% of the coast is inaccessible, and the rest is very heavily utilised for residential and economic purposes. About 5% of the land is 7.6 m above sea level or less, but only about I% is l m above sea level or less. Erosion is a common characteristic of the low-lying coastal areas.

Sandy beaches are rare (about 2% of the total coast), but are heavily populated with tourists during the summer. The beaches support many unique environments, including saline marshlands, sand dunes and rocky habitats. Sea-grass meadows are important ecosystems. Posidonia meadows survive in areas away from urban run-off and support a diverse marine fauna, including fish and molluscs. The sea grass *Cymodocea nodosa* is more tolerant of salinity fluctuations and occurs in inshore waters and bays. These meadows are increasingly being threatened by urban run-off and construction developments, and other pollution.

There has been little study of future climate change and sea-level rise in Malta. The most recent authoritative work on the subject is *Implications of Expected Climate Change on Malta* (1993). The issue is given little importance in Malta, as it is not expected to have a major impact. A sea-level rise of 1 metre would not have a significant negative effect on the settled areas of the islands, but some low-lying coastal areas could be severely affected. The worst-case scenario is a mean temperature rise of nearly of 2.7°C and a mean sea-level rise of 52 cm by 2050, with little change in rainfall but an increase in the severity of storms.

The main possible effects of climate change can be summarised as follows.

General

- Little, if any, change in annual rainfall;
- sea-level rise which will directly affect only a small proportion of settlements but many tourism structures;
- increase in mean temperature;
- increase in climate variability, leading to higher temperature maxima and lower minima;
- more thunderstorms, a decrease in cloud cover and a decrease in hours of bright sunshine; and
- increase in suspended particles, including pollutants, in the atmosphere.

Water

- The hydrological cycle will be affected by possible sea-level rise leading to seawater intrusion, and by higher rates of evapo-transpiration.

Agriculture

- Soils will suffer increased evapo-transpiration, with higher aridity and soil degradation;
- agriculture will suffer from immigrant species replacing native ones;
- there will be increased danger from pests and possible water inundation in certain areas;
- some low-lying areas currently under cultivation may be threatened by sea-level rise.

Fishing
- Introduced sea grass species could threaten the Posidonia meadows, which are the breeding grounds of many fish and molluscs.

Health
- The level of suspended dust particles may rise, with effects on respiratory systems;
- sewage flooding could threaten health;
- heat stress may effect the elderly; and
- certain tropical diseases might appear, especially those which are vector-borne.

Tourism
- Tourism will be negatively affected if sandy beaches become inundated;
- sun-related dangers, such as ozone depletion, may deter tourists; and
- increasing storm activity and flooding may affect transport, and hence tourism.

Suggested remedial actions to reduce the impact of sea-level rise include:
- elevating coastal areas at risk by means of back-filling;
- improving scientific knowledge regarding climate change and sea-level rise;
- setting up monitoring stations (some instrumentation has already been installed);
- formulating an energy plan relying more on renewable energy;
- improving water drainage and culverts to reduce flooding;
- protecting coastal aquifers from possible increase in salinity through sea-water intrusion;
- discouraging settlement in low-lying areas.

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Water, Sanitation and Hygiene Strategies for SOPAC (2001-2004)

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Department for International Development (DFID) is funding the position of the Head of the Water Resources Unit (WRU) at SOPAC for three years. The funding is provided to improve the capacity of the WRU and PIC counterparts, to develop strategies to prioritise SOPAC interventions, to increase regional linkages with other organisations and to design, implement and manage a work programme in accordance with donor and SOPAC member-country priorities. The support of DFID is indicative of the renewed interest from development agencies in the water sector worldwide, and recognition of the increasing need to achieve sustainable water-resource management as a pre-requisite to economic development and poverty alleviation.

The development of regional strategies is an essential part of the project, and should lead to a more focused (in terms of country and regional needs) and sustainable (in terms of donor priorities and support) work programme. In addition to closer country consultation, the strategies require the development of regional and national linkages to optimise the interventions through collaboration with existing and future programmes from other regional and global organisations (e.g., UNEP, WHO, ADB, SPREP, SPC, GPA/GEF, UNESCO/IHP, PWA, and NGOs e.g., FSPI, VSO, CUSO, Live & Learn), minimise duplication of activities and maximise access to funding agencies (e.g., ADB, EU, World Bank, Ausaid and NZODA) for the benefit of the member countries. The strategies are designed to be implemented over the three-year period of the project, after which the strategies should be reviewed to ensure that the future work programme remains focused and sustainable.

The regional strategies have been prepared based upon a needs analysis of the existing conditions and demands of the 14 island member countries of SOPAC, as presented by PIC representatives at various regional forums and reported by regional and global organisations. The responses have then been developed into strategic plans incorporating internationally accepted guiding principles for development. Implementation of the strategies will involve SOPAC WRU staff, PIC counterparts and additional resource persons as required from NGOs, research institutes and universities, regional development organisations and consultants.

The strategies will be presented to Council during the Annual Session for consideration and proposed endorsement by the Member Countries.

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Dating the "Royal Society core" for the Quaternary history of Funafuti Atoll, Tuvalu

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In 1838, Charles Darwin proposed that atolls formed when coral reefs grew upwards in the shallow waters above subsiding volcanoes and later (1881) begged that an atoll be bored to check this. In response, expeditions under the auspices of the Royal Society drilled several holes on Fongafale Island, Funafuti Atoll, Tuvalu, from 1896 to 1898. The deepest reached 340 m and recovered core entirely of limestone, without reaching basalt. Despite the suggestion that some of the core may have been reef-front talus deposits and thus from deep water, some coral was thought to be in growth position and thus to support Darwin's ideas.

Isotopic dating of rocks had not been developed in 1898 and there were no means of determining the ages of the limestones in the core. Surprisingly, and despite the expedition being a high-profile one with the results mentioned in many textbooks, relatively little work has been done on the core since. If the Royal Society core can be successfully dated, a range of studies can be undertaken spanning a long time interval - the time range is unknown but is certain to extend beyond the last glaciation and may be much older. The core will probably include one or more unconformities (corresponding to dissolution during the low sea levels of glacial periods) and sufficient samples must be dated to delineate these. Ages plotted against the global sea-level curve will give a subsidence/time curve for Funafuti volcano and will aid the interpretation of reflectors seen in seismic profiles taken across the atoll.

The only other studies of material from deep within Pacific atolls are from Enewetak and Mururoa, where drilling during nuclear-testing programmes found basalt at depth, and Midway. As these sites are more than 3000 km to the northwest and 4500 km to the east-southeast of Funafuti respectively, the results are of limited application to the SW Pacific.

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Life On A Plate Edge: The Lae Urban Area, Papua New Guinea, During The Holocene

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Humans (*Homo sapiens*) have been in Papua New Guinea since before the peak of the Last Glacial Period (White et al., 1970). Descendants of the early arriving communities are now largely confined to the PNG Highlands, having presumably been displaced from coastal areas by later arrivals. Whatever the details of human occupation of PNG may be, it seems highly likely that the modern Lae urban area, or areas adjacent to it, have been the site of human settlements throughout the Holocene and probably for much longer. What then was life like for these people, from a geohazards perspective? Our conclusion is that they experienced recurrent episodic devastation every few hundred years, interrupting intervals of relative calm.

We have completed a detailed study of the sedimentology and stratigraphy of the Quaternary (mainly Holocene) strata in the Lae urban area, Papua New Guinea, accompanied by 14C dating, together with a study of landscape elements and features using 1:2000-scale maps contoured at 1-m intervals, published by the PNG National Mapping Bureau in 1983; and also newly available 20-m-contoured bathymetry (Prior, et al., 2001 in press). Together with limited geophysical and structural data, these data have been interpreted in the context of Lae's tectonic location straddling the boundary between two converging lithospheric plates, in order to develop a Holocene geological history of the Lae urban area. This study is built on our earlier work in this area (Crook, 1989a, b; Liu, 1993; Liu et al., 1995; Whitmore et al., 1999).

The boundary between the Australian and South Bismarck plates transects the Lae urban area. The average uplift rate for the interval ca. 11.7 ka to 5.7 ka was 5.5 m/ka, throughout the part of Lae that lies on the South Bismarck plate. Since 5.7 ka, uplift in this part of Lae has been partitioned, with an area NE of the Bumbu Fault Zone rising at 1.1 m/ka, and an area adjoining the plate boundary west of the fault zone rising at 8.9 m/ka. Uplift appears to be episodic and is probably largely co-seismic.

Data from the SW part of Lae, that lies on the subsiding Australian Plate, are limited to shallow boreholes that penetrated gravel and sand units overlain by mud and peat, indicating episodic sinking. A single radiocarbon date implies an average rate of subsidence of 7.3 m/ka.

These observations and interpretations provide the basis for a tectonic synthesis that utilises the analogy between features of the subaerial arc-continent collision zone in the vicinity of Lae, and features typical of the trench floors and lower parts of the inner trench walls of modern deep-sea subduction zones. This analogy leads to the conclusion that low-lying parts of Lae, near the coast, are destined to be either subducted, as in the case of the Lae Port Facility, or uplifted and deformed. Uplift and deformation by folding appears likely in the case of the old Lae Airfield, whereas uplift and deformation by differential block faulting appears likely in the case of Lae's Central Business District and Lae Hospital. In human settlement terms, the older parts of Lae, near the coast - as distinct from the newer inland parts, including the PNG University of Technology - are areas of extreme geohazard potential, because no high magnitude earthquake with at epicenter <50 km from Lae has occurred during the past 100 years.

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An Integrated Approach to Rainwater Harvesting Analysis Using GIS: Technical Evaluation of Roof Catchment Legislation for Tuvalu

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Roof catchments consist of a runoff surface, conveyance, and storage. The systems are simple, self-contained, affordable, long lasting and viable for Pacific island countries that generally receive continuous rainfall all year round.

Of all Pacific island countries, Tuvalu is one of the most advanced in terms of roof-catchment development. Necessity has been the predominant driving factor, as there is no island-wide water-distribution system. Each household has its own water catchment, supply and distribution system. To manage their water supply system more effectively, and in response to water shortages experienced during the 1999 drought, Tuvalu put in a request to SOPAC to perform a review of roof-catchment standards in the country. In addition to reviewing the feasibility of draft legislation on rainwater catchment systems, a GIS database of all water-supply assets (roofs, gutters, tanks) was developed for the Tuvalu Public Works.

The success of rainwater catchment systems depends on whether the total rainwater supply is sufficient to meet total user demand. Currently, systems in Funafuti seem to be right on the threshold of this limit. Rainwater supply is enough to meet user demand, but only just. As demand increases past the absolute amount that rainwater can supply, as is predicted, catchment systems will start failing with increasing regularity, and alternative water sources will have to be investigated.

Central to the analysis of catchment systems was the development of a GIS, in which items such as tank capacity, material type, roof and gutter condition, etc., were collected. With this tool in place, design parameters for average domestic systems could easily be queried from datasets within the GIS. Rainfall and tank water-level data were also collected in the field for the purpose of determining consumption.

Mass curve with dimensionless-constant analysis was found to provide the most flexible and effective roof-catchment design. The dimensionless graph determined from this method, although derived from a particular roof, will work for all demands, for any roof area and with any runoff coefficient. It can be used to size any system immediately and with little calculation.

If the rainwater supply systems in Tuvalu are to have any kind of consistent reliability, several key points will have to be addressed. These include the following:

- roofs, gutters and storage tanks need to be properly maintained
- water-conservation practices should be encouraged
- roof areas with guttering need to be maximised
- rationing schedules for users need to be developed and followed during periods of drought.

The Government of Tuvalu provided for regulations on the design of roof catchments as part of the Tuvalu National Building Code developed in 1990. Recommended amendments to the design standards of roof catchment systems in the draft legislation include the following:

- appropriate design constants should be used
- the method of dimensionless-constant analysis should be used to size individual systems in Tuvalu
- the dimensionless-constant analysis graph should be updated every 10 years (i.e., after every census).

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The Wave Energy Module (WEM)
A U.S. Wave Energy Project

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The Wave Energy Module (WEM) is a patented device that is designed to use the motion of ocean waves to generate electrical power. A description of the development of the device since its innovation in 1976, along with results of early test programs, is presented. One of several test units is illustrated in Figure 1. This particular test unit is a 1-kW model at scale 1/10 of the ultimately expected one-megawatt system. This model was put into operation on Lake Champlain, South Hero, Vermont, USA in 1978 and 1979.

Figure 1: the 1-kW system in Lake Champlain

The system comprises a circular raft, below which is suspended a circular reaction plate, by means of a plurality of single-acting (pull-only) reciprocating piston pumps. Relative motion between the raft and plate due to wave activity causes the pumps to transfer hydraulic fluid from a low-pressure accumulator to a high-pressure accumulator. The collected high-pressure fluid is then used to operate a hydraulic motor which, in turn, drives an electric generator to produce electrical power.

At the present time, U.S. Wave Energy is in the process of producing design drawings for a one-megawatt WEM system for possible use in the SOPAC island countries. These drawings are being made available to SOPAC, as well as to shipbuilders in New Zealand and Australia. It is estimated that the overall design package will be reasonably complete by the end of 2002.

The expected performance of the one-megawatt system is reviewed, based on a variety of empirical studies, and an economic analysis is presented. Scale-model tests in a laboratory wave tank were recently carried out at the University of Rhode Island, using a 1/30 scale model of the WEM. These test results represent the first step of the current investigations being carried out at URI. Analytical studies represent a second step. Unlike earlier laboratory tests using regular waves, the present research involves the use of irregular laboratory-generated waves that simulate various actual naturally occurring wave climates.

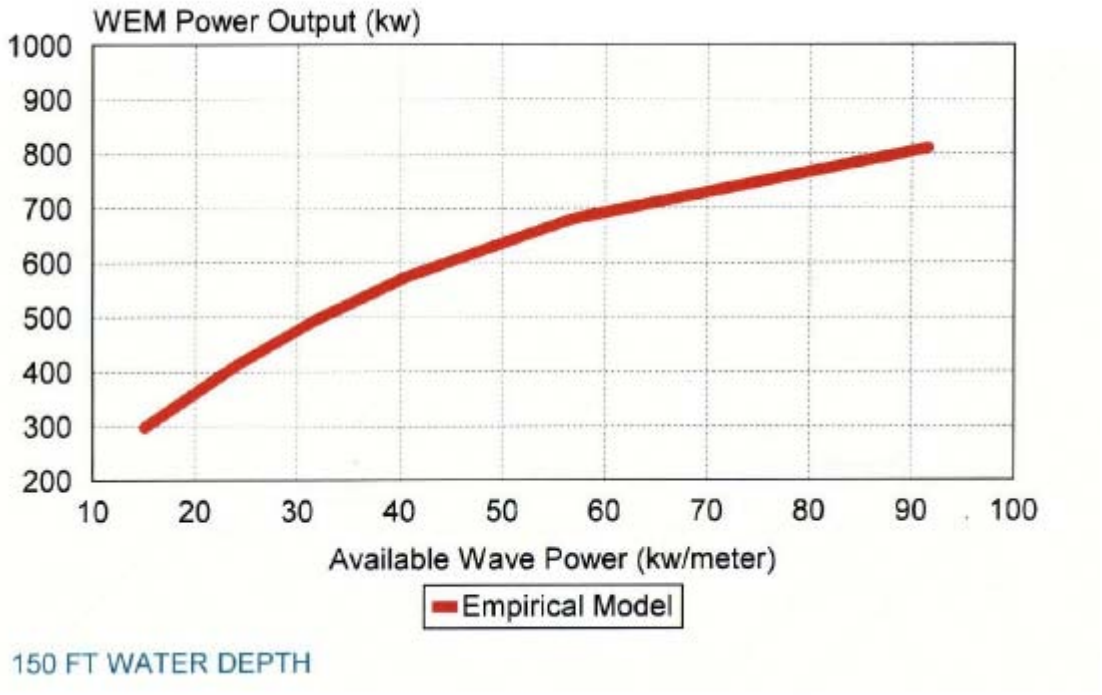

Figure 2: One-Megawatt WEM Power Output

Figure 2 illustrates the expected performance of the one-megawatt system based on existing empirical models and laboratory data.

The present economic analysis predicts a cost of WEM-produced electrical power of $0.129/kW hr on a 20-year amortization basis, and $0.089/kW hr on a 50-year basis. The ultimate objective of the present research is to develop a theoretical model which, combined with laboratory data involving irregular waves, can be used to more accurately predict WEM performance, and potentially open the door to higher-efficiency performance and attendant reduced cost of electricity.

