ABSTRACTS OF PAPERS PRESENTED AT THE STAR* SESSION 1997

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Editors

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*SCIENCE, TECHNOLOGY AND RESOURCES NETWORK

TABLE OF CONTENTS

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 when Keith Crook took over the helm. 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 held in Noumea and Lifou, New Caledonia in November 1994. The next in the series is a Conference on Marine Benthic Habitats and Their Living Resources: Monitoring, Management and Application to Pacific Island countries, to be held in Noumea 10-16, November, 1997.

STAR is not merely a technical meeting at which individuals present scientific papers and discuss 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 rapporteurs' reports on highlights of STAR technical presentations, is tendered to Council by way of an address in Plenary by the Chair of STAR, and in the Technical Advisory Group (TAG) sessions during 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 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 1980's.

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. As a result of SOPAC's Governing Council examination of the future role and direction of the organisation at the 1996 Annual Session the following were identified as priority focal areas: minerals policy and advice, environmental science and human resources development. SOPAC's 1998 Work Program, which all participants should examine, reflect these priority focal areas and encompass a broad spectrum of geoscience activities. SOPAC's track record demonstrates that this approach to program development is synergistic, forwarding both the national needs of island nations and fundamental research. I commend it to you.

Keith A W Crook
Chair, STAR

Hawaii Undersea Research Laboratory
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17 September, 1997.

STAR Presentations at SOPAC Annual Session, 1997

PROGRAM

Time	Theme	Authors & Speaker	Title
Monday 29th September			
8:30-8:35		Crook	Opening of STAR Session
8:35-9:05	COASTAL	Ebrahim & Collen	Sediment composition and processes, Tarawa Atoll, Kiribati: preliminary results
9:05-9:35		Glenn	'Landsat TM' as a classification tool of reefal environments, as used at Ashmore Reef, NW Australia
9:35-10:00		Sinclair	The Laser Airborne Depth Sounder (LADS)
10:00-10:25	**MORNING TEA**		
10:25-10:50		Terry & Raj	Some effects of tropical cyclones Gavin and June in 1997 on the terrestrial and coastal environments of the Fiji Islands
10:50-11:15		Edward	Biological study of the dredge sites in Pohnpei, Federated States of Micronesia (NO ABSTRACT)
11:15-11:40		Butcher	The application of multimedia presentation techniques in the geosciences: an example of the use of the technology in SOPAC's National Capacity Development Program and an introduction to other opportunities.
11:40-12:05		Mullane, Fletcher & Richmond	Coastal erosion and beach loss on the islands of Oahu and Maui
12:05-12:30		Cruickshank	Environmental impacts from offshore mining of sands in Pacific islands
12:30-13:30	**LUNCH**		
13:30-13:55		Tappin & Smith	Fine aggregate resources of small, Pacific Island nations: problems of supply, impact of extraction and development.
13:55-14:20	WATER	Falkland	Groundwater assessment and development on small coral islands
14:20-14:45		White, Falkland, Kamaie, Metai, Metutera & Crennan	Groundwater recharge in low, coral islands: results of the UNESCO-SOPAC study on Tarawa Atoll, Kiribati
14:45-15:10		Patrizi , Ricci & Scott	Mathematical modelling of atoll freshwater lens system Tarawa, Kiribati.
15:10-15:35		Burke	Future of freshwater resource/supply management on small high volcanic islands: a case study from Rarotonga, Cook Islands

15:35-16:00	**AFTERNOON**	**TEA**	
16:00-17:30		Working Group	
18:00-20-30		Working Group	

Tuesday 30th September			
8:20-8.45	TIME SERIES	Kuroda	TRITON Program: Surface meteorology and upper ocean observing moored buoy network
8:45-9:10		Johnston & Merrifield	Interannual north-south oscillations in sea level in the tropical Pacific
9:10-9:35		Erb	GOOS interests in the Pacific, the status of GOOS planning and what IOC is doing with SOPAC and SPREP (NO ABSTRACT)
9:35-10:00	HAZARDS	Granger	Towards understanding community risk – the AGSO cities project and *Risk-GIS*
10:00-10:25	**MORNING TEA**		
10:25-10:40		Kaloumaira	The wider approach to disaster mitigation in the Pacific Island Countries (NO ABSTRACT)
10:40-11:15		Petterson, Tolia, Qopoto, Papabatu & Toba	Understanding the volcanological record of Savo Island, Solomon Islands
11:15-11:40		Petterson, Tolia, Qopoto, Papabatu & Toba	Towards a volcanic hazard assessment of Savo volcano, Solomon Islands
11:40-12:05		Neall & Cronin	Volcanic history and hazards project on Taveuni, Fiji
12:05-12:30		Shorten & Smith	Pacific Cities: seismic hazard mapping in Port Vila
12:30-13:30	**LUNCH**		
13:30-13:55	MINERALS & TECTONICS	Barrie	Exploration and mining on coral islands
13:55-14:20		Binns, Scott, Gemmell & Crook	Modern analogue of a mineral field: sea-floor hydrothermal activity hosted by felsic volcanic rocks in the Eastern Manus Basin, Papua New Guinea
14:20-14:45		James	Geology of the Gold Ridge epithermal gold deposit, Guadalcanal Island, Solomon Islands
14:45-15:10		Coleman	The forms of localised uplift
15:10-15:35		Wessel & Kroenke	Refining plate motions and locating hot spots using a newly recognised geometric relationship between hot spots and seamounts
15:35-16:00	**AFTERNOON TEA**		
16:00-17:30		Working Group	
18:00-20-30		Panel Discussion	

(Poster)		Auzende, Grandperrin, Hénin, Lafoy & Van de Beuque	Evaluation of the living and non-living resources of the New Caledonia Economic Zones
(Poster)		Petterson, Neal, Mahoney, Kroenke, Saunders, Babbs, Duncan, Tolia, McGrail & Barron	Structure and deformation of north and central Malaita, Solomon Islands: Tectonic implications for the Ontong Java Plateau - Solomon Arc collision, and for the fate of oceanic plateaus
(Poster)		Pelletier, Missegue & Butscher.	Bathymetric maps of the central and northern New Hebrides Island Arc
(Poster)		Pelletier, Missegue, Butscher & Auzende.	Bathymetric map of the North Fiji Basin and the New Hebrides Island Arc
(Poster)		Lafoy, Guyomar & Dupont	Mapping of surficial deposits for the assessment of geological hazards (landslides, erosion)
(Poster)		Collen	Sedimentary processes around Fongafale Island, Tuvalu
(Poster)		Collen & Newell	Studies of tropical Pacific foraminifera
(Poster)		Xue & Collen	Towards a better understanding of reef flat and beach sediment processes, Kosrae, Federated States of Micronesia
(Poster)		Eagar	Ecological significance of benthonic ostracoda (crustacea) from Tarawa Atoll, Kiribati
(Poster)		Collen	Recolonisation of reef flats by foraminifera: significance of the Funafuti example, Tuvalu

Evaluation of the living and non-living resources of the New Caledonia Economic Zone

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Like many island states, the Territory of New Caledonia has a limited land surface compared with the size of its EEZ. It was one of the first to show interest in the evaluation of the marine resources of it's economic zone. In November 1990 the French High Commissionner established a working group to take charge of the definition of a program for the evaluation of the New Caledonia EEZ resources (ZoNéCo program). During 1991 this Group defined the basis of the ZoNéCo program, with most mining prospects, it was divided into three phases.

- A strategic phase, the objective of which was mainly the analysis of existing data and the production of sea bed topography maps by swath mapping cruises in selected areas.
- A tactical phase, the aim of which is the identification and quantification of possible living and non living resources.
- A third phase named "target study" is to be devoted to the evaluation of the economic potential of these resources.

The ZoNéCo program defined by these three phases appears as a multidisciplinary and multipartite program. The different partners of the program are the representatives of France (Ministry of Research and Universities, Hydrographic Department of French Navy), the New Caledonia Territory (Service of Administrative Methods and Computers, Service of Mines and Energy, Services of Fisheries and Merchant Navy), the three Provinces and, the French Research Institutions (Institut Français de Recherche pour l'Exploitation de la Mer, IFREMER; Institut Français de Recherche Scientifique pour le Développement en Coopération, ORSTOM; Université Française du Pacifique, UFP).

The first actions have been devoted to the compilation and analysis of the data existing in the New Caledonia domain including bathymetry, geophysical features, physical oceanography, and fisheries. These preliminary analyses have been used to define the first operations carried out by the program.