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Latest Developments in Remote Sensing

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In many Pacific Island Countries, available maps are obsolete and may date from the 1950s and even 1940s. The high cost of photo flights often prevents their update, and the countries therefore do not have an overview of their land cover and natural resources. However, high-resolution space-borne image data now provide a cost-effective alternative to photo flights for mapping at 1:10 000 scale, and the purchase of these data is increasing. The paper will detail the image-data needs and the newly available image data. SOPAC has the mandate to handle image data for its member countries, and the paper also outlines the implications for: a) informing Pacific Island Countries about image data availability, b) informing the users about suitable image data for their application, c) assistance in data purchase, and d) service in image pre-processing and image-data enhancement.

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Quantification of Change through Rectifying Historical Aerial Photographs by High-Resolution Satellite Images

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Shoreline and vegetation cover changes rapidly in many Pacific Island Countries because of increasing population and consequent increase in utilisation of aggregates, fuel wood and agricultural area. Historical

aerial photographs are available in many countries, but they are difficult to use for a quantitative analysis as the photographs have to be rectified, and it is difficult to identify ground control points on historical maps if such maps are available. Now, high-resolution image data can be used as reference instead of maps. They show more features usable to identify ground-control points than do maps, and a rectification of historical aerial photographs becomes possible. Therefore, quantification of change of coastline or vegetation is practical.

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Contributions of Molluscan Shell Material to Marine Coastal Sediments

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Coastal sediments of oceanic islands with associated significant coral reefs are dominated by carbonate particles typically of biogenic origin. While distribution, transport and dissolution of carbonate particles are driven by geophysical processes, the production and composition of island coastal sediments result from predominantly biological processes. The stability and persistence of coastal sediments thus represents the balance between erosion/dissolution and carbonate shell secretion within the biological community. Sedimentary particle composition reflects (1) relative abundance of specific taxa within the community, (2) taxon-specific aragonite and calcite production rates, and (3) taxon-specific resistance to erosion and dissolution of discarded and/or post-mortem shell material. Although rarely dominant, molluscan shell material is a significant component of island coastal sediments. The aragonite and calcite matrices of mollusc shell possess greater resistance to dissolution than material produced by the dominant autotrophic carbonate-secreting species, such as corals, foraminifera and calcareous algae. Thus, sediment composition may reflect an influence of mollusc populations (with relatively low biomass and/or carbonate production rates relative to autotrophs) out of proportion to their total abundance in the biological community.

This study examined the composition of shallow coastal sediments collected from various locations within the lagoon at Funafuti Atoll, Tuvalu, during 1995-1996. Samples (total n = 93, with 80 used in this analysis) were collected from shorelines (lagoon and ocean beaches) and within the lagoon along transects extending up to 750 m from shore in water depths up to 20 m. Surficial sediment (upper 1 cm) was collected using either a small grab or pipe dredge. “Wet” samples collected subtidally were stained with rose bengal then dried; shoreline samples were not stained before drying. Dried samples were sieved, splitting the sample into the following size classes: 0.063, 0.125, 0.250, 0.500, 1.000 and 2.000 mm. Sediment composition was calculated by using a binocular stereoscope to identify 300 clasts in each size class, and multiplying by the mass of that size fraction. Thus, percent composition was based on mass of that category in the entire sample, and more than 125 000 clasts were identified in this study.

Overall, the following was the rank order for taxa contributing to surficial sediments at Funafuti: foraminfera tests 44.1%, calcareous algae 24.4%, coral 22.1% and molluscs 9.0%. Particles of non-living origin totaled less than 1%, and only 0.12% of particles were unidentifiable. Other taxa each contributed much less than 1% to sediment particles (bryozoans, crustacea, ostracodes, echinoids, sponge spicules and worm tubes).

Dominant particle classes composing surficial sediments varied significantly among sites (Table 1). Foraminifera dominated samples from the lagoon and lagoon beach, whereas coral grains dominated the ocean-beach samples. Composition varied considerably among samples within each habitat, with the min-max range spanning an order of magnitude or more for the dominant particle classes (Table 1). Particles identified as bivalves were more abundant than gastropods; the abundance of bivalve-derived material increased with distance from shore and water depth, whereas gastropods were uniformly distributed in lagoon samples. Overall, the percentage of mollusc-derived sediment particles increased with distance from shore and water depth. Likewise, percent composition of six of eight categories of foraminifer taxa increased with distance/depth, as well as percent calcareous algae. The percent contribution of coral particles and the remaining two taxa of foraminifera decreased significantly with increasing distance from shore and water depth.

Table 1. Composition of surficial coastal sediments collected at Funafuti Atoll, Tuvalu, 1995-1996. Results are presented as mean percentage (range).

Particle Category	Lagoon	Lagoon Beach	Ocean Beach
Total foraminifera	**41.5** (3.5-61.7)	**37.5** (13.5-67.8)	**6.1** (1.0-19.1)
Calcareous algae	**32.0** (0.5-93.5)	**13.5** (0.3-32.6)	**0.2** (0-0.5)
Coral	**12.7** (0.9-44.4)	**35.0** (11.3-69.3)	**87.8** (67.9-96.3)
Total molluscs	**9.7** (0.9-21.4)	**11.2** (5.9-21.8)	**4.6** (2.2-10.1)
number of samples	*61*	*12*	*7*

The percentage of molluscan shell material within these sediment samples was remarkably stable across habitats in comparison with the dominant taxa. The composition of coastal sediments varied significantly among habitats, with molluscs showing the least variation (~two-fold difference), versus 6.5-fold for foraminifera, 7-fold for coral and 150-fold for calcareous algae. These data imply that material from dissolution-resistant mollusc shells is less labile than material from other taxa, making a relatively uniform and broadly distributed contribution to island coastal sediments. Conversely, any long-term reduction in production rates of mollusc shell would have significant and broad effects on coastal sediment composition.

Molluscan shell contribution to coral-reef sediments has been used as a benchmark for assessing environmentally induced oscillations in the reef community. Lidz and Hallock (*J. Coastal Res*. 2000) interpreted the composition of shallow coastal sediments with respect to a declining coral-reef system, the Florida Keys. During the period 1952 to present, increasing percentage of mollusc shell in sediments corresponded with nutrient enrichment stimulating production of algae (phytoplankton and benthic turf) supporting heterotrophic molluscs. Therefore, long-term trends in the mollusc shell fraction of coastal island sediments could provide a useful baseline for assessing coral-reef health, as well as providing insights into the population dynamics of the principal taxa responsible for biogenesis of sedimentary particles.

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A Strategy for PacificGOOS. Pacific Islands Global Regional Alliance for Global Ocean Observing System

M. Gautier, C. Pratt, A. Simpson, & W. Erb

The Pacific Ocean covers more than a third of the earth's surface and plays a critical role in the important Global Ocean Observing System [GOOS] initiative, which aims to:

- develop and implement an internationally coordinated strategy for the acquisition and exchange of data to:
    - improve our understanding of the coastal and open-ocean environment, and its resources
    - improve our understanding of the complex interactions between the ocean and atmosphere
- facilitate and encourage the development of enabling tools and services to ensure the sustainable use of ocean resources and the coastal and open-ocean environment
- facilitate the active participation and engagement of developing States in GOOS.

Regional and national organisations in the Pacific have already put considerable effort into defining basic ocean observing and monitoring, identifying capacity-building needs and developing action plans and pilot projects to address these. However, the need for further capacity building in ocean-sector-related activities in Pacific Island Countries, and for a more considered, deliberate approach to ensure that long-term ocean monitoring becomes a reality and is used productively, is widely acknowledged.

At the regional level, a draft Strategy has recently been developed to consolidate support for the Pacific Islands Global Regional Alliance [PI-GRA] for Global Ocean Observing System [GOOS].

The presentation seeks to:

- provide an overview of GOOS and the potential benefits for global, regional, national and local users;
- outline the key regional initiatives that have been undertaken since the establishment of PacificGOOS in 1998; and
- present the proposed strategic initiatives for strengthening PacificGOOS.

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Geothermal Small Power Generation Opportunities in SOPAC - Member Countries

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There are six SOPAC member countries that are likely to have geothermal resource potential adequate for the generation of electric power. They are Tonga, Samoa, Fiji Islands, Vanuatu, Solomon Islands and Papua New Guinea. All of these countries are located over active crustal plate-boundary subduction zones and near transcurrent faults, and are loci of active volcanism and/or seismicity.

The demand for electric power in these countries is not large, ranging from <1 to 25 MW, but the current power generation costs are from $US 0.15 to $US 0.30/kWh and geothermal power can probably be generated and sold for less than $US 0.12/kWh. Among the conditions in the region that favor development of geothermal projects are the 4-5% average annual growth rate in the power demand, the current high cost of power generation and the existence of several possible markets for power-hungry desalination plants. The difficulty in obtaining financing for small power projects will be the chief deterrent to geothermal development.

Geothermal indicia reported in the prospective countries include high (up to boiling) surface temperatures of hot springs, high (130-200^{o}C) subsurface geothermometric temperatures and favorable water and gas geochemistry. Contrary to popular belief, geothermal projects do not have to be in the range of tens to hundreds of megawatts. Judicious use of recent technological advances in slimhole drilling and small binary and single-flash, backpressure power plants should permit conduct of one or more technically and economically viable geothermal power projects in the SOPAC region.

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Advances in Deep-Water Marine Habitat Characterization: A Combined Geological and Biological Approach to Habitat Mapping

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Historical marine geologic maps contain considerable information useful to the identification of marine benthic habitats. Existing maps can be updated with geophysical information from multibeam swath bathymetry and backscatter data, and groundtruthed with submersible or ROV observation and sampling. These types of revised map are being used along the northeastern margins of the Pacific to define marine groundfish habitats. With the support of the Alaska and the California Departments of Fish and Game, and NOAA (NMFS and the National Sea Grant Program), we are compiling existing seafloor geologic data with recently released industry proprietary information into a GIS (ArcView) format to produce habitat maps useful in the management of groundfish fisheries. We use a geological-based, biologically supported, deep-water habitat scheme to distinguish the various groundfish habitats. In addition, we are developing metadata to facilitate comparisons of habitat types and geologic units within the GIS database. Fisheries information such as catch-per-unit-effort data and fish tag release and re-capture information have also been included.

Five major megahabitats, which are based on size (kilometers to 10s of kilometers, mapped at scales of 1:100 000 or larger) and depth, are defined in our metadata as continental and island shelves (0-150 m); continental slope, basin and island flanks (150-2500 m); continental rise, aprons and fans (1500-3500 m); basin floors, borderland types (1000-2500 m); and ridges and seamounts (200-2500 m). The induration of the seafloor is used to distinguish soft (sediment-covered with either mud or sand) or hard (rock outcrop or cobble/pebble pavement) bottom types. Mesohabitats, which are based on sizes of tens of meters to kilometers (mapped at scales of 1:150 000 to 1:100 000) and macrohabitats, which are based on one to tens of meters (mapped at scales of 1:10 000 to 1:50 000) are also distinguished in our metadata. Descriptors of bottom textures, physical

processes and biology are used as modifiers. These metadata distinguish habitat type with a series of upper-case, lower-case and subscript letters that are associated with standard United States Geological Survey nomenclature for rock types, ages, and formation names. The intent is to develop a deep-water marine benthic habitat scheme that is intuitive and universal. This type of characterization should be beneficial in delineating and evaluating lagoonal, reef and other marine benthic habitats of the SOPAC region.

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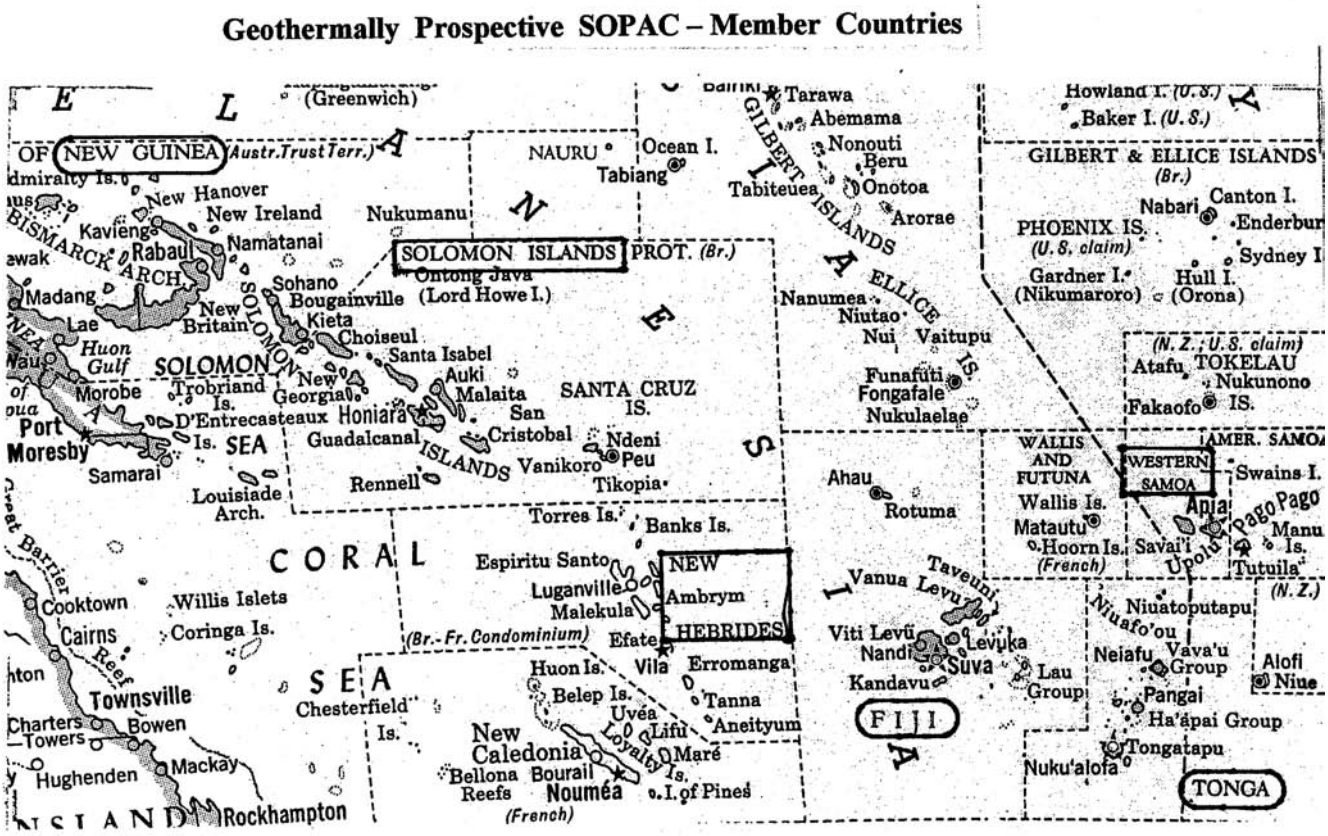
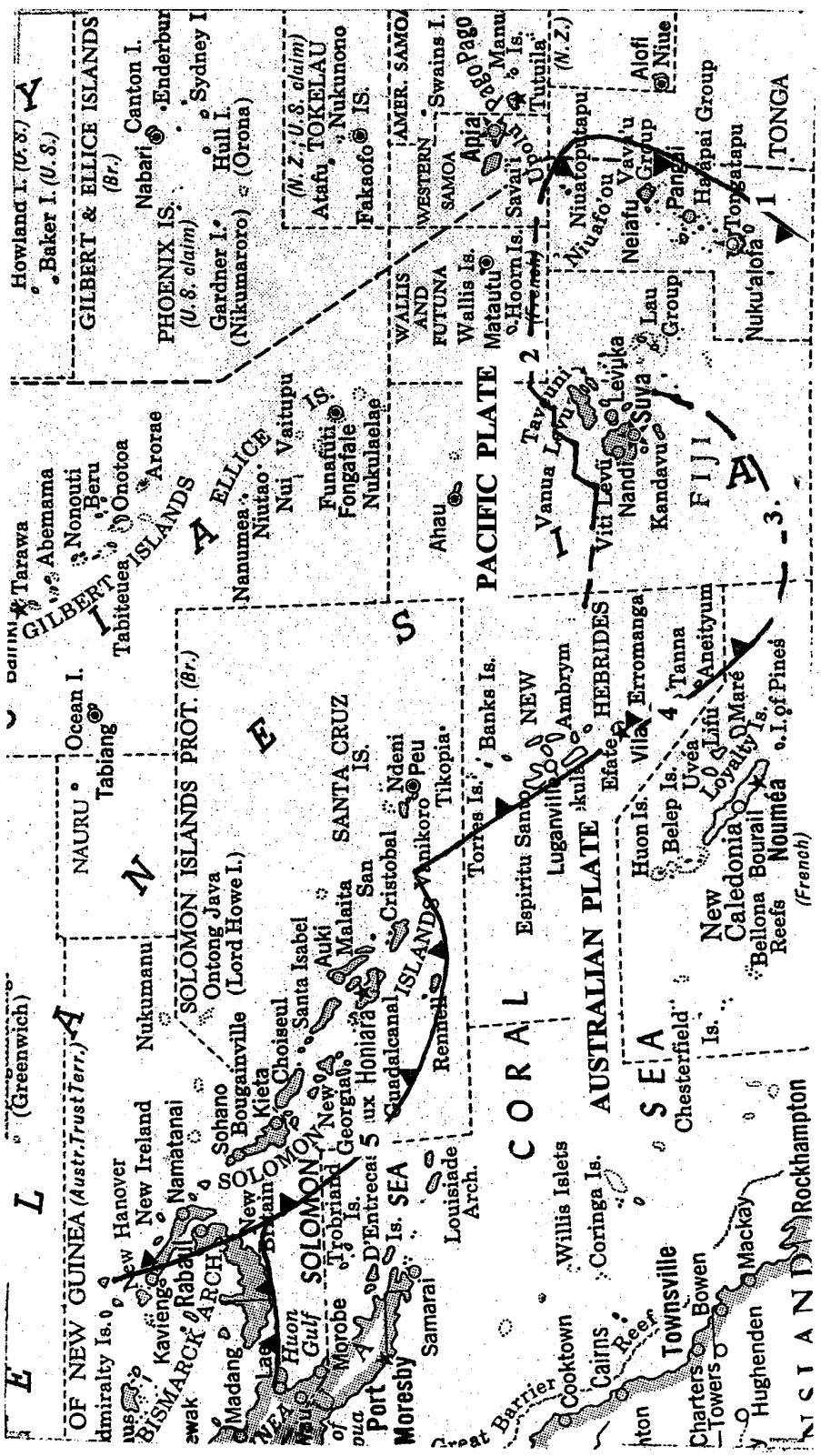
Figure 1