First quantitative results can be presented after the ZoNéCo 1, 2, 3 and 4 cruises carried out with *L'Atalante*: more than 200,000 square kilometres have been mapped with complete coverage. About 150 volcanic features less than 1000 m deep have been discovered or precisely located. 1700 square kilometres of oceanic bottom shallower than 500 m and 15000 square kilometres shallower than 1000 m have been mapped. These areas constitute the best areas for the inventory of living and non-living resources. In addition, the bathymetric surveys carried out with *L'Atalante* define a new navigable zone for high tonnage ships, such as between New Caledonia and the Surprise-Huon Reefs in the area named Grand Passage.

During the ZoNéCo I cruise a mesoscale (100 to 200 km in diameter) anticyclonic whirl, stable throughout the cruise duration and present between 0 and 500 m depth was recorded in the southern prolongation of New Caledonia. This whirl could have an effect on the nutrient productivity of the area, however we cannot draw conclusions about its temporal stability due to the lack of observations. Surface and subsurface currents have also been recorded during the ZoNéCo 2 cruise, in particular along the eastern coast of New Caledonia; these observations confirm and support the results of previous studies in the same area. The thermal structures, the haline and thermal fronts associated with the water mass circulation, have also been described. Cold water upwellings (coastal upwellings) have been observed along the western coast depending on the wind conditions and during long periods of time (from one week to 10 days). These phenomena could explain the variability of the productivity in the area. The last point concerns the comparison of lagoon and offshore waters. It appears that the lagoon waters and the offshore waters have different temperature and salinity. The lagoon waters being generally colder and more salty than the offshore waters.

The long-line fisheries operated in the northern part of New Caledonia and on the Loyalty Islands Ridge demonstrate that the bathymetric maps acquired during *L'Atalante* cruises are valuable guides for fishing. This long-line fishery allowed definition of the habitat of brood-stocks already exploited by local fisheries and also showed the abundance of species still unknown in the local market. In contrast the deep sea trawls carried out off the eastern coast and to the south of New Caledonia have not revealed good

evidence of the existence of possible resources. This could be due to the substratum nature and topography. The study of the topography of the seamounts mapped by *L'Atalante* also allowed quantification of the fishing potentiality of the area.

The ZoNéCo program constitutes an excellent chance for cooperation with neighbouring countries such as Australia and New Zealand. Close links already exist between New Caledonia and these countries.

The ZoNéCo program constitutes an original integrated approach which due to its multidisciplinary concerns the political authorities of France, New Caledonia Territory, New Caledonia Provinces, and their Research Institutions. The limited life of the program necessitates a rapid relay by applied actions involving the socio-economic partners of New Caledonia, France and Pacific Island Countries. The results already obtained in terms of fisheries lead us to the hope that the transfer of the program to the development sectors will occur in a relatively short term (3 to 5 years).

ZoNéCo appeared as an exportable program not only in the French Territories and Departments but also the multitude of small island countries of the intertropical zone (ITZ) of the world oceans. Because of the over-exploitation of their coastal zones, the demographic pressures and the introduction of sophisticated fishing methods (nylon nets, motorised canoes, etc), the island countries have to identify a new sustainable fishing resource in order to ensure the full employment of their citizens and avoid migratory fluxes toward the cities. They also have to install commercial circuits and increase the local consumption of fishing products in order to diminish the importation of manufactured seafood. To accomplish this, one natural way is to change the fishing activity toward offshore regions like the outer slopes of reefs and seamounts. Within the frame of this planned change, programs such as ZoNéCo will be an indispensable and precious tool for the research and exploitation of new sustainable resources.

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Exploration and mining on coral islands

John Barrie, Managing Director, Avian Mining Pty Ltd, Canberra, Australia

During 1969, Avian Mining Pty Limited, carried out a program of exploration for phosphate and other minerals on islands in the Pacific region. Niue, the southern Cook Islands, and the Line Islands in eastern Kiribati were examined and several were drilled. Results demonstrated the validity of the concept that insular phosphate deposits could be buried beneath younger coral growth.

Exploration on Niue identified it to be a major prospect for epithermal minerals.

Since then high grade phosphate has been found beneath coralline limestone on Matahiva, in French Polynesia, drilling on Niue has found compelling evidence that a major metallogenic event has taken place, and numerous modern deposits of precious and base metals have been found forming now on the sea floor.

The feasibility of exploring for mineral deposits beneath the surface of coral islands is based on modern geophysical techniques and remote sensing. Volcanic rock with variable magnetism occurs beneath almost all coral islands. The patterns of magnetic variation, obtained by aerial geophysical surveys, can be used to interpret the shape and structure of the volcanic rock, and its depth below the coral.

Phosphate deposits like those of Nauru and Banaba may occur in the coral limestone, and rich mineral deposits, particularly of gold and silver, may occur near the top of the hidden volcanic rock. Gold deposits like those of the Emperor Gold Mine in Fiji, and Lihir Island in Papua New Guinea, may be there to be found, as is indicated on Niue,

Mining beneath sea level on coral islands does not present any special problem. Any program of mineral exploration and development must include proper consideration for the social and environmental implications.

Modern analogue of a mineral field: sea-floor hydrothermal activity hosted by felsic volcanic rocks in the Eastern Manus Basin, Papua New Guinea

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IntroductionThe eastern Manus Basin (EMB) contains three known active hydrothermal zones, and is becoming recognised as a regional-scale modern analogue for volcanic-hosted mineral fields on land. Unlike the central Manus Basin, where back-arc spreading is creating new oceanic crust with basalt-hosted hydrothermal deposits[1] resembling those of mid-ocean ridges, the EMB is a pull-apart rift zone between two transform faults. A basement of Eocene-Oligocene arc crust is being thinned by extension, with rapid sedimentation on the tilted blocks. Present-day submarine igneous activity, with which hydrothermal activity in the EMB is associated, has arc geochemical affinities and is related to subduction of the Solomon Sea Plate at the New Britain Trench.

PACMANUS Hydrothermal Field (1655-1740 m depth) Discovered in 1991[2,3], PACMANUS is the central active portion of a 10 km zone of hydrothermal deposits. These are scattered along the crest of a volcanic ridge formed by fissure eruption of very fluid, mostly aphyric andesite, dacite and rhyodacite lava. Three high temperature (to 268°C) black-grey smoker chimney fields (Satanic Mills, Roman Ruins, Rogers Ruins) are situated at fracture zones in relatively unaltered dacite block lavas and sheet flows. Chimneys dominated by chalcopyrite and sphalerite, with barite and some bornite, have average compositions of 11 wt% Cu, 27 wt% Zn, 230 ppm Ag and 18 ppm Au. Low mounds of ferruginous and manganiferous oxides emitting clear, shimmering fluid (29-65°C) surround the chimney fields and also form at independent centres.

A fourth active field (Snowcap) shows extensive diffuse venting of low temperature fluids (to 6°C) through extensively altered dacite-rhyodacite with disseminated pyrite and native sulphur, at a small eruptive centre. This elevated zone, a former eruptive centre, is fringed to one side by Zn-Pb-rich chimneys, and is possibly underlain by subhalative massive sulphides and deeper-seated subvolcanic mineralisation styles. End-member vent fluids at PACMANUS are acid (pH 2.5-3.5) and have compositions reflecting reaction with dacitic wallrocks. Variable salinity supports other evidence of subsurface phase separation. Trace element and isotopic compositions of the deposits suggest an important component of magma-derived fluids and metals.

DESMOS Hydrothermal Field (1930 m depth)DESMOS, discovered in 1990[4], is a small but very active hydrothermal field at one wall of a 250 m deep caldera on a low basaltic andesite volcano. Extensive silicic and argillic alteration is associated with venting of extremely acid, sulphate-rich fluids (to 120°C; pH 2) of magmatic derivation[5]. No massive sulphides are known at DESMOS, but disseminated pyrite, native sulphur, and alunite occur in the altered basaltic andesites.