Figrue 2

Figure 2

Selected Crustal Plate Tectonic Features



1. Tonga Trench
2. Fiji Fracture Zone
3. Hunter Fracture Zone
4. New Hebrides Trench
5. New Britain Trench

Note: Triangles point in the direction of subduction

Figure 3

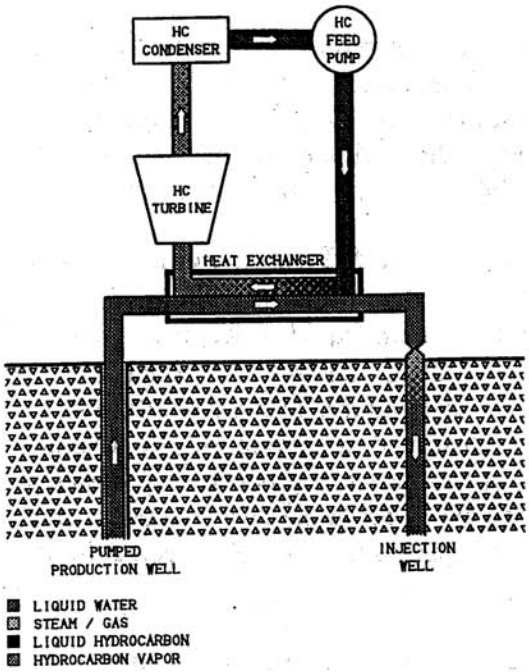


Figure 3 **Schematic diagram of a binary-cycle geothermal power plant driven by a production well equipped with a downhole pump.**

Figure 4

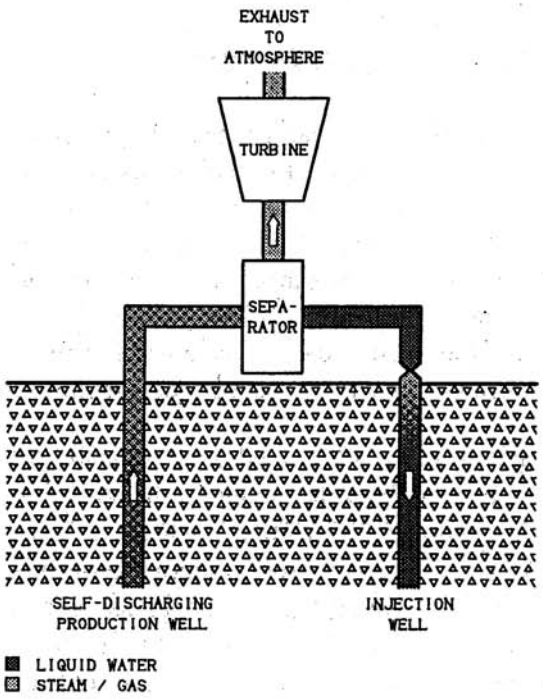


Figure 4. Schematic diagram of a back-pressure single-flash steam turbine wellhead generator driven by a self-discharging geothermal well.

Classification of Coastal Depositional Environments Based Upon a Quantitative Analysis of Wave, Tidal and Fluvial Power: Relevance for Environmental Management

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A statistical assessment of wave, tide and river power was carried out using a database of 721 Australian coastal depositional environments to test whether their geomorphology can be predicted from numerical values. The geomorphic classification of each environment (wave/tide-deltas, wave/tide-estuaries, lagoons, strand plains and tidal flats) was established independently from remotely sensed imagery. To our knowledge, such a systematic numerical analysis has not been previously attempted for any region on earth.

The results of our analysis indicate that a relationship exists between the ratio of annual mean wave power to mean tidal power and the geomorphic development of coastal depositional environments. Deltas and estuaries are associated with statistically significant differences in mean wave and tidal power. Information on fluvial discharge and fluvial flow rate (defined as discharge divided by open water area) permits statistically significant distinctions to be made between populations of deltas, estuaries, strand plains and tidal flats. Our results support the hypothesis of previous workers that wave, tide, and river power exert a primary control over the gross geomorphology and facies distribution patterns within coastal depositional environments. Mean values and confidence limits of wave power, tide power and fluvial flow for different coastal depositional environments predicted in this study may provide a basis for the comparison of modern environments, as well as constraints for palaeo-reconstructions.

The classification of coastal depositional environments is the first step towards developing management in relation to several key environmental parameters, including water turbidity, water circulation, sedimentation and changes to habitat types and their distribution.

Turbidity is a problem for estuarine management in as much as it limits photosynthesis (which seagrass habitat and phytoplankton viability) and is, perhaps, aesthetically displeasing. Whereas turbidity can be used as a water-quality indicator in coastal waters that are normally "clear", it is not a useful measure in tidal systems that have naturally high turbidity levels. Tide-dominated systems typically have naturally high turbidity levels, whereas wave-dominated systems do not. Turbidity in a wave-dominated estuary may be an indicator of human-induced effects.

Mixing rate and flushing efficiency of an estuary are important management considerations. The geomorphology of an estuary identifies which type of oceanographic regime is likely to be present. Stratification and estuarine circulation are uncommon in tide-dominated estuaries and macrotidal deltaic distributary channels, which are generally well mixed. Wave-dominated estuaries having a low-energy central muddy basin are often stratified and may exhibit estuarine (salt-wedge) circulation. Negative (reverse) estuarine circulation is also a common feature of coastal environments, particularly lagoons subject to high evaporation rates and low precipitation.

Since all estuaries are sediment traps, they gradually infill and evolve towards a deltaic state. This natural evolutionary process results in the loss of some habitats and environments that are only present in immature estuarine systems, including the central muddy basin of lagoons and wave-dominated estuaries and the rocky shoreface and reefs of some wave- and tide-dominated systems. Human-induced effects in the catchment that result in greatly increased fluvial sediment loads can accelerate the natural process of habitat loss.

Some immature estuarine systems are effective sediment traps, whereas systems that have matured and become deltaic retain none of the sediment delivered to them. This "trapping efficiency" is important to environmental managers, because the fate of most contaminants is linked with the dispersal and deposition of fluvial, fine-grained sediments. Wave-dominated estuaries and lagoons tend to have greater trapping efficiencies than other coastal environments. Tidal systems are highly energetic and turbid, and fine-grained sediments escape onto the adjacent shelf. Blind, wave-dominated estuaries will trap 100% of all fluvial inputs until such a time as a flood event cuts a new inlet through the wave-built barrier and flushes the estuary.

Type of Coastal Environment	Sediment Trapping Efficiency	Turbidity	Circulation	Habitat Change due to Sedimentation
 Tide-dominated Delta	Low	Naturally High	Well Mixed	Low Risk
 Wave-dominated Delta	Low	Naturally Low	Salt Wedge/ Partially Mixed	Low Risk
 Tide-dominated Estuary	Moderate	Naturally High	Well Mixed	Some Risk
 Wave-dominated Estuary	High	Naturally Low	Salt Wedge/ Partially Mixed	High Risk
 Tidal Flats	Low	Naturally High	Well Mixed	Low Risk
 Strand Plains	Low	Naturally Low	Negative/ Salt Wedge/ Partially Mixed	Low Risk
 Lagoon	High	Naturally Low	Negative/ Well Mixed	High Risk

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Coastal Sedimentation, Erosion, and Management of Majuro Atoll

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Erosion along about one hundred kilometres on both lagoon and ocean coasts on the east, south and southwest rims of Majuro Atoll is basically induced by coastal development, including aggregate excavating, landfill, groynes, artificial channels and causeways. The lagoon-coast erosion on the west part of south rim and the southwest rim is mainly induced by development on the east rim and the east part of south rim. Recommendations of coastal management have been proposed, mainly to reform coastal constructions on the lagoon shore of the east part of the south rim. Distribution of beachrock demonstrates existence of continuous land on the south rim. Can not make openings on the south rim, which will induce big erosion, especially excavating channels.

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The Challenge of Measuring Absolute Sea-Level Rise and climate change in the Pacific Islands

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The leaders of the Forum Island Countries, in particular those of Pacific Island atoll countries, expressed great concerns about the potential impacts of human-induced global warming (the "greenhouse effect") on climate and sea levels in the South Pacific. The Australian Prime Minister announced, at the South Pacific Forum in 1988, an initiative to study the establishment of a regional network to monitor sea-level and climate change. The South Pacific Sea Level and Climate Monitoring Project was developed as an Australian response to address this issue. The primary goal of the Project was "to generate an accurate record of variance in long-term sea level for the South Pacific and to establish methods to make this data readily available and usable by Pacific Island countries". From 1991 to 2005, the project has been implemented and managed in three phases.

The project involves the following Forum Countries; Kiribati, Tuvalu, Marshall Islands, Samoa, Cook Islands, Tonga, Fiji, Vanuatu, Solomon Islands, Niue, Papua New Guinea, Federated States of Micronesia, Niue, Palau and Nauru.
Phase I of the Project ran from 1991 to 1995, and saw the establishment of sea-level/meteorological monitoring stations at eleven sites, one each in Cook Islands, Fiji, Kiribati, Marshall Islands, Nauru, Papua New Guinea, Solomon Islands, Tonga, Tuvalu, Vanuatu and Samoa. A near-real-time system for transmitting the data and computer databases were established for archiving and accessing the data from Australia. In addition, public-awareness programmes on the climate-change issues and the project were delivered through governments, schools, media and local communities.

The Project was extended into Phase II, from 1995 to 2000; it placed more emphasis on training and information dissemination and continued to collect data from the tide-gauge stations to assist governments calculate the relative sea level and climate variability signals at national and regional levels. In addition, it added another observing tide-gauge network to the Federated States of Micronesia.

Within the overall goal stated above, the three major objectives of the project were:

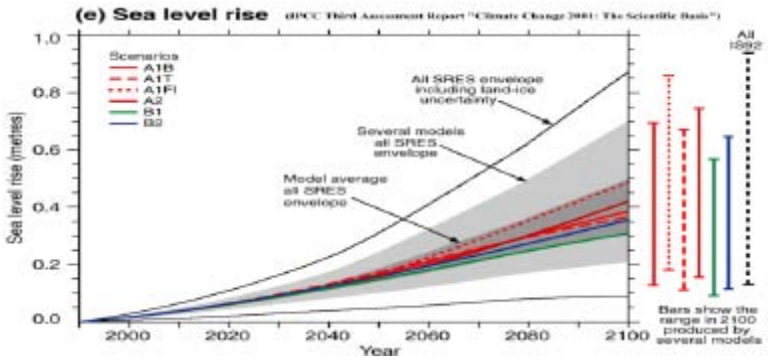
1. to provide quantitative data to assist Pacific Island countries to predict direct consequences of climate change and associated rise in sea level;
2. to assist countries in building technical capacity to monitor climate change and associated environmental phenomena; and
3. to provide tidal information for use in navigation, surveying and associated marine activities.

<u>Phase III - Measuring absolute sea-level changes in the Pacific region.</u>
Under this phase, some of the challenges include determining the absolute and relative sea-level changes, collecting and archiving long-term sea-level data, transfering technology and facilitating adaptation policy developments.
Phase III, in 2001-2005, has the four main components:

- Sea-level Tide-Gauge (SEAFRAME) Network.
- Geodetic levelling and Network.
- Sea-level Databases.
- Information Products.

A Continuous Global Positioning System (CGPS) network linked to the tide-gauge stations (known as Sea-Level Fine Acoustic Measuring Equipment-SEAFRAME) has now being established. CGPS receivers are now being installed near the SEFRAME stations in the 12 Pacific countries. Data and results from the respective sites and the region are now being collected with the objective of determining the absolute sea-level changes.

Results from the project on the relative sea-level changes during the last 10 years from individual and regional perspectives will be discussed and compared with other regions and Intergovernmental Panel on Climate Change report (3^{RD} IPCC).



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Morphology and Evolution of the Southernmost Atolls, Middleton and Elizabeth Reefs, Southwestern Pacific.

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Middleton and Elizabeth Reefs (29°27'S, 159°06'E and 29°56'S, 159°03'E respectively) are the southernmost atolls in the Pacific Ocean, occurring just over 500 km from the Australian mainland. They occur within a linear chain of islands and seamounts related to Tertiary hot-spot volcanism. The only subaerial exposures of basalt in this chain are on Lord Howe Island and Balls Pyramid 200 km to the south. A discontinuous 6-km-long fringing reef has also grown on Lord Howe Island. Guyots and seamounts are present to the north. Drilling, vibrocoring and seismic profiling indicate the three-dimensional morphology and stratigraphy of the atolls. Each atoll consists of a rim of reef framework which is 8 m thick on the windward side of Middleton Reef, the only location where the Pleistocene basement was directly sampled. On both atolls the reef rim encloses a lagoon partly filled with sand composed of coral, coralline algae, foraminifera and other lesser skeletal components. Radiocarbon dating indicates that the windward reef rim commenced growth around 6700 radiocarbon years BP over a Pleistocene reefal-limestone foundation. Reef growth adopted a keep-up strategy on the windward margin, reaching modern sea level by at least 5000 years BP, but 'catch-up' growth characterised leeward margins. The lagoons have infilled progressively from the margins, with a small area of deeper lagoon persisting within which reticulate 'mesh' reefs are being smothered by prograding sand sheets. Reef-island accumulation on the atoll rim is restricted to minor ephemeral sand cays on the leeward margin.

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Mapping the coastal morphology of Savai'i Island, Samoa (Pu'apu'a to Sasina)

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[3]SOPAC Secretariat, Private Bag, GPO, Suva, Fiji

A field survey, a part of continuing KIGAM-SOPAC cooperation programs, was performed along the northeastern area of the Savai'i island, Samoa, during 22nd-29th November 1999. The survey object was to check ground features identifiable in aerial photographs and update the previously used geomorphic maps for making final maps later. This is a preliminary result of the field survey done in 1999.

The survey area can be divided into two regions based on the coastal features, the northern reef-fringed coast and the eastern cliffed coast, respectively.

The northern coast from Sasina to Sale'aula can be classified as a reef-fringed coast featuring fringing reefs, sand spits, lagoons with fresh-water creeks, swamps, and marshes. This area is relatively dense in population and active in artificial modification.

The eastern coast from Sale'aula to Pu'apu'a is dominated by coastal cliffs. Numerous notches and small pocket beaches are recognizable. New buildings could be recognized along the road nearby the Samalaeula village. This region can be subdivided into northern and southern parts. The northern part, from Sale'aula to

Samalaeula, covered by thick lava flow of recent volcanic eruption, shows few prominent forests and artificial constructions. The southern part from Sale'aula down to Pu'apu'a, however, shows thick forests reaching the adjacent coastal cliffs.

The survey results were compiled and summarized into a map based on the previous morphologic maps. The new map was produced in DXF and postscript format for future GIS work.

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Initiation of Subduction, Forced Changes in Absolute Plate Motion, and the Development of Rifting: A Pacific Perspective

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In the process of inspecting Pacific Basin reconstructions and new absolute plate-motion (APM) models, e.g., Engebretson et al. (1985), Scotese et al. (1988), Yan and Kroenke (1993), Lee and Lawver (1995), Kroenke (1996), Wessel and Kroenke (1997, 1998) and Sterling et al. (2000), it unexpectedly became evident that the initial alignment of all subduction zones, i.e., the strike of the newly formed trench axis, consistently seemed to roughly parallel the APM of the adjoining oceanic plate during the time the zone was being formed. Every major subduction zone whose original alignment relative to APM could be established, invariably exhibited this relationship. Furthermore, two types of subduction-zone initiation could be recognized: A) those that preceded, and may have been responsible for subsequent, major, long-lived changes in APM; and B) those that followed major changes in the APM, whose development may have enabled the accommodation of the ensuing convergent stress build-up following the change. In the latter situation, APM changes appeared to have occurred concomitant with terrane collision and/or accretion and, although sometimes impressive, were often short-lived. In both situations, however, subduction-zone alignment roughly paralleled plate motion during the initiation of subduction. More unexpectedly, however, the same reconstructions/APM models seemed to suggest that the initial alignments of rift axes/spreading ridges also were roughly parallel to the APM at the time of their formation. We examine the tectonic initiation of Pacific-margin subduction and rift zones in the context of absolute motions of the ocean plates as determined in the hotspot frame of reference. The primary plate-motion driving force is assumed to be the pull of the descending lithospheric slab. The cause and effect of changes in plate motion, as well as the timing of these changes, will be considered in relation to the tectonic initiation and development of both subduction and rift zones.

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Development of TRITON Array and Recent ENSO Observations in the Equatorial Pacific Ocean

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1. Development of TRITON project

An operational network of meteorological observatories on land, placed all over the world, has been enabled us to monitor the change of global atmosphere, but we have fewer observational platforms in world oceans and less understanding of oceanic environmental changes. Through the TOGA (Tropical Ocean and Global Atmosphere) decade, basin-wide observing networks of mooring array, surface drifters, XBT lines and tide-gage stations have been developed to monitor and study ENSO (El Niño/Southern Oscillation). In particular, the TAO (Tropical Atmosphere Ocean) array was successful in monitoring the 1991-93 and 1997-98 El Niño, and largely contributed to improving the capability of ENSO prediction models.

A standard TAO-ATLAS buoy can measure wind vector, air temperature, relative humidity and subsurface temperature. The array enabled us to detect the basin-scale thermocline displacement with surface wind forcing and helped us to understand the ENSO physics. However, each El Niño indicated different features such as onset process, strength, and duration, and they have not yet been well understood theoretically nor predicted well by prediction models. For better understanding of ENSO, the necessity of development of the new buoy network named TRITON (TRIangle Trans-Ocean buoy Network) has been considered; this could measure surface heat and freshwater flux, and also subsurface salinity changes to elucidate the heating process in the western Pacific Ocean.

The technological development was started from feasibility studies, conceptual buoy design and simulation of buoy motion during 1992-1994, and the prototype buoy was built in 1995. Since 1995, the open sea tests were carried out at 4000 m depth near Ogasawara Islands and technological improvements were made. R/V Mirai, specially designed for buoy operation, was launched in 1997 and the four TRITON buoys were deployed in 1998 along 156E in the western tropical Pacific Ocean. TAO buoys west of 156E were replaced with TRITON buoys, and the TAO/TRITON array was officially started in January 2000. At present (in summer 2001), eleven TRITON buoys are working and monitoring ENSO, harmonized with the TAO array.

2. ENSO observations from TRITON and TAO arrays

A 20°C isothermal line representing a sea-surface thermocline is the indicator of reserved heat in the seawater. The depth of 20°C isothermal lines and anomaly depth showed the remarkable depth of 210 m (30 m deeper than the average) in the western Pacific in the period of March-April 2000 after the historical El Niño event of 1997/1998. The TRITON buoy observations suggested that the circumstance for appearance of the next El Niño was settled after the ending of the last El Niño in May 1998 and succession of La Niña about two years later. The accumulation of warm water in the entire tropical Pacific is also apparent in the time series of mean sea level from the sea-level network of the University of Hawaii. It indicates that the mean sea level is as high as one just before the 1986/87 El Niño, although is less than those before the 1982/83 and 1986/87 El Niños.

The warm water in the western Pacific moved eastward with several Kelvin waves from November 2000 to May 2001. We observed also significant strong eastward currents reaching 150 cm/sec in late June by a current meter on the TRITON buoy at 0, 156E, which were driven by a westerly wind burst associated with stagnated intraseasonal atmospheric disturbance, and the high-speed currents over 70 cm/sec continued to the end of July. The high-speed currents caused a large warm and fresh water convergence in the west of 180° and it propagated into the eastern Pacific. The warm-water propagation in the subsurface was apparently observed in early August 2001, but the trade winds persisted in the eastern Pacific and depressed the warming of the sea surface in the eastern Pacific. Thus, the magnitude of the warm episode will be small through the year 2001, and El Niño development in early next year should be watched by TRITON and TAO arrays.

As this report indicates, continuous measurements by the TRITON and TAO arrays are quite important to the monitoring of ENSO developments and the reduction of the impacts of abnormal weather induced by ENSO in the Pacific countries.

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Causeways – Solution or Problem: A Proposal to Study and Mitigate the Impacts on Atolls by Causeway Construction

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The Pacific Ocean contains almost 100 atolls. A number of nations, for example the Republic of the Marshall Islands and Kiribati, have no land other than atolls. Atolls originate from high volcanic islands that subside into the ocean. The original island's fringing reef grows into a barrier reef. When the last volcanic material finally disappears below sea level, the coral rim of the reef, now an atoll, remains. The central lagoon of a huge atoll such as Kwajalein atoll may be more than 240 km wide. but the width of dry land on an atoll is usually less than 2 km from inner to outer beach. Entirely landlocked lagoons are nonexistent; passages through the barrier reef are found more often on the leeward side than the windward. Atolls are seldom higher than 7.5 m.

Modern society is threatening the world's atolls. The dangers of the greenhouse effect and global warming are more severe in atoll countries than anywhere else. Water levels could rise by 1 m in 50 years, 3 m by the year 2100. On atolls, this will mean the imminent intrusion of salt water into the groundwater supply, and later, possibly more disastrous results.

On a local level, particularly on populous atolls, outlying islanders often wish to be connected to the most populous island, which may have electricity and jobs. Since the atoll countries are not wealthy, such islands usually are connected by causeways, rather than by high suspension bridges. These causeways, usually built with an insufficient number of costly culverts, interfere with ocean tides, which had previously flushed the lagoon to keep it clean.

The primary impact of causeways on atolls is the restriction of circulation within the inner lagoons. Restricted circulation leads to reduction of nutrients, increase in temperatures, reduced oxygen and locally concentrated turbidity and erosion. Causeways can also impede the natural distribution of sediments and alter habitats critical to the stability of a healthy ecosystem. All this can lead to a reduction of a food source within the lagoons, and indirectly, of the fisheries outside the lagoon.

We propose to develop a program, The Atoll Project (TAP), to assist developing atoll nations that are building causeways in obtaining grants to allow them to build causeways and bridges in the least ecologically destructive way. The ultimate goal of TAP is to help set up mechanisms by which developed nations and foundations can work with atoll nations. Once funding is established, the first stage of the project would be to make an inventory of the atolls and proposed causeways. We propose to carefully study one potential causeway, and calculate the cost of an ecologically sound method to build the crossing. We would then estimate what would be the approximate cost of solving the problems of all the currently planned causeways. Our intent is to produce proposals that would solicit funds from private foundations and developed fisheries nations.

TAP will work under the philosophy that it is inappropriate to take any broad position as to whether islands on an atoll should be linked together or not. We recognize that the question of building a causeway, for instance, involves a complex balancing by atoll countries of the needs for development and the desires of outer islanders against possible ecological harm.

What TAP hopes to do is to supply atoll nations with accurate scientific information as to the harm that any given causeway could cause. This would provide the political authorities with accurate information on which to base its decisions.

Our presentation will consist of informing STAR and SOPAC of our proposed project and to obtain scientific feedback. We seek no funds from STAR or SOPAC, but wish an endorsement to use for fund raising purposes.

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Foraminiferal Assemblages and Their Contribution to Carbonate Sediment, Green Island Reef, Great Barrier Reef Province

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Foraminifera are significant producers of carbonate sediment on reefs. They provide 15% by dry weight of reef-top carbonate sediment of Green Island Reef in the Great Barrier Reef Province. Only four foraminiferal genera, *Calcarina*, *Baculogypsina*, *Amphistegina*, and *Marginopora*, contribute the bulk of this fraction, with contributions of 42 wt%, 25 wt%, 14 wt%, and 12 wt%, respectively. These taxa are especially abundant on and near the reef flat, and close to the reef rim where macroalgae are abundant. Small hyaline and porcellanous forms are more significant in the deeper-water zones surrounding the reef flat.

A diverse foraminiferal assemblage is epiphytic on the seagrasses and macroalgae at Green Island Reef (54 and 94 species, respectively). Total epiphytic foraminiferal densities were highest on the reef rim-restricted species of macroalgae such as *Laurencia* sp. and *Chlorodesmis fastigiata* (2080 and 1047 individuals/gdw, respectively). *Calcarina spengleri*, *Baculogypsina sphaerulata* and *Neorotalia calcar* are the common species occurring on these algae, preferring their filamentous morphologies. *Cymbaloporetta bradyi* and *Sorites orbicularis* are permanently attached forms which are common and dominant on the seagrasses as these plants provide flat attachment surfaces. *Halodule uninervis* and *Thalassia hemprichii* are the preferred seagrasses (0.95 and 0.94 individuals/cm^2, respectively).

Macroalgae are the preferred substrate for epiphytic foraminifera, with standing crops higher on the algal turf zone than in the seagrass meadows. The average standing crops in the seagrass meadows vary between 2 400 and 54 000 individuals/m^2 for the total assemblage and between 20 and 6 400 individuals/m^2 for *Calcarina spengleri*. In the algal turf zone the average standing crop is 8.2×10^5 individuals/m^2, between 6.1×10^4 and 1.1×10^6 individuals/m^2 for *Calcarina spengleri*, and 1.5×10^5 individuals/m^2 for *Baculogypsina sphaerulata*. Carbonate production on the seagrass and algal turf is estimated to vary between 3.9 and 1.4×10^3 g $CaCO_3$ m^{-2} yr^{-1} for *Calcarina spengleri* and 480 g $CaCO_3$ m^{-2} yr^{-1} for *Baculogypsina sphaerulata*. These values are similar to estimates which have been made for other western Pacific reef localities.

Species richness is lower in the epiphytic assemblages than in assemblages obtained from sediment. The main species contributing to the surface sediment are abundant in the epiphytic communities, indicating a clear provenance linkage. Post-mortem transport is characteristic of the reef flat, with common reef-flat species found in both backreef and forereef locations. Transport is mainly to the north-west, the prevailing wind and current direction, with minor southern transport during storms.

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Results of an Energy Audit of the SOPAC Secretariat Premises

Rupeni Mario, SOPAC, Private Bag, GPO, Suva, Fiji. Email: rupeni@sopac.org

As a follow up to a presentation on an energy audit of the SOPAC Secretariat premises at STAR during the 29th SOPAC Annual Session in Kiribati, September 2000, the poster summarises the methodology used, with results showing comparisons of historical and current electricity bills, and savings achieved. The presentation also identifies other opportunities in improving on the current savings, gained solely from energy education and good housekeeping practices.

The ultimate goal of the energy audit was to demonstrate that energy efficiency and conservation programmes can begin with no financial costs, as the usual perception about such a programme is that it is inconvenient and costs money.

The recommendations of the audit report[1] were presented to an all staff meeting in March 2001. Following the official announcement of the energy efficiency and conservation campaign by Management, users had a more conscious approach to electricity usage at the premises. Since then, the Secretariat's electricity bills have shown significant savings. The savings as shown in the Figure below was primarily attributed to users taking advantage of the cool weather conditions and not using the air conditioning. Other contributing factors were the switching off of lights, computer screens and other electrical appliances when not needed. It is noteworthy that the savings identified over this period were brought about by simple housekeeping measures which had no financial cost to the Secretariat. This saving of around 11% is comparable with that calculated as being achievable during the initial phase of the energy audit.

An effective energy conservation and efficiency programme does not end with achieving energy and monetary savings. Although it may take one to two years to eliminate wastage altogether and practise energy conservation and efficiency habits, it is also important that the programme is on-going that and continual reminders are provided. Currently the Secretariat staff are informed of consumption and savings on a monthly basis.

Electricity consumption at the SOPAC Secretariat

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[1] Energy Audit of the South Pacific Applied Geoscience Commission – SOPAC Miscellaneous Report 393, June 2000

Pacific Island Countries Mark Earth Day 2001

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The focus of this year's Earth Day on the 22nd April was on energy and global warming. This is one of the most severe environmental challenges facing the world today, and is particularly near and dear to the hearts of a great percentage of SOPAC member country populations whose homes are located on the low-lying coral atolls of the Pacific.

Gaylord Nelson, then a Senator from Wisconsin in the United States of America, founded the original Earth Day on 22nd April 1970. The primary objective was to organize a nationwide environmental protest so as to force this issue into national agenda. This succeeded when about 20 million Americans took to the streets to demonstrate for a healthy and sustainable environment. Earth Day went global in 1990 with 200 million people from 141 nations voicing their concerns.

To join and acknowledge Earth Day 2001 within the region, SOPAC, as the focal point for the coordination of regional energy programmes and activities, organized an energy education/awareness programme that focused on a school essay and/or poster competition with the theme: "Energy, Transport and the Atmosphere". This was also the theme of discussions at this year's Ninth Session of the Commission for Sustainable Development (CSD9) held in New York in April.

In supporting and encouraging a greater awareness throughout the region in relation to issues associated with energy, the environment, atmosphere and transport, the following key energy components were selected for the Earth Day 2001 celebrations.

- Government's commitments to a Clean Energy Future;
- Human Rights and Environment;
- Power Save – Habits for Energy Efficiency;
- Green Energy Funding; and
- Safe Power

The poster presents concerns of Pacific island children expressing their views in drawings, essays and poems.

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INET/ICANN Conference

Franck Martin, South Pacific Applied Geosciences Commission, Private Bag, GPO, Suva, Fiji. Email: Franck@sopac.org.fj

Every year the Internet Society organises a conference called INET to highlight the societal and technical developments of the Internet and to give directions on the future. During this conference a special symposium for developing countries is organised where various organisations and countries come to share their experience. At the same time the ICANN, who is in charge of regimenting domain names, organises a conference to discuss the creation of new domain names and to discuss dispute-resolution procedures.

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PPA Conference - GIS Opportunities

Franck Martin, South Pacific Applied Geosciences Commission, Private Bag, GPO, Suva, Fiji. Email: Franck@sopac.org.fj

The Pacific Power Association (PPA) had its 10th annual conference this year. It was the time to review 10 years of partnership between power utilities as well as to define the future tools for utilities. Amongst these tools are the Geographic Information Systems, which can help utilities in managing their assets, reducing electricity theft and improving the quality of the network. Several utilities in the region have shown interest in such systems. PPA is requesting assistance on behalf of its members.

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First announcement of the 2002 International Marine Technicians Workshop (INMARTECH2002) October 7-11, 2002, Yokosuka, Japan

Takeshi Matsumoto, Associate Scientist, Deep Sea Research Department and Deputy Manager, Research Support Department, Japan Marine Science and Technology Center (JAMSTEC)
Email: takeshi@jamstec.go.jp

The 2002 International Marine Technicians Workshop INMARTECH2002 will be held in Yokosuka, Japan, from 7 to 11 October 2002.

The purpose of INMARTECH is to provide a forum for international exchange of knowledge and experiences among marine technicians and to improve equipment performance during scientific cruises on research vessels. INMARTECH2002 is hosted by Japan Marine Science and Technology Center (JAMSTEC) and supported by the International research Ship Operators Meeting (ISOM).

The INMARTECH Workshop is organised biannually. INMARTECH2002 is the fourth workshop. The first workshop was held in 1996 in Southampton (UK), the second in 1998 at the Scripps Institution of Oceanography in San Diego, California, USA, and the third in 2000 at the Netherlands Institute for Sea Research (NIOZ) on the island Texel, The Netherlands.