Susu Knolls Hydrothermal Field (1160-1550 m depth) Discovered in December 1996, the Susu Knolls field extends for 5 km across two high-standing porphyritic dacite domes erupted above aphyric andesite lavas (North Su, South Su), and an adjacent ridge with a low knoll (Suzette). The site was a locus of prolonged harmonic tremor during the 1994 Rabaul eruptions bordering the EMB. Mafic dacites at the crests of the high knolls are extensively brecciated and altered, and carry widespread disseminations and stockworks of pyrite and covellite as well as localised chimneys, mounds and sulphide breccias. Suzette has exposures of both andesite and dacite, and a field of actively venting, chalcopyrite-rich massive sulphide chimneys. The latter are associated with mounds of finely laminated to coarsely banded sulphidic sediments. The nature of an intense hydrothermal plume above Susu Knolls suggests additional venting lower on the slopes than has so far been discovered. Broadband acoustic emission occurs at South Su, presumably from a high velocity steam or CO_2 vent site. Bacterial mat and floc are widespread at this site. Preliminary analyses of three Suzette chimneys average 19 wt% Cu, 22 wt% Zn, 125 ppm Ag and 23 ppm Au.

Regional-Scale Analogue of a Mineral Field Both PACMANUS and Susu Knolls are rare examples of hydrothermal activity associated with submarine felsic volcanic rocks. In this respect they are among the closest modern analogues known for ancient volcanogenic massive sulphide deposits. Although both are

unusual in terms of metal tenor, and perhaps in an alteration style having epithermal affinities, their detailed characterisation will help interpret land-based equivalents and their geological setting.
The potential analogy extends to a regional or provincial scale. Together, the PACMANUS-DESMOS-Susu Knolls sites define a hydrothermally active region of volcanic edifices and sedimented graben some 4000 km^2 in extent. This is comparable in size to important mineral districts on land containing clusters of orebodies with varied characteristics, and offers the possibility of establishing regional as well as local controls on location and style of mineralisation. Despite their contrasted volcanological and tectonic settings, the PACMANUS and Susu hydrothermal fields both occur at bathymetric highs, reflecting maximum magmatic activity, which in turn is localised by geodynamics. Resolving the role of magmatic fluids in arc and back-arc hydrothermal settings is the focus of much current research. Drilling will shortly be conducted to test for subsurface mineralisation. The PACMANUS and Susu discoveries provide an opportunity to compare and contrast two felsic-hosted massive sulphide sites in the same general tectonic environment, and thereby to reach generally applicable conclusions regarding ore genetic processes.

References

[1]Tufar, W. 1991. ...sterreich Geol Gesell Mitt 82:183
[2]Binns R.A.; Scott S.D. 1993. Econ Geol 88: 2226
[3]Binns R.A. et al. 1995. In: Mauk, J.L., St George, J.D. (eds) Proceedings 1995 PACRIM Congress Auckland NZ, Aus Inst Min Metall, 49
[4]Gammo, T et al. 1993. Deep-Sea Res 40:2335
[5]Gammo, T. et al. 1997. Geology, in press.

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Future of freshwater resource/supply management on small high volcanic islands: a case study from Rarotonga, Cook Islands

Ed Burke, SOPAC Secretariat, PMB, GPO, Suva, Fiji

In the past if additional freshwater was required the normal management procedure was to construct another intake or dam another river or drill another well. However with increasing pressure being placed on water resources due to increasing population, growing water demands through development activities (tourism, irrigation, industry, etc) and with the increased incidences of pollution of freshwater supplies, this "tap another source" philosophy cannot be continued for freshwater supplies are quickly running out. The new philosophy must be, how much freshwater is available and how best should this water be used.

Initiating water demand management and conservation practices, relating to legislation, data collection, policies, planning, resources, and education, will enable good stewardship of freshwater resources for generations to come.

A recent visit to Rarotonga to investigate freshwater resources will be used as an example that is typical of many small, high volcanic islands in the Pacific.

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The application of multimedia presentation techniques in the geosciences: an example of the use of the technology in SOPAC's National Capacity Development Program and an introduction to other opportunities.

Andrew Butcher, SOPAC Distance Education and Training Coordinator, SOPAC Secretariat, PMB, GPO, Suva, Fiji

An overview of some of the concepts in hypertext, hypermedia and multimedia are presented with an explanation of key terms and features. Having established these, the design concepts are considered in a review of commercial multimedia authoring packages. Some of the problems associated with authoring packages are examined and explained.

Several of the features are demonstrated using one of SOPAC's popular publications, "Coasts of Pacific Islands," which has been scripted as an electronic document for publication on CD ROM.

A number of further potential applications are presented including training and distance education courseware.

The forms of localised uplift

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The profiles of islands such as Christmas Island, Indian Ocean, the raised terraces at Honiara, Guadalcanal, the terraces on Malekula, Vanuatu (and there are others) are stepped, with long treads and steep emphatic rises. The profile of Christmas Island, which has risen on the bulge just outboard of the Java Trench, is that of a planed-off ziggurat. Swift and major changes of sea level have played a part in the creation of stepped profiles but questions remain. The answers may include the notion of spasmodic uplifts at very fast rates, faster than is generally considered acceptable. What goes up can come down so this topic has relevance to SOPAC countries, especially the lowlying and atoll countries.

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Recolonisation of reef flats by foraminifera: significance of the Funafuti example, Tuvalu

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Many Pacific island beaches and islets consist largely of foraminiferal tests derived from reef flat communities. Although not usually making up more than 40% of the reef flat sediments, because of various concentrating processes tests of the larger foraminifera (particularly *Amphistegina* and *Baculogypsina*) may comprise up to 80% of the sediments forming Fongafale, the main island of Funafuti Atoll, Tuvalu. The foraminiferal component is similar for the sands of other atolls, and its significance to carbonate sediment budgets and to problems of coastal erosion is thus clear. However, populations of larger foraminifera may be threatened or eliminated by natural and human changes to their environments, and it is therefore important to understand their rates of response to these.

One of the effects of tropical cyclone Bebe which struck Funafuti Atoll in 1972 was the formation of a nearly continuous rampart of coral debris along the eastern ocean reef[1]. This was initially deposited on the outer reef flat, and averaged 37 m wide and 3.5 m high (well above mean high tide) over a distance of 18 km. Over succeeding years, waves moved the coral rampart inshore across the reef flat[2] and it now forms the ocean shore for most of the eastern islets. During the present study it was observed that between June 1995 and June 1996, the shoreline moved inland a further 1 m. Seaward of it now is a reef flat between 60 m and 100 m wide. The cyclone-induced waves and their entrained debris destroyed the reef[3]; these effects, plus emplacement and subsequent movement of the coral rampart across the reef flat, would certainly have killed and completely removed all living foraminifera. Even today, much of the ocean reef flat has a smooth, scoured surface largely lacking coral rubble, pools and hollows.

Repetitive sampling since mid-1995 has shown that the ocean reef flat has living populations of *Baculogypsina sphaerulata* with lesser numbers of *Amphistegina lessonii, A. lobifera, Marginopora vertebralis* and a variety of smaller species. All live epiphytically on algae, mainly *Turbinaria ornata* and *Caulerpa racemosa*, from the inner edge of the reef crest to within 1 m of the low tide mark (10 cm water depth at low tide). It is likely that the rate of recolonisation is largely controlled by the rate at which larger algae repopulate the reef flat.

It is not known how much earlier than mid-1995 the foraminiferal populations were present, but it is apparent that recolonisation of the reef flat by foraminifera has occurred in much less than 20 years and probably in less than 10 years. This is very important information for those atolls where the populations of larger foraminifera have disappeared in recent years and where a major component of the sediment system is thus no longer being replenished. It suggests that once the source of a problem is removed and as long as there are populations of foraminifera surviving nearby and algae available to provide a habitat, the main sand-forming foraminifera can re-establish themselves and hence again contribute to the sediment budget within a short period.

References

[1]Maragos *et al.* 1973; *Science*, 181: 1161-1164
[2]Baines & McLean 1976; *Marine Geology*, 21: M1-M8
[3]Maragos *et al.* 1973

Sedimentary processes around Fongafale Island, Tuvalu

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Sediments around Fongafale Island, Funafuti, have been studied using a large suite of samples (200 plus) collected over a number of years by SOPAC staff and by the author. Samples vary greatly and sufficient have been analysed in detail to allow for facies changes. Overall, they are generally medium to coarse and usually moderately sorted calcareous sands. Their study is important because of the processes of coastal erosion and sand and gravel extraction on Fongafale, and the possibility of the infilling of borrow pits with lagoon sediments.