For further information, please contact Dr. Takeshi Matsumoto, JAMSTEC (takeshi@jamstec.go.jp).

Outline of the workshop:

Meeting schedule (tentative):
7 October (Mon.) ... Registration
8 October (Tue.) ... Opening session, Technical sessions (oral/poster)
9 October (Wed.) ... Technical sessions (oral/poster)
10 October (Thu.) ... Technical sessions, Summary session
11 October (Fri.) ... Technical tour

Venue:
Headquarters, Japan Marine Science and Technology Center (JAMSTEC)
2-15, Natsushimacho, Yokosuka 237-0061, Japan

INMARTECH2002 is concentrated on the following key themes:
(1) Data acquisition technology
* CTD Technology
* ADCP Technology
* Meteorological Observation Technology
* Chemical Analysis of Sea Water
* Sediment/Rock Sampling & Storage
* Biological Sampling
* Seismics & Geophysical Observations
* Observation in High Latitudes
* Others

(2) Handling and operation of instruments
* Manned & Unmanned Vehicle Technology (including Work System)
* Seafloor Monitoring Technology (including Lander Technology)
* Mooring Technology
* Seismics & Geophysics Technology
* Ship Operation Technology
* Handling Heavy & Large Equipment
* Cable & Winch Technology
* Others

(3) Data management and data quality control
* Database Management
* Data Quality Control
* Data Publication
* Others

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Managing Unacceptable Risks – A Model for the Pacific

Alan Mearns, DMU Coordinator, South Pacific Applied Geosciences Commission, Private Bag, GPO, Suva, Fiji
Email: Alan@sopac.org

The goal of the SOPAC Disaster Management Project is to strengthen national disaster-reduction programming capacities and to incorporate risk-management practices, within the context of an integrated national planning process.

The unacceptable risks facing Pacific Island Countries can be more effectively managed by adopting this broader risk-management approach, that will then underpin greater sustainability in national development planning, enhance levels of community resilience, strengthen disaster response and recovery capacities and reduce the severity of disasters. To more effectively address the issues of managing unacceptable risks, the DMU has developed an integrated and whole-of-country approach or model of risk management through Comprehensive Hazard and Risk Management (CHARM) which is defined as a programming tool within the context of an integrated national development planning process.

Risk management programs that are linked to hazards and their impact on development programs and communities are cross cutting, and therefore require the integrated support and cooperation of national governments, regional organizations, NGOs and in many cases the private sector to be successfully implemented.

The CHARM programming approach will:

- Intrinsically link together development priorities and programs of individual countries
- Clearly identify gaps within existing or proposed country project activities
- Enable SOPAC to work closer with its regional partners and to develop the DMU's annual work plan and activities schedule around clearly identified country needs and priorities

There are many government line ministries and departments, together with regional organizations, that are currently undertaking risk-management projects. Many of these are undertaken in isolation, with very little information sharing or collaborating partnerships being established, which in turn leads to duplication of effort. In order for national officials to identify programming gaps, they must first have a big picture of all the hazards and the risks that exist, together with an overview of what projects are being undertaken or proposed. Usually it is only the national planning offices that would have this type of information, however research has found that there is not usually a matrix that identifies all projects and their linkages. The CHARM programming approach aims to develop this matrix using an adaptation of Australian and NZ risk-management processes. The key steps include:

- Identifying known hazards
- Analysing each hazard against national development priorities and determining levels of unacceptable risk
- Identifying vulnerable sectors in relation to each of the hazards
- Identifying risk-treatment options to either eliminate or reduce the level of risk
- Identifying what activities are already being implemented or proposed
- Identifying any gaps
- Determining lead responsibilities for managing the implementation of the risk-reduction strategies
- Identifying implementation support mechanisms

The DMU model of risk management using the CHARM approach is a new concept that requires training and skills enhancement of national development planners and disaster managers. The successful completion of this task will have significant benefits to national governments and vulnerable Pacific communities. For SOPAC it also provides a management tool through which we can establish collaborative partnerships for more-effective support to countries. For national governments the matrix will provide a useful tool to establish the linkages between each of the development projects. It will ensure more-effective use of available resources through information sharing, collaborative partnership opportunities and less duplication of effort. It will also serve as a useful tool for identifying priority gaps within the development planning needs of the country.

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Trench Slope Failure Observed off the Northern Coast of Papua New Guinea and its Relationship with Large-Scale Tsunami Hazards

Takeshi Matsumoto[1], David Tappin[2] and the SOS-4 Onboard Scientific Party
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[2] British Geological Survey. Email: drta@bgs.ac.uk

The SOS (Sissano Offshore Survey) Programme started in 1998 through the collaboration between JAMSTEC and SOPAC (including the government of Papua New Guinea) after the devastating 1998 Papua New Guinea Earthquake (M7.1) and subsequent large-scale tsunami (17 July 1998). Major objectives of the programme are to detect the nature of the 1998 Tsunami and the driving force of these geological events under the condition of the regional tectonics. Four cruises including regional geophysical survey and precise seafloor observations have taken place so far under the programme.

Detailed observation by the ROV and submersible surveys revealed remarkable fresh en-echelon cracks with a sharp edge, extending up to 15 km in length and corresponding to the tensional stress along the mid-slope in the eastern to central part of the amphitheatre off Sissano Lagoon. The western part of the amphitheatre is characterised by cracks with a round edge covered with sediment, suggesting that this part is rather old. The contrast between the eastern and western parts of the crack is also described by the small-scale topographic features and the distribution of chemosynthetic biological community on and around the cracks on the eastern slope.

The SOS-4 cruise was carried out in February 2001 to study the precise sub-surface structures corresponding to the hazardous earthquake and tsunami events by use of digital single-channel seismic profiler. A focused survey was carried out on the amphitheatre area to identify active deformational structure which was a probable origin of the 1998 event. The seismic data revealed possible collapse, underwater landslide, and seismic faulting on the amphitheatre, and also confirmed major contrast between the eastern and western parts of the slope of the amphitheatre.

A clear northward-dipping lower reflector on the foot of the western part of the scarp is interpreted as a fossil fault escarpment which 300 m-thick soft slump sediment overrode. The lower reflector underneath the amphitheatre scarp and the slump sediment mound north of the scarp are interpreted as a formation of the rotational failure underneath the slope. The failure of the upper scarp identified during the SOS surveys is considered to be the most recent event. The eastern half of the amphitheatre is characterised seismically by layered stiff sediment where a rotational failure must have taken place quite recently. The sediment in the eastern part seems to be cohesive due to a certain process of compaction or some specificity of the origin of the sediment derived from the nearest on-land area. This is also supported by the piston core sample showing no sign of recent turbidity current on the foot of the amphitheatre.

A regional seismic survey off Vanimo - Sissano - Aitape was also carried out during the SOS-4 cruise and identified some recent/fossil events as suggested by the regional tectonics. A transparent sedimentary layer block with the estimated total volume of 70 km3, apparently derived from a slope failure on the headwall, was located in the fore-arc area of the New Guinea Trench off Vanimo. The sediment block completely fills the fore-arc basin. The northern coast of Papua New Guinea is characterised by an oblique subduction of the North Bismarck Sea Plate underneath the mainland Papua New Guinea on the Australian Plate, towards the WSW along the plate convergent margin on the Wewak Trench and the New Guinea Trench. Then the convergent plate boundary (trench) shifts towards the seaward side and rolling back of the oceanic lithosphere takes place due to the difference in the lithospheric structure of both sides and the consequent gravitational instability. The surface of the convergent plate-boundary area is characterised by tensile stress. Slumping of the surface sediment and normal faults appear remarkably in this case. The observed large-scale seamounts colliding against the trench axis may induce an abrupt increase of the tensile stress perpendicular to the general trend of the trench axis in the whole fore-arc area and also the

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The Mineral Resource Sector in Papua New Guinea

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This document is intended to summarise the Mineral Resource Sector in Papua New Guinea and highlight potential problems Papua New Guinea will be facing in the mining sector in the years to come.

Papua New Guinea has been exporting gold since 1930 and is ranked as the 11th largest gold producer in the world and the 10th largest copper producer. Silver is a commercial by-product from most of the five mines, and minable reserves of nickel, cobalt and chromite have been identified but remain to be exploited. Mining products have maintained their position as the leading primary export commodity of PNG, at 46% of the total exports in 2000 and 17.1 % of the total GDP. There are currently five operating mines.

Like mining, exploration has a direct or indirect impact of its own on the economy. It has progressively declined from a peak of $US80 million in 1988 to $US15 million in 2000.

Exploration expenditure within the country still remains at an unacceptably low level. Mineral production from most major mines instead has exceeded the forecast for the first half of 2001. Eight potential developments await infrastructure development and increased commodity prices to enhance their economic viability.

However, PNG faces potential problems in years to come, as the investment climate in PNG is becoming increasingly unattractive. In ten years time the mining industry may grind to a halt, when the current mines are exhausted and no new mines come on stream. Primarily, the international perception is that PNG's fiscal system is not competitive and, secondly, the government's unilateral decision to acquire additional equity interests in mine projects is unwelcome. Proposed incentives to change the trend include company income-tax holidays, royalty reductions, additional profit tax exclusion and the revision of the mining levy schedule.

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Pacific Strategic Action Plan on Wastewater

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In the framework of the Global Programme of Action (GPA) for the Protection of the Marine Environment from Land-based Activities in the Pacific Islands Region, UNEP, SPREP and SOPAC are collaborating in developing a Strategic Action Plan in the Pacific.

An overview of land-based pollutant sources and activities affecting the marine, coastal and freshwater environment in the Pacific Islands Region has been produced and can be found in the UNEP Regional Seas Reports and Studies No. 174. In this study sewage was indicated as the major source of pollution in almost every country in the Pacific, and it was consequently indicated as a priority for action.

Together with the GPA/UNEP Coordination Office, SOPAC, SPREP and PWA joined forces in organising a Regional Meeting for Stakeholders in Wastewater Management in the Pacific. The objective of the meeting will be the preparation and adoption of a Regional Strategic Action Plan on the management of wastewater.

The following outputs are expected as a result of the Regional Meeting:

Recommended Guidelines for Decision-Making in the Pacific; exchange of experiences and expertise with regard to innovative financial, technical or institutional arrangements; strengthened capacities of the public sector in order to become equal partners with other stakeholders, including the private sector; and identification of demonstration projects and regional centers which can be used for capacity-building purposes.

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Key Outcomes - Regional Workshop on the Issues and Challenges of Marine Scientific Research in the Pacific, Papua New Guinea, February 2001

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In order to address issues and concerns relating to the conduct of marine scientific research in the Pacific region, the SOPAC Governing Council and Technical Advisory Group [TAG] at the 29th SOPAC Annual Session held in Tarawa, Kiribati in October 2000, jointly endorsed a recommendation that a workshop be convened to provide a regional forum for dialogue on marine scientific research issues, between researching States and Pacific coastal States.

A Regional Workshop on the Issues and Challenges of Marine Scientific Research [MSR] in the Pacific Region was held in Port Moresby, Papua New Guinea, from Tuesday 27th February to Thursday 1st March 2001. The workshop was co-ordinated by the South Pacific Applied Geoscience Commission [SOPAC], hosted by Papua New Guinea's Department of Mines and co-sponsored by ocean research institutes from Japan, Korea and France. Fifty-five participants, representing eight coastal States [Cook Islands, Fiji, Kiribati, Marshall Islands, Papua New Guinea, Solomon Islands, Tonga, Vanuatu], three researching States [France, Korea and Japan] and other affiliations attended the forum.

Presentations on MSR of offshore mineral resources and vent communities in the region, the governance and legal framework for MSR and the MSR consent regime as it applies to individual Pacific Island coastal States and research States, and issues and challenges of MSR were made during the first two days of the workshop. A synthesis of the issues and challenges facing MSR in the Pacific region were summarised from the presentations and discussions made in plenary session, and used to develop themes for working-group discussions on the second and final day of the workshop. Four working groups were formed to discuss specific issues under the following broad themes and suggest possible pathways for resolution of some of the issues raised:

- *Governance and Institutions*
- *Key MSR Issues*
- *MSR and Commercial Exploration*
- *Needs of Researching States*

Recommendations relating to the legal framework for the conduct of marine scientific research; capacity building in ocean science and management; transfer of marine science and technology, including data; and, marine mineral exploration and parallel marine scientific research activities, which were developed and endorsed in plenary session are deemed to be the key outcomes of this regional forum.

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The Argo Project in the Pacific – Global Ocean Observations for Understanding and Prediction of Climate Variability

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The Argo Project (Roemmich and Owens, 2000) is a part of the Global Ocean Observing System (GOOS), aimed at tracking heat and hydrological variability through global measurements of temperature, salinity, and ocean currents. When fully implemented in 2005, Argo will include 3000 autonomous instruments drifting at 1-2 km depth, covering all of the world's oceans at an average spacing of about 300 km. Each Argo float will collect a profile of ocean temperature and salinity from the drift depth to the ocean surface, plus a measurement of ocean current, every 10 days. Altogether, the number of profiles will total over 100 000 per year. Data are immediately transmitted to shore via satellite and made publicly available via the Global Telecommunications System (GTS) and the internet (http://www.ifremer.fr/coriolis/).

The ocean plays a fundamental role in the climate system of the Earth through the heat and hydrological cycles. About 96% of the planet's water is found in the sea. Over 90% of the global warming observed in the past 50 years has occurred in the oceans (e.g. Levitus et al, 2000). In addition to the ocean's providing vast reservoirs for storing heat and water, its circulation redistributes them and exchanges them with the overlying atmosphere. Climate phenomena such as El Niño depend strongly on the ocean's capacity to store and transport heat and to release enormous quantities of heat to the atmosphere.

Argo is a collaborative international program endorsed by the IOC and the WMO, and regionally by SOPAC. It's a key part of the World Climate Research Project (WCRP) Climate Variability and Predictability (CLIVAR) program. Large-scale deployment of Argo floats has begun during 2001. Argo floats are being contributed by a consortium of 14 nations worldwide, with contributions in the western Pacific planned by the U.S., Japan, China, Australia, New Zealand and the Republic of Korea. At the present time, there are about 35 Argo floats in this region (see http://sio-argo.ucsd.edu and figure below), with the number expected to increase steadily to several hundred floats over the next few years.

Argo has many applications in basic oceanographic research and in operational oceanography. Those of greatest regional interest in the western Pacific will include better understanding and prediction of El Niño/Southern Oscillation (ENSO) episodes, long-term ocean warming and its local effects – such as on sea-level rise and coral bleaching - studies of fisheries populations in relation to ocean thermal structure, and air-sea interaction during tropical cyclones. Argo data are now being received and assimilated at climate-prediction centers such as NOAA/NCEP, the Australian Bureau of Meteorology, the UK Met Service and ECMWF. The data are used in subsurface ocean analyses, which in turn are used to initialize coupled ocean-atmosphere models. A primary justification for Argo is that more comprehensive measurements of the ocean will lead to substantial improvements in seasonal forecasts. In the WCRP/CLIVAR program, Argo data will be used to study the physical processes through which the ocean plays a role in the climate system. Another application of Argo data will be to provide climate-relevant data for use in secondary and tertiary education. One such education project, called SEREAD, is being developed for Pacific Island schools. For more information on Argo, see web sites of the international Argo Science Team (http://www-argo.ucsd.edu) and the Argo Information Center (http://argo.jcommops.org).