Grains larger than 0.25 mm were identified to 29 categories and counted using a binocular microscope. A minimum of 300 grains per size fraction were counted, except where insufficient material was available (mainly in coarse size fractions), giving up to 1200 or more counts per sample. Results were normalised using weights of grain size fractions to give the overall composition of the samples. Overall, for 93 samples the main components are fragments or entire individuals of foraminifera (42%), coral (21%), *Halimeda* (24%), molluscs (9%) and echinoids (2%).

In the shallow lagoon (less than about 11 m water depth), foraminifera are generally the dominant component of the sand and gravel, followed in decreasing order of abundance by calcareous algae, coral debris and molluscs. In deeper water, foraminifera are generally replaced by *Halimeda*. Close inshore, mechanical abrasion reduces the proportion of calcareous algae and echinoids greatly and may slightly reduce that of the foraminiferan and molluscan material. On land, freshwater preferentially dissolves aragonitic material and removes coral, *Halimeda* and molluscan material. This may increase the proportion of calcitic foraminiferan tests to as much as 80% of the subsurface sediment.

On ocean beaches, the sand is composed almost entirely of coral fragments derived from rubble thrown up by tropical cyclone Bebe. However, foraminiferan tests coming from populations of *Amphistegina lobifera* and *Baculogypsina sphaerulata* living on the ocean reef flat are increasing in abundance, and rapid recolonisation of the foraminifera back into areas from which they have previously been excluded can be demonstrated.

Despite the surficial dominance of coral debris resulting from the cyclone event, sedimentological data and observations from pits suggest that this was a rare event in the development of Fongafale Island. No features resembling cyclone deposits have been observed in borrow pits, and it appears that much of the accretion of Fongafale occurred by non-catastrophic processes similar to those forming sandbanks today.

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Studies of tropical Pacific foraminifera

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The foraminifera (Foraminiferida, forams) are an order of acellular marine organisms that consist of a mass of protoplasm enclosing a complex internal shell (test). The group has been very widely used in the earth sciences for determining ages and paleoenvironments of rocks, and is now being increasingly used for modern paleoenvironmental studies. Foraminifera are important in the tropical Pacific, both as part of the marine ecosystem and as components of the carbonate sedimentary systems. However, they are relatively poorly known overall for the southwest Pacific region. A multi-disciplinary study is underway into many aspects of the taxonomy, distribution, ecology and carbonate productivity of the foraminifera by staff of Victoria University of Wellington and the University of the South Pacific, in collaboration with SOPAC.

General studies are being made of foraminiferal taxonomy and distribution as the basis for ecological studies, as faunas have only been described for a few islands. The faunas are diverse but their taxonomy requires further study, especially for the miliolids which are often very variable.

The term "larger foraminifera" is used informally for large tropical specimens (up to several centimetres in diameter) that live in shallow waters and usually have symbiotic algae in their tissues. In the southwest

Pacific there are a dozen or more species present which range in size from about 0.5 mm up to several centimetres in diameter. These include the large discoidal *Marginopora* and *Sorites* commonly seen on beaches, and the very abundant *Amphistegina* and *Baculogypsina* which are often orange and may make up most of the sand-sized clasts. Repetitive sampling has been undertaken at sites on Funafuti and Viti Levu in order to determine life cycles of common species as part of an investigation into rates of carbonate production.

The term "microforaminifera" is used for a group of very small species that are usually less than 80 microns across when fully grown. They have not been reported previously from outside the Mediterranean, Red Sea and North Atlantic. However, in the present study specimens have been found in shallow marine samples from a number of islands and they are probably widespread in the Pacific. Species found include taxa similar to those reported from the Red Sea, and distribution is likely to be by means of drifting algae. Their distribution may give insights into environmental processes and, in particular, they may be important in studying the response of environments to environmental stress and to pollution control because of their very short life cycles.

The research will aid studies of environmental response to pollution and its control, because of the range of life cycles from several days to several years, and of rates of carbonate production on island reef flats.

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Environmental impacts from offshore mining of sands in Pacific islands

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Awareness of the problems resulting from the removal of sands and aggregates from beaches, reef and hinterland for commercial or public use has been accentuated recently in a number of Pacific islands including Tonga, Tarawa, Samoa, and Hawaii, all of which are vulnerable to the effects of severe storm waves and tsunamis from time to time. Appropriate deposits offshore appear to have been located in some instances but before production can be initiated, environmental analyses are called for, to examine the perceived and the real potential for negative impacts that would arise from the mining operations and the removal of the sand bodies. The first step in the environmental analysis is to determine the concerns deemed to be important to the local government and to the private sector and this can be done through the public hearings or scoping process. The results may be surprising because the concerns of the private sector may be quite different from those of the government, even where both communities are environmentally conscious.

Examples are given for several sites, each of which is being considered for offshore sand recovery. Consideration is given to the variety of concerns which arise because of the natural environment in the specific area. These include: alternative sources of material; physical effects of mining; costs of production; effects on tourism, fisheries and transportation; and the risk of pollution. Models are available that can be used to quantify some of these concerns.

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Ecological significance of benthonic ostracoda (crustacea) from Tarawa Atoll, Kiribati

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Preliminary results from a study of the benthonic ostracod (bivalved Crustacea) fauna of Tarawa Atoll, Republic of Kiribati, are presented. The ostracods were obtained from the intertidal zone, from samples dredged from the lagoon and from two boreholes. A decrease in the number of species through time reflects both sea-level change and the effects of the construction of causeways linking the islets of the atoll.

A variety of samples have been utilised in this study. Six samples were collected by Dr R.Howorth of SOPAC in 1982 on the southern limb of the atoll, followed in 1983 by a further fourteen littoral samples. This material, together with core samples from boreholes 15 & 25 located between Betio and Bairiki, was collected as part of a study of the movement of sediment in and around the southwestern extremity of Tarawa Atoll prior to the construction of the Bairiki-Betio causeway. Later (1995), littoral samples were collected by Victoria University researchers from the lagoon reef flat, lagoon beach, ocean beach and

ocean reef environments at Bikenibeu, Eita, Ambo, the Stewart Causeway near Ambo, Betio, and from North Tarawa. Samples were also dredged from the lagoon along north-south and east-west traverses.

Ostracoda have not been recorded previously from Tarawa but have been recorded from a number of other Pacific islands since 1867. The closest previous records of ostracods to Tarawa are from Onotoa, Kiribati. Many of the recorded species have been considered to be endemic to the region.

Studies so far of the Tarawa ostracods show two sets of changes in the fauna. The first are recent changes that probably relate to human activities such as pollution and causeway construction. Pollution is likely to have had a relatively minor influence, as studies elsewhere suggest that the biota can generally adjust to such influxes. The effect is confined to the 1000 m zone along the lagoon coast and to a few sites on the oceanic coast. The major recent influence is the change to the water circulatory pattern, allowing less movement in the eastern part of the lagoon. Here the number of species has increased, particularly the smaller forms such as *Loxoconcha*. Where oceanic water passes between the islets, as at Buota and Taborio, there are diverse faunas.

Overall for Tarawa, fewer species and specimens are present in the 1995 samples than in those collected in 1982/1983, although the more recent sampling covered a wider geographical area. The reason is probably the influence of the causeways and the increase in population.

Changes shown in the fauna from the borehole samples indicate changes that have occurred over a longer period of time. The borehole material represents a lagoon environment that becomes more oceanic or mixed upward, as *Hermanites transoceana*, *Cytherelloidea* sp. and *Hansacypris* sp. were not found.

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Sediment composition and processes, Tarawa Atoll, Kiribati: preliminary results

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We present here the preliminary results of a study of the composition of sediments from Tarawa Atoll, Kiribati and of the processes controlling their formation and deposition. To date, about 100 samples have been analysed, mostly from the coasts of South Tarawa and from east-west and north-south transects across the lagoon. Quantitative analyses include grain size and sorting determinations, and sediment composition. Grain size data show that well sorted, coarse sand is predominant along the coast of South Tarawa, medium sand dominates the lagoon sediment except near patch reefs, and fine sand occurs in a few locations on the lagoon reef flat and further out in the lagoon.

The compositions of the coarser than 0.25 mm size fractions have been identified in terms of 29 categories, including determinations of the percentages of all species of larger foraminifera. The main components of all samples studied so far are fragments or entire individuals of coral, foraminifera, molluscs and *Halimeda*, averaging 44%, 25%, 18% and 8% respectively overall. Crustacean, echinoid and polychaete tube fragments are the most abundant of the minor constituents present.