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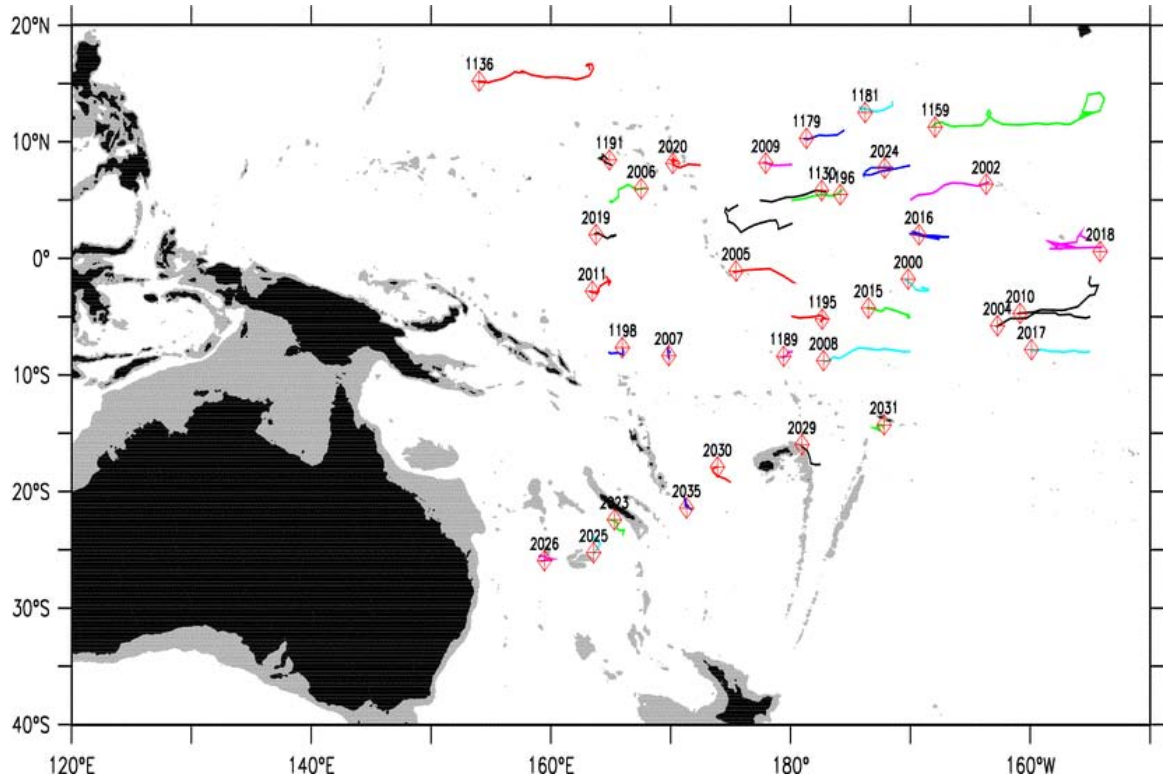

Figure 1: Location of Argo floats in the western tropical Pacific, as of September 19, 2001. Lines indicate float trajectory since deployment, with the diamond symbol at the float's most recent position.

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Climate Change Induced Coral Bleaching and the Implications for Marine Protected Areas Design and Coastal Management

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Healthy coral reefs are the primary defense system for coastal areas in the insular Pacific, and nowhere more so than on atolls. All life on atolls is dependent on fully functioning and viable coral reef systems.

The 1997-1998 El Niño Southern Oscillation (ENSO) event caused mass coral bleaching of unprecedented proportions over large areas of the Caribbean, Indian and Pacific Oceans. Such ENSO events have the potential to kill reefs on a much larger scale than localized destructive human activities on reefs. In the Pacific, large-scale coral bleaching events have increased in intensity, frequency, and geographic distribution in the last two decades, and this trend is expected to continue. Coral bleaching, one of the emerging threats to coral reefs, has already led to the probable extinction of some coral species from reefs in the Panama and Okinawa regions, at opposite ends of the Pacific.

While mass coral bleaching is viewed by some as an intractable problem, the fact that not all corals succumb to bleaching during or after an event provides hope. Some corals show *resistance* (meaning individual corals have the ability to either resist bleaching, or to successfully recover after they have been bleached) or *resilience* (the ability of coral colonies to bleach but recover to reestablish reef communities). Building these patterns of resistance and resilience into management strategies for Marine Protected Areas (MPAs) is a new concept that provides the opportunity to mitigate bleaching impact on coral reefs worldwide.

The Nature Conservancy (TNC) teamed up with the World Wildlife Fund (WWF) to develop this concept into practical actions. A small working group of reef scientists and managers, who collectively represented experience with coral research and conservation worldwide, met in May 2001 to explore new strategies for coral-reef conservation that would help mitigate the impact of these bleaching events. The workshop participants evaluated observations proposed by TNC that certain factors appear to favor survival or recovery of corals from bleaching. They agreed on a list of factors that seem to confer bleaching resistance and resilience to coral-reef organisms and outlined a general approach for a global program to test and verify this possibility. The group recommended that additional criteria and principles linked to survivability should be considered along with the existing ones when selecting and designing new coral-reef MPAs, but stressed the need to assist the recovery of bleached reefs by protecting them from other human threats.

The group will work with MPA practitioners around the world to evaluate the vulnerability of existing MPAs to bleaching and the practicality of implementing the new management approaches. The goal is to maximize the protection of coral reefs in the face of the expected increase in frequency and intensity of climate-related bleaching events. This will have significant implications for coastal management efforts within the Pacific region.

The key to the worth of the environmental factors is that they must be reliable and not responsive to changes in atmospheric and oceanographic circulation caused by ENSO events. The environmental factors linked to bleaching resistance include a range of physical features that reduce temperature stress, flush harmful bleaching products, decrease light stress, and correlate with bleaching tolerance. Additional environmental factors linked to bleaching resilience include connectivity within and among reefs, strong recruitment, several ecological factors that correlate with recovery, and good potential for recovery because of an effective management regime.

The reliability of these factors will be tested and applied to generate additional MPA selection criteria and design principles through a two-track approach: 1) worldwide assessments, research and monitoring designed to provide solid scientific evidence to back up available observational and limited empirical data supporting the contribution of environmental factors to bleaching resistance and resilience; and 2) drafting additional MPA selection criteria and design principles to be distributed globally through various networks for application, verification and refinement.

The current list of MPA selection criteria and design principles have scarcely changed over the last two decades, yet they retain their value for defining management strategies for effective coral-reef conservation. However, these criteria and principles are less useful for defining specific interventions to address emerging global threats, such as climate-related coral bleaching. For the latter we need new *mitigation* strategies that

complement our usual range of *management* actions to ensure that the areas we conserve are not only protected from the more immediate and manageable effects, but also from the larger-scale and unmanageable ones.

The concept of coral reef survivability has never been explicitly defined and listed as a criterion for MPA selection or in the principles for MPA design. This concept is something new and is seminal to ongoing efforts to assess the management effectiveness of MPAs and their vulnerability to global climate change. It is a concept that needs to be carefully weighed and tested as it has the potential to change the way we approach coral reef conservation globally at a scale capable of significantly mitigating the anticipated impact of climate related bleaching on coral reefs.

Just as bleaching is not exclusive to a country or region and recognizes no institutional or national boundaries, neither is exclusion the intention of this program, which would clearly benefit by implementation through a global partnership. TNC, WWF and the workshop participants expressed firm commitment to take this initiative forward as a partnership with any other interested private or public organizations. Programs, projects and people wishing to partner in this initiative should contact Rod Salm (TNC).

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Impact of Tele-Storm Waves from TC Paula on Tonga and Fiji Islands

Graham G. Shorten (SOPAC) and Stephen Oliver (GEMS)

Tropical Cyclone Paula developed from an intense tropical depression to the northwest of Santo in Vanuatu on 26th February, 2001. It intensified to 935 hPa (Category 4 cyclone) and moved in a path to the south of the Fiji Islands where its centre approached no closer than 250 km to Viti Levu. TC Paula began to weaken slowly towards a Category 3 cyclone, but continued to proceed in an east-southeast direction towards the southern part of the Tonga group where the closest approach of the cyclone centre to Tongatapu and Eua was over 300 km to the southwest on 2nd March.

Despite this, TC Paula was responsible for appreciable wave damage and flooding in both southwest Viti Levu and Tongatapu and Eua. Villages on the southwest coast of Viti Levu were flooded and coastal road embankments damaged by waves. The main Nafanua Harbour on the northwest coast of Eua was overtopped and significantly damaged by wave action as was the nearby Hideaway resort. In Tongatapu, the wave action damaged the Good Samaritan resort on the northwest coast. Eyewitnesses at the Good Samaritan described a gradually rising water level on the reef platform in the evening of 2nd March, continuing past the predicted astronomical high tide, and large waves encroaching over the platform and further onshore throughout the night and early morning.

Like a number of similar events which have occurred recently in the region, this event was widely attributed to storm surge, even though the centre of the cyclonic depression was at too great a distance to cause a such a barometric effect. Meteorologists believe that the wave trains produced from the northeast quadrant of TC Paula were reinforced by the constant direction of forward movement towards the east-southeast between about 170° E and 178° W. Numerical models are available to predict such effects and more effort is required to bring the use of such predictive models within the realm of national disaster management offices in Pacific island Countries.

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Low-Frequency Earthquake Resonance in Suva from an ML 4.7 Event in the Fiji Fracture Zone

Graham G. Shorten (SOPAC)

A series of earthquakes of ML 4-5 occurred on the northern edge of the Fiji Platform on 4-6th September 2001. The earthquakes originated in the western part of the Fiji Fracture Zone – an area of east-west, sinistral strike-slip tectonism marked by intense activity of small and moderate earthquakes – which accommodates westward movement of the Pacific Plate to the north of the Fiji group. The first, and largest, shock caused noticeable and alarming resonance in high-rise buildings in Suva, over 200 km to the south of the epicentre. Buildings were evacuated and residents in a limited number of homes near the Tamavua escarpment also reported feeling the shock.

The predominant frequency of the first shock recorded on the MRD seismograph in Suva was around 1.4 Hz. All of the multi-storey buildings from which swaying was reported except two are founded on long piles to bedrock. Occupants of a 2-storey building on a shallow footing over at least 14 m of organic silt, felt a distinctive shock,

while a swaying motion was felt by occupants of the 15-storey Reserve Bank building which is founded directly on bedrock. The city high-rise buildings in which the effects were felt varied in height from 2 to 15 stories. However, when the depth to bedrock beneath the buildings is taken into account, the total height of the building-foundation system as a whole (superstructure height plus foundation depth) of all the buildings concerned fell into a distinct height range of 20-30 m.

This low-frequency, tele-seismic event provided confirmation of the contributing factors to earthquake resonance and, in particular, a valuable insight into to the engineering behaviour of the organic silt deposit on which much of the central business district is founded. Resonance modelling carried out as part of an earlier study of seismic hazard probability and microzonation of Suva had assumed a shear-wave velocity in the organic silt of 140 m/s based on the results of Nakamura testing. By contrast, measured shear velocities of similar sediments in San Francisco, Porirua and Mexico City lie between 55-115 m/s. Based on the behaviour of the high-rise buildings during this event, and in the absence of direct measurements, it is now considered more likely that a shear velocity of around 80 m/s applies in Suva.

The two residential structures from which felt effects were reported are located on opposite slopes of a steep gully near the edge of the Tamavua escarpment immediately north of the city area. Both houses are modern reinforced concrete structures, and both show strong asymmetry in their foundation design. One house is characterised by wide concrete cantilevers and is founded partly on a deep retained fill over the gully side, while the other is characterised by long slim piers on the gully side with little lateral bracing.

The factors which accentuate earthquake resonance – thick deposits of weak sediment, abrupt differences in elevation along cliff-lines, soft (unbraced) and asymmetric foundation designs and heavy, cantilevered superstructures – have all been highlighted by the event of 4th September. A recent joint study carried out by SOPAC, IRD and the Geophysical Institute of Israel indicate that such resonance effects at around frequencies of 1.0 Hz in Suva are capable of magnifying earthquake accelerations by up to 2-3 times those felt on bedrock. Modern concrete structures in Suva are untested by a large earthquake event and many exhibit undesirable structural and foundation features given the relatively high seismic hazard for the region.

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Modelling for Earthquake, Tsunami, Storm Surge and Cyclonic Wind Effects in Mele Bay and Port Vila Harbour, Vanuatu

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Numerical models for the analysis of storm surge, wave and cyclonic wind, earthquake and tsunami effects require input from a wide range of sources. The current work to assess risk in Port Vila and Mele, Vanuatu, has involved the co-operative efforts of a number of SOPAC units and a variety of other international organisations and Vanuatu Government Departments.

The ship-track cruise database maintained by the Oceans Unit was used to develop deep ocean bathymetry offshore Efate, while the high-resolution bathymetry of Mele Bay was derived from multi-beam swath mapping carried out by the Coastal Unit in a recent search for a downed aircraft. The detailed bathymetry and sub-bottom structure of Port Vila Harbour was determined using a 3.5 kHz echo-sounder during investigations for the Port Vila Pacific Cities project for the Hazard Assessment Unit. A coarse digital terrain model for Efate was developed from the VANRIS GIS database, while a detailed terrain model for the Port Vila area was built from controlled aerial photography by Airesearch of Brisbane.

The bathymetric and terrain models, together with the United States Geological Survey earthquake database will be used by the Pacific Disaster Center of Hawaii and PMEL of Seattle to model tsunami generation and effects at the head of Mele Bay and in Port Vila Harbour. The elevation models will also be used together with cyclone climatology data by Global Environmental Modelling Systems of Melbourne to model storm surge and wave effects, as well as cyclonic wind effects onshore.

Sub-bottom seismic reflection information combined with digital elevation model data provides valuable new insight into the geological structure of Efate and active faulting in Port Vila. Earthquake studies of the Efate region by IRD have helped define the tectonic setting, while earthquake probability modelling and seismic hazard microzonation of the Port Vila area carried out in conjunction with the Geophysical Institute of Israel and IRD round off the effort to establish the levels of natural hazards for Port Vila.

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Islands System Management: Manihiki Lagoon – The Application of Remotely Sensed Mapping Technology in Support of Coastal and Lagoon Marine Resources Management

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Manihiki is an atoll located in the Northern Cook Islands at 10° 25' S and 161° 02' W (magnetic variation 11° E). It consists of two main motu, Tauhunu and Te Pae Rao Ngake e Tukao, and more than 50 smaller motu of varying sizes. There is only one small boat passage into the lagoon, near Tukao Village at the northern end of the atoll, and most of the reef flats between the motu are less than 1 m deep. The lagoon is studded with small islands (kaoa) on top of steep pinnacle reefs, and is characterised by a raised outer rim, which permits only minor exchanges between the lagoon and the surrounding oceans except during significant wave events.

In November 2000, an abnormally high mortality of the black-lip pearl oyster occurred which galvanised the authorities to develop a management plan for pearl oyster culture within the lagoon which addressed the following : reduction of oyster stocking density; cessation of activities that lead to increased nutrient levels and reduced water quality; and identification of potential pollutants such as heavy metals and hydrocarbons. Studies that may significantly simplify and improve coastal and oceanic marine resource management include the use of a geographic information system based on multibeam bathymetric mapping of lagoon and forereef-slope morphology, along with high-resolution multispectral IKONOS satellite imagery coupled with realtime monitoring systems.

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Tarawa Atoll: A Reclamation Concept to Bridge the Gap between Land and Water Resources

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Tarawa is an atoll, triangular in shape, with a relatively shallow lagoon covering some 335 km^2 with an average depth of 7 m. Large tidal flats on the lagoon side of the northeastern and southern arms are of variable width, extending up to as much as 2 kilometres into the lagoon. The lagoon is unusually shallow, with a maximum depth of about 30 m. The total land area of Tarawa atoll is approximately 3100 hectares.

The population of Kiribati was estimated at about 77 600 in the 1995 Census. Of this, 28 500 people or 37% of the population live on South Tarawa. Social and health problems, from overcrowding, pollution, low incomes, substandard housing, inadequate supply of safe water and a lack of basic sanitation facilities, sea-level rise, saltwater intrusion and coastal erosion are serious problems faced by the Kiribati Government. The pressure is even greater in Betio, where the population density is projected to increase from 5396 per km^2 in 1990 to 8700 per km^2 by 2010 (MHARD, 1995). These population pressures are exacerbated by the very limited land resources of South Tarawa.

Small land-reclamation projects have been ongoing in Tarawa atoll since WWII. The largest of these was the reclamation of Temaiku Bight in the early 1970s, which saw the reclamation of some 300 hectares of tidal flats, an idea mooted as early as 1968 as an early response to the growing need for additional land (Town 1977).

We propose that as a long-term solution to problems of land and water resources, vulnerability to sea-level rise, and to furthering economic growth in Tarawa atoll, the shallow southeast quadrant of the lagoon be infilled with loose materials dredged or pumped from the deep (>100 m?) outer atoll slopes. These deep materials bear no protective value to the present atoll barrier islands and will be lost to the deep ocean eventually if not recovered. With engineered water lenses, the reclamation of up to 5000 hectares of new land could be achieved in three stages over a 20-to-30 year period.

Specifically, a Ghyben-Herzberg freshwater lens engineered beneath this fill area could eventually store a supply of up to 76 x 10^6 m^3 of fresh water for South Tarawa, using a mean engineered height above present sea level of 5 m near the centre of the extant lagoon for an area of 1700 hectares. This lens could be slowly developed using natural rainfall or more rapidly filled by offshore tankers and/or desalinisation plants. Since the lens is engineered, a natural or artificial seal can be placed between the freshwater and the underlying seawater reservoirs to minimise or eliminate saltwater encroachment caused by storms or overuse of wells.

Once developed, the potential for agricultural and recreational development on par with larger islands can be realised. Improved communications and transport of materials via new interior roads between islands is also possible, as well as increased base value to a potential tourism market centred on historic sites on Betio. For example, development of golf courses and scenic pasture, the latter of great value to the local food base, will be possible. Together with the existing assets of scenic beauty, a talented and friendly local population, sites of historic interest, and a viable and expandable airport facility, the planned development of the lagoon has the potential to create a local tourism industry. While the above scenario is specifically tailored for South Tarawa, its successful implementation can act as a model for application to other populated atolls and low-elevation islands with shallow lagoons facing a similar fate.

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Relationships Between Chemosynthetic Faunas, Fluid Flow and Sediment Slumping in the Source Area of the 1998 Papua New Guinea Tsunami

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The Sissano or Aitape tsunami that struck the north coast of Papua New Guinea (PNG) in the evening of July 17th 1998 left more than 2 000 people dead and 12 000 homeless as three villages were completely destroyed and four more badly damaged (Davies, 1998, Kawata, 1999, Tappin et al., 2001, in press).

The source of the local tsunami remains controversial and has been postulated as due either to seabed dislocation (fault) or sediment slump, although there is increasing recognition that the latter alternative is most likely. The alternative source mechanisms of the tsunami were addressed during 1999 to 2001 by offshore multibeam bathymetry, sub-bottom profiling, sediment sampling and observation from the JAMSTEC Dolphin 3K Remotely Operated Vehicle and Shinkai 2000 Manned Submersible.

One of the most intriguing discoveries during the offshore surveys was of extant chemosynthetic biological communities, comprising bacterial mats, mussels, *Calyptogena* sp. and tubeworms. These were found in the amphitheatre region where the source of the tsunami was located. Their presence indicates the active expulsion of sulphide- and methane-rich pore fluids from the sediment. The spatial variation and style of the faunas provides information on the mechanisms controlling fluid expulsion, the chemical composition of the fluid, and the levels of fluid flow. There is also undoubtedly a close association between the chemosynthetic faunas, levels of fluid flow and the generation of sediment slumping.

On the landward scarp slope of the amphitheatre there are distinct variations with an increase in fauna eastward. In the west, faunas were not observed; in the centre, there are isolated bacterial mats and rare tubeworms; and in the east there is a profusion of bacterial mats, mussels, *Calyptogena* sp and tubeworms. The bacterial mats are intimately associated with black sulphide-rich sediments lying at the seabed. Additionally, there is active fluid venting. On the 14-Kilometre Fault there are bacterial mats, mussels and tubeworms. On the reef there are mussels and tubeworms. No extant faunas were observed on either traverse of the 40-Kilometre Fault. We conclude that fluid expulsion is most active at the eastern part of the amphitheatre landward scarp with subsidiary activity along the 14-Kilometre Fault.

Observation and sampling of the faunas show that smaller, more juvenile forms are located in the east. Mussels of 15 to 17 cm length were sampled on the subsided reef and 14-Kilometre Fault. In the east they are smaller, at 7 cm length. In hydrothermal areas initial growth rates of mussels have been measured at up to 4-6 cm per year, decreasing logarithmically as they age to up to 20-30, years when they approach 20 cm shell length. Cold-seep mussels from the Gulf of Mexico grow slower and reach smaller maximum lengths; however, the seep mussels here reach maximum lengths similar to those of the hydrothermal variety and may therefore grow

at similar rates. The 7-cm-long mussel shells suggest an age of 1-2 years if growth rates are similar to those at some hydrothermal locations. The submersible survey on which the samples were acquired was carried out 14 months after the tsunami struck. It is therefore probable that the initiation of active venting in the east is very recent and is associated with the observed slumping.

There is a concentration of fluid expulsion at the base of the amphitheatre landward scarp. In Monterey Bay, California, observed a strong relationship between geomorphology and cold-seep fluid flow. Here both active and dormant seeps are restricted to the scarps of canyon walls and slope failures. Both create bathymetric indentations that focus fluid expulsion if the head gradient is above hydrostatic gradient. For slope failure the alternatives are fluid expulsion as the source or result of rupture (or slumping in this case). An intriguing aspect of our study is the identification of slipped tabular limestone in the eastern amphitheatre landward scarp. In morphology and association it appears to be authigenic. Authigenic limestone is often a precipitate of pore fluids high in bicarbonate which is derived from the bacterial oxidation of methane or other carbon. Its tabular form suggests low and diffuse fluid flow. Restricted fluid expulsion through the fine clay sediments may have led to hydrofracturing that resulted in slope failure ultimately triggered by the earthquake.

The variations in the concentrations of faunas together with variation in the location of active venting and sulphide-rich sediments allows discrimination between active and less-active seabed deformation in the form of faults and slumps in the area of the amphitheatre. Variations in extant mussel-shell size may enable the timing of deformation to be elucidated.

In conclusion, we propose that the increased levels of venting and increased populations and concentrations of chemosynthetic faunas in an eastward direction along the amphitheatre headwall indicates a strong likelihood that seabed deformation in this area is very recent, and provides evidence additional to that from bathymetry and seismic profiling, that a sediment slump here was the cause of the 1998 tsunami.

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The Regional Energy Information Database

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Over the last decade there has been a significant amount of effort given to developing the energy sector in the Pacific region. This effort in most cases has been documented in reports; however, it is spread far and wide throughout the region and resides in a number of national offices and regional libraries. It is considered that there will be a significant loss to the region if at least some attempt is not made to capture this resource of past experiences.

In considering opinions, it was not considered realistic to try and collect all these reports and house them in one place as a regional repository of regional energy information. Therefore, capitalising on the electronic age, it was felt that to electronically capture at least some of this information was a realistic option. This will meet the need for energy information to be readily available on projects and technologies, either implemented or tested in the region, and research and development activities carried out by regional and international institutions, and has been identified as a relevant resource to be considered by current energy personnel in the Pacific islands in developing new projects and programmes.

To document these resources SOPAC has developed a Regional Energy Information Database, in Microsoft Access Version 7.0, to store the information which can easily be obtained for future use. SOPAC, with the

assistance of national energy offices and regional organisations, has obtained and compiled a significant amount of information into the database.

In addition to providing information on the whereabouts and status of energy-related technologies, projects and R&D activities, the regional information database also provides contact details for energy personnel in the region and incorporates features to enable information to be sent via email. The user-friendly nature of the database will enable anyone with very little knowledge of Microsoft Access to search for information.

Data returned from the national information databases are then incorporated into a regional database. The updated version of the regional energy-information database will then be available on an annual basis with the long-term vision of having the database accessible via the SOPAC website. The regional version has additional features such as printing and email options that allow the user to print and send out search results.

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LATE ABSTRACT(S)

Eocene-Oligocene geology of Guam

Franck Kilmer

The Facpi Formation (volcano remnant) and the Alutom Formation (intra-arc basin deposit) form the Late Middle Eocene/Early Oligocene basement rocks of Guam; these units represent elements of the >300km wide Palau-Kyushu-Arc (Fig. 1) that originated in the western equatorial Pacific about Early Eocene time (Fryer, 1992). The Alutom terrain exposes extensive rock sequences composed of volcaniclastic, pyroclastic, carbonate and minor flow rock in southcentral and southwest Guam. The sequences are exposed in four major fault blocks (Figs. 2, 3) named Sasa (7,360 ft. +), Tenjo (4,700 ft. +), Tarzan Falls (3,500 ft.), and Bolanos (1,450 ft.). Lithofacies that form the sequences include: (1) turbidites, (2) tuff, (3) interbedded breccia/conglomerate, sandstone and shale, (4) interbedded breccia, pillow lava, sandstone/shale and (5) micrite (oozes)/limestones. Sedimentary processes reflected in the Alutom sequences include turbidity currents, debris flows, and gravitative settling through the water column; cross-bedded units indicate that other forms of bottom currents were present. Downslope movements produced convoluted bedding and large-scale slump folds. A single mappable unit of pillow lava, breccia, sandstone and shale (Unit Av) is the only unit present in all four blocks; its origin may be due to widespread eruptions of pillow lava triggering debris flows that incorporated slabs of flow-rock as they moved downslope.

The blocks are bounded by high-angle faults (Sasa, Atantano-Sigua, Talofofo, and Adelup), apparently normal faults, which exhibit relative vertical displacements up to ~1,000 ft.; other faults typically show vertical displacement of 200 - 300 ft. Fault striation geometries indicate that some faults have experienced oblique-slip with strike-slip components greater than dip-slip. Each block exhibits a number of anticlines and synclines. The Tenjo, Tarzan Falls and Bolanos micritic-rich sequences show, with few exceptions, substantial correlations among themselves, but the three show little correspondence to the Sasa micritic-poor section, which is juxtaposed against the Tenjo Block along the Sasa Fault. Deformation along the Sasa fault, coupled with the inability to correlate readily across it, suggests that the Sasa Block is allochthonous, and has moved in a left-lateral direction probably in excess or 15 - 20 miles (Fig. 4). The Sasa section was deposited in an intra-arc basin, that was located north of Guam's present site and unconnected to the Tengo-Tarzan Falls-Bolanos basin.

Unconformities occur in all the fault block sections, some of them showing angular discordance up to 60 indicating that the sequences were subject to frequent uplift, erosion and subsidence during Alutom time. This evidence strongly suggests that faults bounding the main blocks (Sasa, Atantano-Sigua, and Talofofo faults), as well as intra block faults, were active throughout the duration of Alutom intra-arc basin deposition, and probably were established even earlier, when the Palau-Kyushu-Arc was forming, presumably under strong extensional stresses, during the Paleocene/Early Eocene interval, or all of the faults, probably have remained active into the latest Cenozoic time.

The Alutom sequences, of Late Middle Eocene to Late Eocene age, were deposited in deep marine environments (middle to lower bathyal), ranging in depth from ~4,500 feet

~1,500m) to, or slightly below, the Eocene Calcite Compensation Depth (~9,600 ft.; 3,200 m). Deposition extended well beyond the present outline of Guam. Stratigraphic distribution of calcareous nannoplankton and radiolaria assemblages suggest that the floor of theTenjo-Tarzan Falls-Bolanos basin deepened northeastwards and that it fluctuated in depth at times. To the southwest, the sea floor apparently shallowed and deposition took place on the flank of the Facpi volcano (Fig. 4). The basin apparently began shallowing to outer neritic/upper bathyal depths (450-4,500 ft.; 150-500m) during Early Oligocene time, possibly a precurser to regional uplift of the Facpi/Alutom complex in the Middle Oligocene. Limestone clasts in Alutom conglomerate, containing traces of coral, mollusks, and calcareous algae, indicate nearby reef complexes, fringing emergent volcanoes or ridges. Rounded basaltic boulders also indicate a nearby shallow water environment (volcano coastline) where abrasion could take place followed by transport into deep water.

The age of the Alutom Formation (Late Middle Eocene-Early Oligocene (Fig. 3) was found to be considerably older than previously recognized and virtually coeval with the Facpi Fm. (Late MIddle Eocene) on which it rests unconformably. Deposition of the fault block sequences apparently began virtually simultaneous with commencement of Palau-Kyushu-Arc volcanism. The Alutom and Facpi arc basement complex is truncated by a Middle Oligocene unconformity (~ 31-29 Ma), the interval apparently coincident with initial splitting of the Palau-Kyushu-Arc, to produce the Palau-Kyushu-Ridge, West Mariana Arc and intervening Parece Vela back-arc basin. Uplift of the Alutom/Facpi arc basement complex during the Middle Oligocene was probably in the order of several thousand feet, or more, producing a slightly emergent arc basement, an embryonic island, on which Late Oligocene/Early Miocene carbonates of the Maemong Limestone Member (Umatac Formation) were deposited. Uplift was accompanied by left-lateral movement along the Sasa Fault and widespread folding of Alutom rocks. Folding may have occurred when uplifting fault blocks were “jostled” and pressed against each other producing anticlines and synclines within their boundaries. The Middle Oligocene uplift marked the cessation of an active Palau-Kyushu-Arc and its conversion to a Ridge (remnant arc). Renewed splitting of the West Mariana Arc (~10 Ma) produced the West Mariana Ridge (remnant arc), the Mariana Trough and the Mariana Ridge. The splitting of the Palau-Kyushu-Arc and the West Mariana Arc enabled elements of the PKA to be translated eastward to form the arc basement rocks of Guam, the Facpi and Alutom Formation

Figure 1

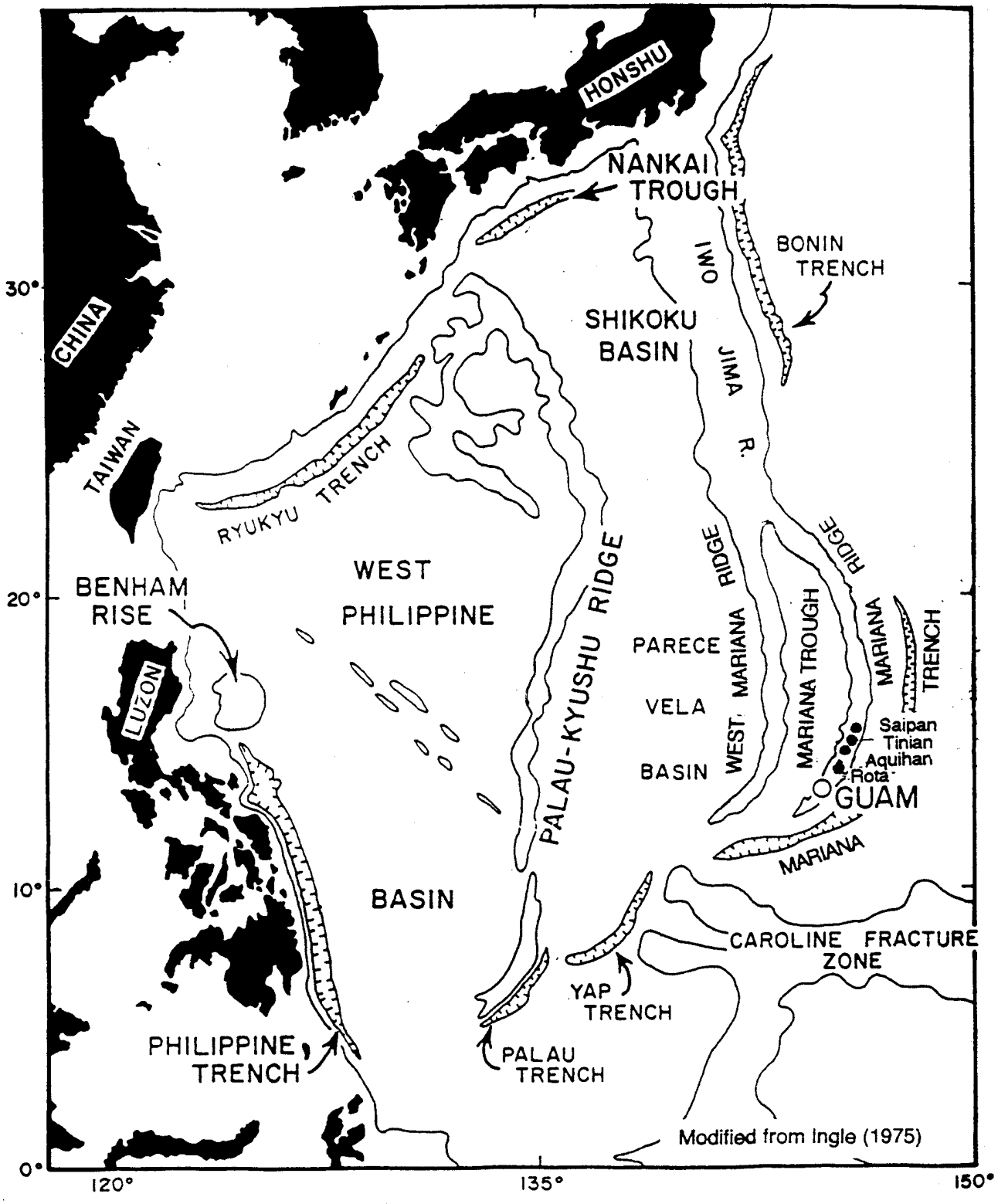

Fig.1 Location Map for Guam and southern Mariana Islands.