Sediment composition, however, varies between different environments. The average composition of lagoon samples is coral (35%), molluscs (26%), *Halimeda* (20%) and foraminifera (12%). Coral fragments increase in abundance shorewards. Beach samples are also dominated by coral. On the lagoon side proportions are coral (43%), followed by foraminifera (32%), molluscs (18%) and *Halimeda* (3%). On the ocean side, the composition is coral (54%), foraminifera (29%), molluscs (11%) and *Halimeda* (<2%).

Land sediments have not yet been examined but field reports suggest that these are dominated by foraminifera with coral providing the next most abundant component. This is supported by samples from Bikeman Island, which are mainly foraminifera (65%) with lesser coral (22%) and molluscs (11%).

The processes operating to cause these differences are probably similar to those already reported for Funafuti but modified by recent environmental changes to South Tarawa, where living larger foraminifera have been found only on the ocean reef flat at the southeast corner of Bonriki. Over large areas of lagoon and ocean reef flat where live larger foraminifera might be expected, none have been found so far. The reasons may include pollution and/or increased siltation. However, foraminifera were probably abundant in the past in the outer reef flat and shallow lagoon areas, although not forming the major part of the sediment. Transport inshore concentrated these in the sediments, as abrasion removed molluscan,

echinoid and *Halimeda* clasts, then processes of dissolution by groundwater are likely to have concentrated them further.

Future work will include field ecological studies and further sampling to extend and confirm the results, particularly with respect to the land areas and to North Tarawa. Analytical work will continue on the chemical and physical properties of the various carbonate components, and experimental studies on their hydraulic properties are also underway.

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Groundwater assessment and development on small coral islands

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The groundwater resources of small coral islands, which provide a valuable source of freshwater to island populations, are often very limited. Special attention to water resources assessment and development is required in order to ensure water supplies are sustainable.

The groundwater on small coral islands generally occurs in the form of thin 'freshwater lenses'. A freshwater lens consists of a zone of freshwater above a transition zone and underlying seawater. The nature of freshwater lenses, in terms of thickness, areal extent and sustainability is a function of three primary factors, namely:

- recharge from rainfall,
- nature of the coral sediments (which directly influence the groundwater storage potential of the island), and
- method of groundwater abstraction.

These primary factors are influenced by other factors including:

- areal and temporal distribution of rainfall,
- potential evapotranspiration,
- vegetation types and densities,
- soil properties,
- size and shape of island, particularly width,
- hydrogeological properties, particularly permeability, porosity of the sediments and the presence of unconformities within the depth range of the freshwater lens,
- tidal range,
- pumping systems and locations,
- abstraction rates, and
- pattern and type of settlement and the extent and degree of pollution.

The above factors show the wide range of influences on usable fresh groundwater resources.

Techniques to measure or estimate recharge to groundwater are reported in a separate paper at this STAR Session (see abstract by White et al, 1997). This paper deals with groundwater assessment and development aspects.

Groundwater resource assessment on small coral islands can be considered at different levels depending on the groundwater development requirements. For reconnaissance level investigations, suitable for preliminary assessment purposes, approximate estimates can be made of groundwater resource potential using empirical relationships and graphs (e.g. relationships relating lens thickness to island width and mean annual rainfall). Caution is required with such approaches. For example, relationships based on average rainfall conditions will not be accurate on islands with large inter-annual rainfall variations.

Preliminary investigations should preferably include surface salinity measurements (e.g. at wells, pits and ponds). Such data can provide valuable information on location of fresh groundwater, although the thickness and sustainability of the freshwater will not be known. The pattern of human settlement is often a guide to fresh groundwater location especially where domestic wells are used. Discussion with local residents and agencies can also provide valuable historical information on water resources and use patterns. The extent of groundwater resources can vary according to different seasons or El Niño Southern Oscillation (ENSO) cycles and it is important to take account of this in analysing data.

For more detailed groundwater assessment, the thickness of freshwater and transition zones can be accurately determined by drilling through the lens and establishing vertical salinity profiles from tests at different depths. Geophysical soundings (electrical resistivity, ER, and electromagnetics, EM) can also provide reasonably accurate data about the base of the freshwater lens. ER and EM survey results are subject to differing interpretations and require independent calibration to be confidently used. In general, EM surveys are more rapid than ER surveys but give less information. The choice of method is dependent on availability of time and funds and the degree of accuracy required.

A drilling and testing program can provide control for geophysical soundings, provide information about permeability, porosity and depth to major hydrogeological features such as solution channels and unconformities, and enable permanent monitoring systems to be installed. Salinity and water level monitoring systems enable long term data to be collected about the behaviour of freshwater lenses and for the calibration of groundwater flow models. On small islands, open holes or continuously perforated casings in holes are not suitable for accurate determination of salinity profiles since mixing of freshwater and seawater can easily occur in the hole. Contamination of the freshwater zone by underlying saline water can also be induced if this approach is used. Suitable salinity monitoring systems for small islands are either multiple holes terminated at different depths with the base of each hole left open, or single boreholes with multiple tubes or pipes terminated at a number of pre-determined depths, between which bentonite (sealing) layers are inserted. Permanent monitoring system holes have been drilled and equipped on a number of coral atolls (Kwajalein and Majuro, Marshall Islands; Tarawa and Christmas Island (Kiritimati), Republic of Kiribati and the Cocos (Keeling) Islands, Indian Ocean) and raised limestone islands (Tongatapu, Kingdom of Tonga and Christmas Island, Indian Ocean). Similar systems have been installed in weathered volcanics and coral sediments on Aitutaki, Cook Islands. Water samples can be obtained by bailing or pumping from the base of each hole and tested with a portable salinity (electrical conductivity) meter. Data from these monitoring systems, some of which data has been collected since the early 1980's, has proven to be valuable in studying the behaviour of freshwater lenses to climate variations (e.g. ENSO cycles) and pumping.

Measurements of water table movements can be useful for determining height above mean sea level and the effects of tides, pumping and climate variations. This data is useful for setting levels for, and analysing impacts of, abstraction facilities. It cannot be used, however, to determine the thickness of the freshwater lens using the 'Ghyben-Herzberg' ratio (approx. 40:1) because the sharp interface assumption is not correct. Water level measurements can also be used to determine tidal efficiencies and lags within the freshwater lenses, which provide an indication of the relative "hydraulic connection" with the sea.

Preliminary estimates of sustainable yield can be made using approximate methods Sustainable yields of between 20% to 30% of mean annual recharge (or approx. 6-12% of mean annual rainfall) have been estimated for a number of atolls. Once again, caution is required in the application of such empirical approaches. For more detailed studies, groundwater modelling is an effective method of estimating sustainable yields. Two-dimensional 'dispersion' (or 'solute transport') models (e.g. SUTRA) have recently been used on a number of small coral islands in the Marshall Islands, Kiribati, and Cocos (Keeling) Islands to model the impacts of different pumping rates. Dispersion models are more accurate than 'sharp-interface' models as they take account of the transition zone, which can often be as thick or thicker than the freshwater zone.

Groundwater abstraction methods on small coral islands are generally of three types: dug wells, boreholes (or drilled wells) and infiltration galleries. Dug wells and boreholes are well known methods while galleries are less known. There are significant advantages in using gallery technology for the development of groundwater on coral islands and lowlying parts of high islands, especially where the depth to the water table is relatively low and where required abstraction levels are high. Infiltration galleries effectively skim freshwater from the surface of the lens, thus distributing the pumping over a wide area. Galleries can avoid the problems of excessive drawdown and consequent upconing of saline water that can occur due to localised pumping from individual boreholes.

Infiltration galleries generally consist of horizontal conduit systems which are permeable to water (e.g. PVC slotted pipes), laid in trenches dug at or close to mean sea level thus allowing water to be drawn towards a central pump pit. Buried conduit systems have been installed and are successfully operating on a number of atolls including Kwajalein in the Marshall Islands, Tarawa, Republic of Kiribati and the Cocos (Keeling) Islands. Open trenches are not recommended as these are subject to surface pollution. On the island of Bonriki, Tarawa, a yield of about 1000 m^3/day is obtained from 17 galleries, each 300 m long. On Home Island in the Cocos (Keeling) Islands, seven galleries have been laid between existing houses as these were built over the only freshwater lens on the island. These galleries, each about 300 m long, produce a

total yield of about 150 m^3/day. Due to their skimming nature, the salinity of abstracted groundwater has been lowered (Home Island) or maintained at pre-pumping conditions (Tarawa).

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'Landsat TM' as a classification tool of reefal environments, as used at Ashmore Reef, NW Australia

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Ashmore Reef was selected to trial the Landsat Thematic Mapper (TM) image classification procedure. Ashmore Reef is a shelf edge platform reef of 150 km^2 (12°17'S, 123°02'E) located on the NorthWest Shelf of Australia.

The 4.8 m tidal regime gives rise to a morphologically diverse reef complex. Close to upwelling this reef has extensive reef- and sand-flats with three vegetated cays on the southern windward side and two lagoons on the leeward side.

Landsat (TM) satellite image processing by P Bierwirth (AGSO, 1995) generated 11 zones and subsequent field work (1996) shows that these computer generated classifications correspond to the physical reef zoning. The satellite image enhances areas of different photo-synthetic activity, particularly on the reef flat. This method would be useful in determining the change in reefal macro algae cover over time. Water quality was found to affect the image quality but despite this limitation, ground truthing confirmed that Landsat TM is a valuable classification tool and could be used successfully in other reefal environments.

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Towards understanding community risk - the AGSO cities project and *RISK-GIS*

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Background

The Australian Geological Survey Organisation (AGSO) has a well established reputation for its work in earthquake monitoring and analysis, in volcanic hazard research, and in fields of geoscience that relate to a wide range of more chronic geohazards such as salinity and acid sulphate soils. The establishing of the Cities Project (the National Geohazards Vulnerability of Urban Communities Project), however, has extended this emphasis on hazard science to the new field of risk science. A series of pilot projects, with an emphasis on earthquake and landslide risks, is being used to develop and test methodologies, identify research needs and to form operational, research and supporting partnerships.

Risk Analysis

The *Risk Management* approach outlined in AS/NZS 4360:1995[1] provides the philosophical base for this research. At the heart of this approach is the recognition that risk is the outcome of the interaction of a hazard event and the elements at risk and their degree of vulnerability to such an impact. This relationship is invariably modified by the degree to which the risk outcome is acceptable to the community involved. Thus we can express the relationship in the following form:

Risk = (Hazard x Elements at Risk x Vulnerability)^{Acceptability}

From this base, a generic approach to the analysis of risk from natural hazards is evolving. This process is illustrated in Figure 1.

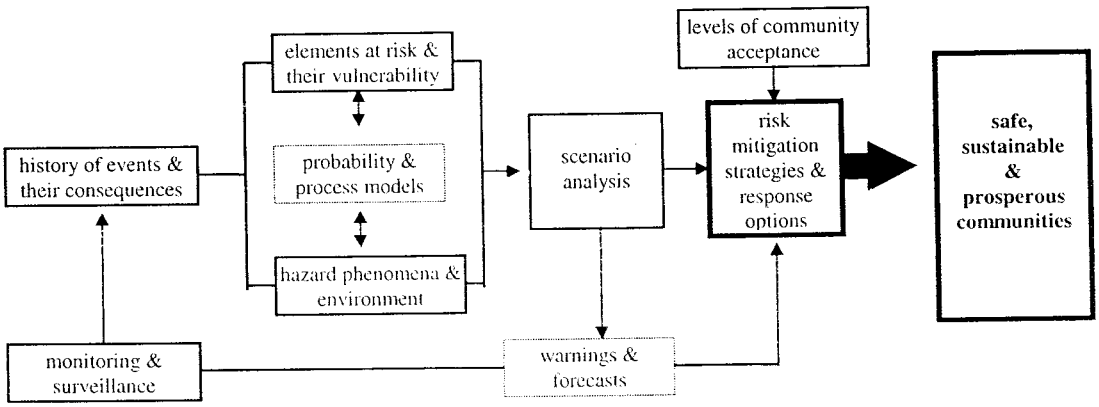

Figure 1: Cities Project generic risk analysis process

Historical knowledge: a detailed understanding of what events have occurred in the past (including paleo-events) and their effects provides the base for understanding what could/will happen in the future.

Monitoring and surveillance: one of the principal sources of historical event information is the extensive network of seismic and other monitoring stations and remote sensing resources.

Phenomenon process knowledge: the focus of hazard science research is on the mechanisms that cause, create, generate or drive the hazard phenomena, eg what causes earthquakes and how their energy is transmitted through various strata. This is underpinned by foundation information relating to the background climatic, environmental, terrain, ecological and geological aspects of the site that are relevant to hazard studies, eg the depth and nature of the sediments and their microtremor response.

Elements at risk and their vulnerability: this is a new area of study and is focused on developing an understanding of the vulnerability of a wide range of the elements that are at risk within the community eg the buildings, lifeline infrastructures and people.

Synthesis and modelling: given that our knowledge of hazard phenomena and the processes that drive them are imperfect, it is necessary to develop appropriate models (process, spatial and temporal) to fill the gap eg the various models of bushfire spread or flood behaviour. A key aspect of these models is an understanding of the probability of events of particular severity occurring. The synthesis of data and the mapping of the relationships between the hazard phenomena and the elements at risk is also an important process in this stage.

Scenario analysis: this is an emerging technique that contributes to 'future memory', an understanding of 'what will happen when...'. The output embraces forecasts of economic loss (eg PML calculations), estimates of potential casualties or assessments of the risk of secondary or consequential hazard impacts such as the spread of fire or the release of hazardous materials following an earthquake. The scenario analysis also provides vital input to **long term** warnings or forecasts.

Acceptability: it is in this area that the science of risk analysis comes face-to-face with human nature and the political 'outrage' dimension of risk management. A key element in determining limits of acceptability rests with effective risk communication and public policy development.

Warnings and forecasts: the most potent mechanism by which to achieve risk mitigation is an effective warning and forecasting system. These are well advanced for hazards such as floods and cyclones but are less well developed for landslides and earthquakes.

Mitigation strategies and response options: the ultimate objective of risk analysis is to develop strategies that will lead to the elimination, reduction, transfer or acceptance of the risk and to ensure that the community is prepared and able to cope with a hazard impact. Included here are strategies such as building codes and urban planning schema.

The outcome of all of this is safer, more sustainable and more prosperous communities.

The greatest challenge for AGSO introduced by the Cities Project, has been the need to develop information and analytical techniques to assess the vulnerability of a wide range of elements-at-risk from the impact of geohazard events. The elements-at-risk include buildings; utility infrastructure; logistic support infrastructure; economic and health facilities; public safety services; and individuals and groups of people. This work is involving collaboration with a very wide range of disciplines including geography, engineering, economics, logistics, public policy, psychology and a range of social sciences.

RISK-GIS

Regardless of the scale and nature of the risk event, the reduction of the uncertainty associated with disasters is dependant largely on the availability of appropriate information. Spatial information is at the forefront in the information needed, because at least 80% of all decisions made in the risk management process have a spatial content. It is also clear that the demand for information is spread throughout the process, rather than concentrated in the heat of the response stage. One of the clear advantages in adopting the more holistic *Risk Management* approach is that the vast majority of data needed to prevent, prepare for, respond to and recover from a disaster can be accumulated, tested, validated and used **before** the disaster event becomes a reality. That is to say, the information (and the various risk management processes it supports) becomes sustainable.

Over the past decade, geographic information systems (GIS) have been used increasingly as tools to provide information to address specific aspects of the risk management problem, especially in hazard mapping and modelling for phenomena such as bushfires or flood and storm tide inundation. There are clear advantages, however, in developing a fusion between a philosophy of risk management and the power of GIS as a decision support tool, hence *Risk-GIS* as it has been christened in the Cities Project. It has as its philosophical roots the risk management approach outlined above, and the view of GIS embodied in Dave Cowan's[(2)] definition as 'a decision support system involving the integration of spatially referenced data in a problem solving environment'.

In this context, the 'problem solving environment' is risk management.

The risk management process imposes a significant demand for a wide range of information products. To cater for this eclectic demand, *Risk-GIS* must be structured to cope with a wide range of external inputs, internal operations and output to a wide range of external consumers. Figure 2 summarises the key structural elements of *Risk-GIS*.