Figure 2

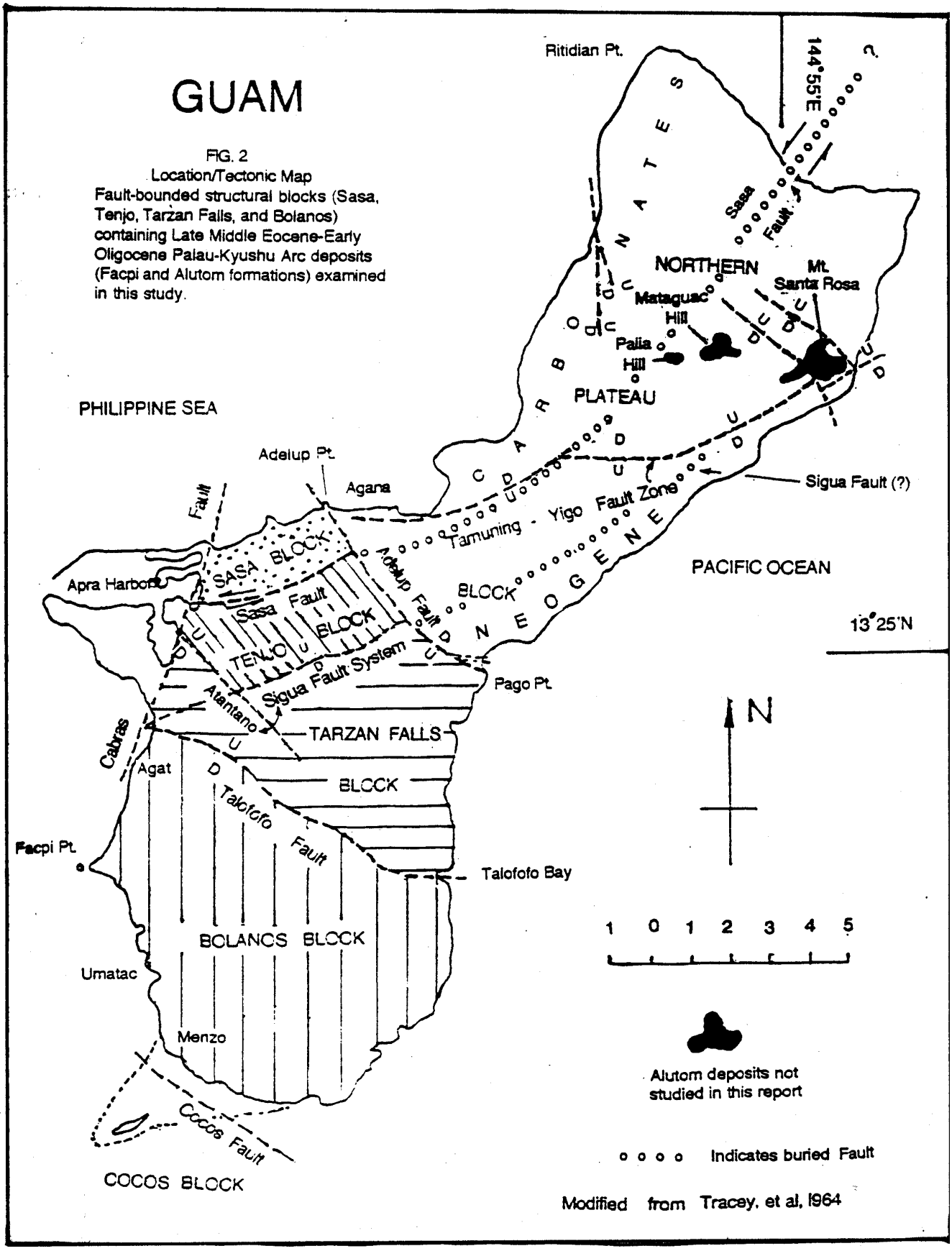
GUAM
FIG. 2
Location/Tectonic Map
Fault-bounded structural blocks (Sasa, Tenjo, Tarzan Falls, and Bolanos) containing Late Middle Eocene-Early Oligocene Palau-Kyushu Arc deposits (Facpi and Alutom formations) examined in this study.
Ritidian Pt.
144°55'E
Sasa Fault
NORTHERN
Mt. Santa Rosa
Mataguac Hill
Palia Hill
CARBONATES
PLATEAU
PHILIPPINE SEA
Adelup Pt.
Agana
Fault
Sigua Fault (?)
Tamuning - Yigo Fault Zone
PACIFIC OCEAN
NEOGENE
SASA BLOCK
Adelup Fault
Apra Harbor
Sasa Fault
BLOCK
TENJO
Sigua Fault System
13°25'N
Pago Pt.
Atantano
TARZAN FALLS
Cabras
Agat
BLOCK
Talofofo Fault
Facpi Pt.
Talofofo Bay
BOLANOS BLOCK
Umatac
Menzo
Cocos Fault
COCOS BLOCK
N
1 0 1 2 3 4 5
Alutom deposits not studied in this report
Indicates buried Fault
Modified from Tracey, et al, 1964

Fig. 3 Generalized Stratigraphy of Guam

Adapted from: Tracey, Jr. et al. (1964), Ingle (1975) and Reagan and Meijer (1984)

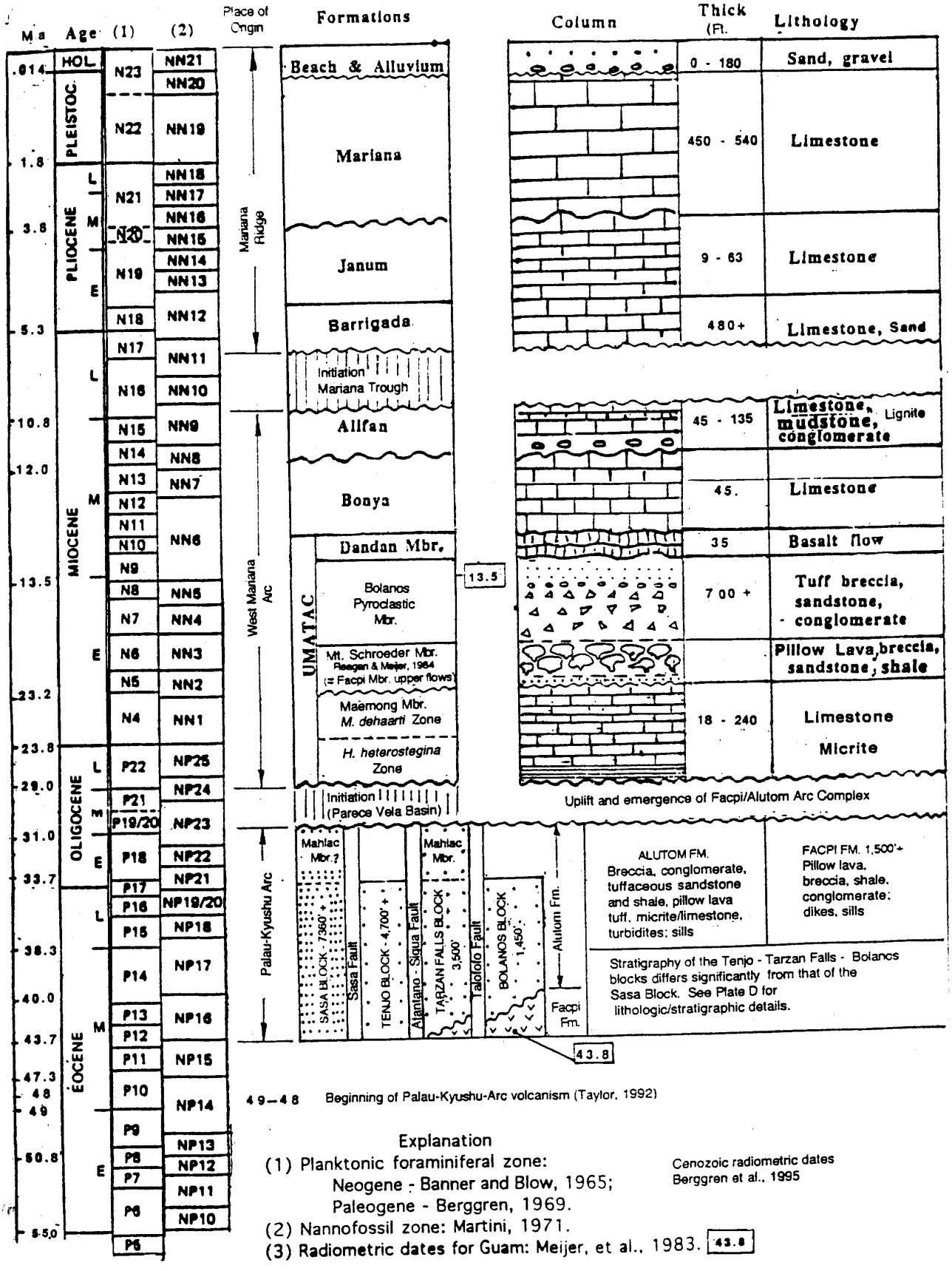

Figure 4

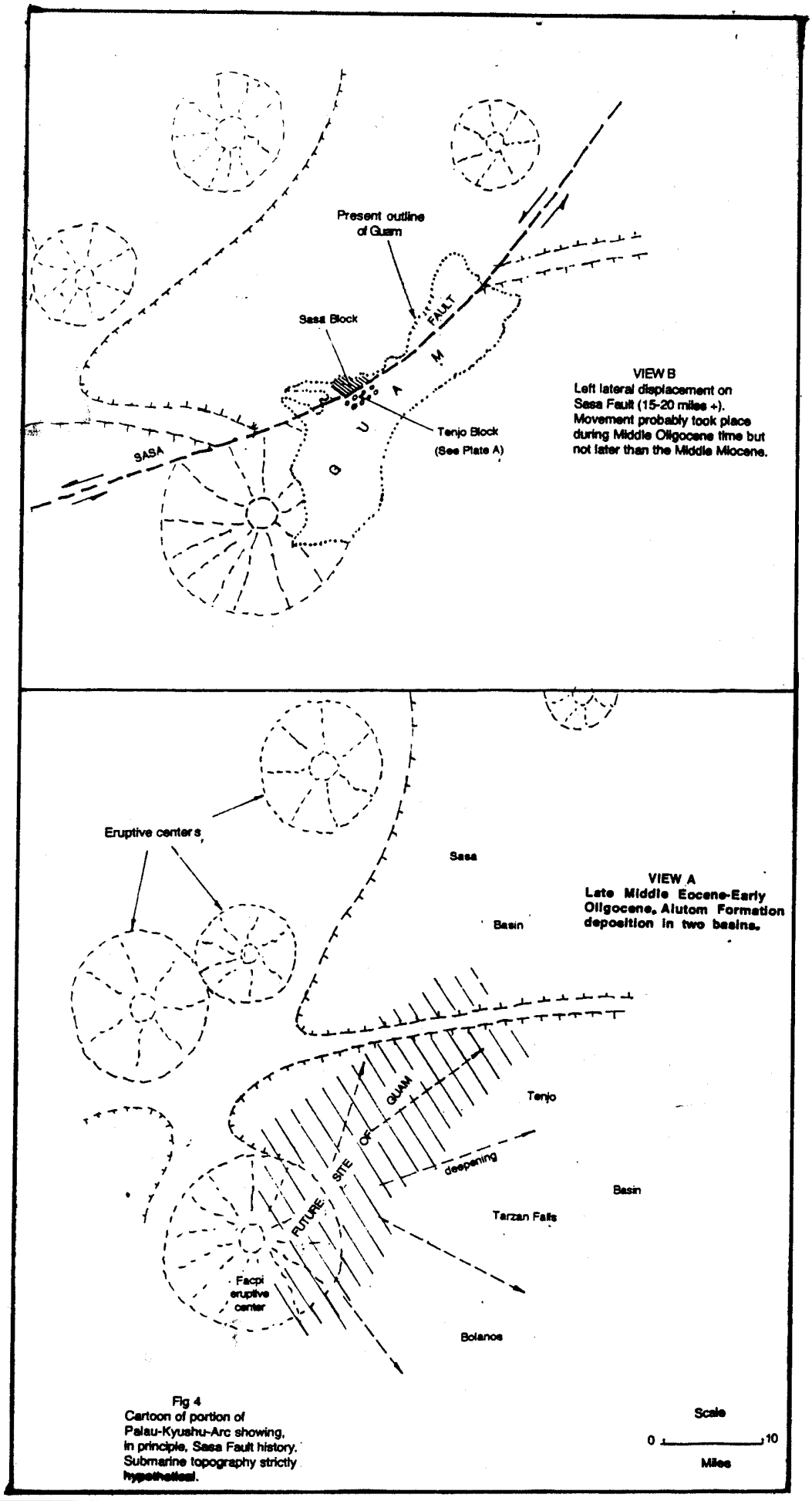

Fig 4
Cartoon of portion of Palau-Kyushu-Arc showing, in principle, Sasa Fault history. Submarine topography strictly hypothetical.

Petroleum assessment of New Caledonia's EEZ

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The potential for finding commercial petroleum reserves in New Caledonia and its offshore area is considered good for two main reasons.

I) Cretaceous (Senonian) coals have been identified as the main potential source rocks onshore (geological mapping; CADART -I well drilled in late 1999-early 2000)

2) Offshore, tile thickness of tile sedimentary basins and the relative high geothermal flux values are compatible with the formation of hydrocarbons. Moreover, seismic results of cruises recently carried out within the frame of the ZoNeCo and FAUST (French Australian Seismic Transect) programmes, constitute the first compelling evidence for gas hydrate deposits in waters that straddle the French- Australian international boundary)

FAUST and ZoNeCo programmes main results

The FAUST programme was initiated in 1998 from France (IFREMER), Australia (AGSO) and New Caledonia (Service of Mines) to improve the understanding of the geological framework, the crustal characteristics and the evolution of the basins and ridges located between the Australia eastern margin and New Caledonia.

The FAUST 1 cruise seismic profiles (RN Rig:Seismic, 1998) have revealed a bottom simulating reflector (BSR) within the Fairway Basin –Lord Howe Rise area. Such BSRs generally are associated. With an interface between overlying sediment with methane hydrate (a frozen crystalline mixture of methane and water) and underlying sediment with free methane gas bubbles.

The size and general characteristics of the likely gas hydrate deposit within New Caledonia's EEZ needed to be established with additional research, including further seismic surveying and direct sampling of tile water column and uppermost sediment.

The ZoNeCo 5 cruise (RN L ' Atalante, 1999) was therefore scheduled, within the frame of the ZoNeCo program that aims at assessing the marine resources of New Caledonia's EEZ, to further investigate tile petroleum potential of the Fairway Basin. Deep diapirs (salt or mud volcanoes) have been identified within the thick sedimentary sequence of the Fairway perched-basin. The diapirs are sourced from a deep, almost transparent layer dated early Cretaceous. The area of diapirs in the basin coincides with the extension of the BSR, suggesting a connection between tile two phenomena. A thermogenic origin for the gas hydrates that may be migrating along the diapirs to the subsurface was thus inferred. To precise the origin of the gas, tile 13 sediment cores' analysis have shown traces of gas in the oxidized surface sequences, this gas being probably partly of thermogenic origin.

To summarize, those results indicate that much of the Fairway Basin (eastern Lord Howe Rise) within New Caledonia's EEZ contains sediment diapirs, gas hydrates and probably free gas.

Prospective

Research cruises need to be devoted to mapping the overall dimensions of the deposit and to understanding its origin. Two detailed follow-up research cruises are planned, a forthcoming (Oct.- Nov,2001) seismic and sampling cruise aboard CSIRO's FRANKILIN R/V, and a multichannel seismic cruise aboard the MARION DUSFRESNES in 2002.

FAUST 3 cruise (RN FRANKLIN, 2001)

The FAUST 3 cruise will, within the New Caledonian and Australian seabed jurisdictions:
continue seismic mapping of basin sequences, sediment diapirs and BSR;
core to help determine the origin and composition of gas in the Fairway Basin;
ground-truth seismic data by sampling older outcropping sequences

ZoNeCo 11 cruise (R/V MARION DUSFRSNES, 2002)

After the ZoNeCo 5 cruise, the need for a new survey to precise the geological framework of the Lord Howe Rise-Fairway Basin area was emphasized. Therefore, the ZoNeCo II cruise will be deploying, Within New Caledonia EEZ's, multichannel and high resolution seismic, together with OBS in order to confirm the extension of the Bottom Simulating Reflector (BSR) and to precise its relationships with the associated transparent layer that feeds overlying diapirs.

The future results of these two major cruises will improve our knowledge on the petroleum potential of offshore New Caledonia, likely prospective, but that still remains under explored.
Therefore, if the existence of tile underlying diapirs associated with the BSR is confirmed, one can expect the presence of hydrocarbons beneath the gas hydrates horizon, which might boost the petroleum interest of the whole Southwest Pacific region.

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