This model goes somewhat beyond the conventional model of GIS as being made up of four elements - technology, data, people and administrative arrangements. Whilst those elements are explicitly or implicitly included, the *Risk-GIS* model also recognises the significance of:

- the 'intelligence cycle' process which commences with direction (identifying the questions for which answers are sought), collection (gathering the data to answer those questions), collation (the management, analysis and interpretation of the data to produce the answers) and dissemination (the communication of the answers). Implicit in this process is the progressive enhancement of data to create information and the eventual formation of knowledge and wisdom;

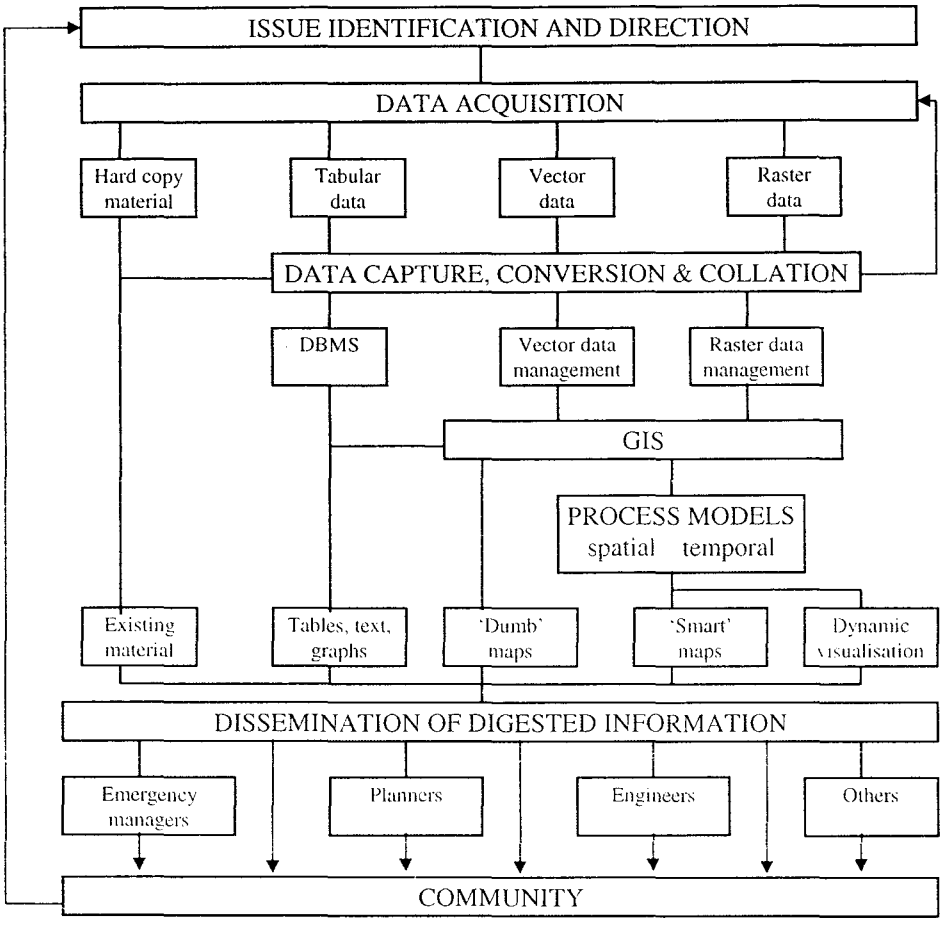

Figure 2: *Risk-GIS* structural elements

- the information infrastructure(s) that facilitate the flow of data and information throughout the model - this includes the institutional framework, technical standards, fundamental data sets and 'clearing house' network components that have been identified as making up the putative Australian Spatial Data Infrastructure (ANZLIC 1996)[3];

- the range of information products that are needed to satisfy the diverse needs of risk managers and the communities they serve. These include conventional and well established 'hard copy' products such as printed maps, books, manuals and so on; simple (one-dimensional) tables, graphs or textual descriptions drawn from databases and spreadsheets; customised, but essentially 'dumb', two-dimensional maps; intelligent, three-dimensional maps (ie those in which the attributes of map features contained in databases are inter-actively linked); and dynamic visualisation including temporal simulations, animations, 'virtual reality' and other 'multi-media' (ie four-dimensional) products;

- the recognition that the process and structures are aimed at meeting the needs of the community as the ultimate beneficiaries.

Results

The results of research under the Cities Project are adding considerably to our knowledge of the risks faced by our urban communities. The contribution of *Risk-GIS* to this process goes well beyond its technology and its capacity to manipulate data. At this stage, however, it has yet to eliminate or even significantly reduce either the uncertainty or the ignorance that existed when this program commenced. However, in its application thus far, *Risk-GIS* has begun to fostered a 'sober cautiousness' when it comes to matters relating to the risks faced by urban communities in Australia.

The generic and holistic approach adopted by the Cities Project is very well suited to the more community oriented societies of the Pacific - indeed it will probably work better there than it does in Australia.

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TRITON Program: Surface meteorology and upper ocean observing moored buoy network

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JAMSTEC is developing a surface moored-buoy network named TRITON (TRIangle Trans-Ocean buoy Network) for observing oceanic and atmospheric variability in the Pacific Ocean and its adjacent seas in cooperation with other interested Japanese and foreign agencies and institutions. The principal scientific objective is to understand actual ocean circulation and heat/salt transports with an emphasis on ENSO, Asian monsoon, and decadal scale variabilities that influence climate change in the Pacific and its adjacent seas.

In the first phase, the buoy network will be established mainly in the western tropical Pacific between 8°S and 8°N. The first four TRITON buoys will be deployed at (8°N, 156°E), (5°N, 156°E), (2°N, 156°E) and (0°, 156°E) in conjunction with TAOATLAS buoys which are presently maintained by Pacific Marine Environmental Laboratory, National Oceanic and Atmospheric Administration, USA.

Subsurface ADCP current meter buoys will be continually deployed along the Equator in a program of the Tropical Ocean Climate Study in conjunction with the surface buoy array. After establishing the network in the western tropical Pacific, two of buoys will be deployed in the Indian Ocean.

An important first step to the understanding of the ENSO mechanism is to undertake a study of the process of the growth and dissipation of the warm pool in the western Pacific, an area where the water temperature goes up to the world's highest, acting as an engine driving the atmosphere. We must also study the variability in low-latitude western-boundary currents such as the New Guinea Coastal and the Mindanao Currents. Other topics that should be surveyed include the relationship between the ENSO and the monsoon climate in the Indian Ocean.

Basically sensors and those depths on the buoy are designed to be compatible with a standard TAO ATLAS buoy in the western tropical Pacific. The improvement is to add the salinity sensors in the full depth range down to 750 m, enable real time data transfer, and carry full surface meteorological sensors. We understand the heat budget in the surface mixing layer may be controlled significantly by fresh water supply at the surface. Further, the water circulation in the western Pacific may be influenced by salinity change induced by subsurface currents associate with seasonal and ENSO cycles. Surface heat and water fluxes are also very important to study the maintenance mechanism of the warm pool.

To ensure the buoy security, maintenance and promote the data utilisation, we need the cooperation of south Pacific countries and related organisations.

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Mapping of superficial deposits for the assessment of geological hazards (landslides, erosion)

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Of the natural hazards that affect New Caledonia, tropical cyclones are the most frequent and have the most damaging effect. Excess rainfall associated with cyclones often trigger landslides. A detailed study was carried

out within the northeastern suburb of Nouméa to assess the risk of landslides, soil erosion and slope failure in an area undergoing increasing urban development. The study area is bounded, to the north by the tectonic contact between the ophiolite overthrusted during the late Eocene and the autochtonous Cretaceous volcanic and sedimentary rocks, and to the south by the Western Lagoon of New Caledonia.

Interpretation of satellite imagery and aerial photography data was completed by detailed mapping (1:5,000) of superficial deposits. A good knowledge of the first few metres of the geological substratum which generally consist of superficial formations, is critical in land-use and environmental development, agriculture, and urban growth.

Within the study area, the following results can be pointed out:

- urban development and infrastructure is increasing northward, on relatively weathered ground materials with steep slopes;
- the risk of slope failure is increased by both the removal of the vegetation and by cut-and-fill practices (poorly compacted material placed on oversteepened slopes) for road construction and to establish building platforms on hill sides;
- two fossil landslides, recolonised by vegetation and therefore unobservable on aerial photographs, have been identified;
- under high rainfall conditions, most of the material transported by the creeks is deposited near the slope-breaks and can cause obstruction of the creeks, followed by flooding in an area where cut-and-fill are numerous due to urban development. Moreover, flooding risk increases during cyclones as, at high tides, lagoon waters can overflow the alluvial plain.

In addition to the flooding risk, rainfall patterns might increase the risk of landslides, soil erosion and slope failure within such an area weakened by human intervention.

Data, converted into the GIS ArcInfo format, are classified in specific and topic-oriented data bases to generate "thematic" and "decision-making" maps.

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Coastal erosion and beach loss on the islands of Oahu and Maui

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The Hawaiian Islands of Oahu and Maui have experienced beach narrowing and loss along much of their shorelines. The sandy shorelines of Oahu and Maui are subject to short- and long-term retreat. The required 40 ft (12.2 m) minimum building setback for beachfront properties has rarely provided an effective coastal erosion buffer zone. The construction of seawalls, revetments, and other coastal armoring has slowed or stopped shoreline retreat, but has led to widespread beach loss.

An analysis of aerial photographic time series of Oahu's shoreline reveals that coastal armoring to protect eroding coastal lands has caused the narrowing of 17.3 ± 1.5 km and loss of 10.4 ± 0.9 km of sandy beach over the period from 1928 or 1949 to 1995. This is nearly a quarter of Oahu's 115.6 ± 9.8 km originally sandy shoreline. A similar study of the shoreline of Maui shows that Maui has lost an estimated third of its beaches. Nearly all narrowed and lost beaches occur in front of coastal armoring structures. This trend of beach loss in the Hawaiian Islands will continue unless alternatives to seawall and revetment construction, such as beach nourishment and erosion-rate based building setbacks, are used by coastal zone planners and the public to address coastal erosion.

Volcanic history and hazards project on Taveuni, Fiji

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Taveuni is the largest of the volcanic islands of Fiji. Quaternary basaltic volcanism has been responsible for constructing a linear chain of volcanoes oriented NNE-SSW, parallel to the Indo-Australian/Pacific plate boundary in this region. A large 1.3 x 2.3 km crater or caldera of Pleistocene age, in the central portion of the island, is filled with a swampy lake (Lake Tagimoucia), in which a partial record of later tephras is preserved within lake sediments and surrounding peat. From this lake[1] reports a radiocarbon date from peat directly above a scoriaceous tephra of 1500 ± 120 yrs BP.

The southern two-thirds of the island is dotted with numerous craters from which basaltic lava flows and scoria cones have been constructed in Holocene times. One of the younger eruptive events yet dated comes from 6 m of scoria overlying a paleosol below the summit of Des Voeux Peak at 1195 m altitude, south of Lake Tagimoucia. Here, wood preserved in the paleosol dates the nearby cinder cone at less than 1660 ± 50 yrs BP [2].

Other cones and young lavas occur throughout the axis of the middle third of the island, before comprising all of the southern third. In an archaeological site (Navolivoli) in the far south of Taveuni, an occupational layer covered by tephra was dated at 2050 ± 150 yrs BP [3]. At least 3 tephra layers (and probably several more), cover this occupational layer. A second occupational layer in soil above these tephras was dated at 710 ± 80 yrs BP.

These three sites of young radiocarbon dates demonstrate that substantial areas of central and southern Taveuni were affected by volcanic activity within the late Holocene, and certainly during the time of human occupation.

Our proposed program is to geologically map, central and southern Taveuni with regard to elucidating Taveuni's volcanic history and potential future volcanic hazards. Volcanic rocks and deposits of differing origins will be mapped with samples collected for further radiocarbon dating, as well as mineralogical, geochemical and physical characterisation. Sources of the volcanic products will be identified and a stratigraphy established for the area. To aid in the determination of tephra eruption frequencies, cores will also be taken from Lake Tagimoucia and other swamps throughout the island. Laboratory analysis will concentrate on characterising the process of emplacement for deposits less easily recognised in the field (e.g. pyroclastic surge and flow deposits), as well as determining any changes in mineralogical and chemical composition of the rocks over time, or between eruptive vents and episodes. Laboratory analyses will also be used to aid in the recognition of marker horizons for stratigraphic purposes. The geological mapping and chronology established will then be used to produce a map of volcanic hazards on the island. Using the hazard map and chronology of volcanic events, volcanic risk will be evaluated for the island's population centres, infrastructure and agriculture. Hazards and risk from volcanic activity on Taveuni will also be assessed for the region particularly neighbouring islands.

References

[1]Southern, W. 1986. The late Quaternary environmental history of Fiji. Unpublished Ph.D. Thesis, Australian National University, Canberra.
[2]Shepherd, T.G.; Neall, V.E. 1991. Soils of Tutu Estate, Taveuni, Fiji. New Zealand Soil Survey Report 85.
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Mathematical modelling of atoll freshwater lens system Tarawa, Kiribati.

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Sustainable management of the freshwater resources of small islands will be assisted by reliable models of their variable density groundwater flow systems. Data from the UNESCO IHP/SOPAC Groundwater Lens Recharge Project on Tarawa, Kiribati has been used with the USGS SUTRA (Saturated-Unsaturated

Transport) model[1] to model a cross section through the lens. This paper describes the mathematical basis and application of the SUTRA model to simulate seawater intrusion in Tarawa. The first phase of the study involves the calibration of the model with estimation of the physical parameters (permeability, dispersivity and porosity). Conventional manual calibration and an automated inverse solution[2] are compared.

The second phase of the study addresses the questions:

- how can the insights gained in developing a model of a specific lens system be of assistance in other islands?
- what minimum observations are required to allow a reliable estimate of sustainable groundwater yield?
- what strategies should be employed to ensure that groundwater extraction is managed during periods of low recharge?

These questions require consideration of the lens behaviour in response to induced (pumping stress) and natural (rainfall, sea-level rise) factors.

References

[1]Voss, C.I. 1984. A finite-element simulation model for saturated-unsaturated, fluid-density dependent groundwater flow with energy transport or chemically-reactive single-species solute transport. United States Geological Survey Water-Resources Investigations Report 84-4329.
[2]Piggott, A.R.; Bobba, A.G. 1993. Inverse analysis implementation of the SUTRA groundwater flow and transport model and User's guide for SUTRA-1. National Water Research Institute Contribution No 93-115.National Water Research Institute, Rivers Research Branch. Groundwater Contamination Project.

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Bathymetric maps of the central and northern New Hebrides Island Arc

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We present two new bathymetric maps of the New Hebrides Island Arc. One is at the scale of 1/1,100,000 with 200 m contour interval and covers the central and northern parts of the arc (8°S-18°S, 165°E-170°E), in Vanuatu and eastern Solomon Islands. the other is at the scale of 1/550,000 with 100 m contour interval and is focused on the central New Hebrides Arc, in Vanuatu (13°S-18°S, 165°30'E-169°30'E). These maps have been made using all the available bathymetric data of the region collected either from conventional echosounders (NGDC and ORSTOM/Noumea data banks) or from multibeam systems.

The most recent conventional bathymetric data used are those acquired by ORSTOM during the Eva 14 (1987, *R/V Coriolis*) and Santa Cruz (1991, *R/V Le Noroit*) cruises, and by the Royal Australian Navy (RAN) during numerous surveys of the *MV Cape Pillar* in the Vanuatu and eastern Solomon Islands waters from 1984 to 1989. The data of the Royal Australian Navy surveys were available from SOPAC and Vanuatu on paper copies, and have been fully digitised. Multibeam bathymetric data used include those collected by ORSTOM/IFREMER during Seapso 1 and 2 (1985) cruises (Seabeam, *R/V Jean Charcot*), by ORSTOM during Multipso (1987) cruise (Seabeam, *R/V Jean Charcot*), by the French-Japanese team during the 1989 cruise of the Starmer program (Seabeam, *R/V Kaiyo*), by SOPAC during Gloria (1989, Seabeam, *R/V HMAS Cook*) and SOPACMAPS 1 and 2 (1993, Simrad, *R/V L'Atalante*) surveys, and by ORSTOM during Calva (1996) cruise (Simrad, *R/V L'Atalante*).

Grauity grid from altimetry (Sandwell and Smith, 1995, version 7.2) have been hepful for the contouring of the Vitiaz Trench in the northernmost part of the map. The less surveyed and, therefore, known area is now the northern New Hebrides trench.

This compilation, especially, allows for the first time a good idea of the topography of three particular areas: the region between Efate and Epi, the junction area between the New Hebrides Arc and the Hazel Holme structure, and the northern part of the New Hebrides Island Arc. The domain of the northern New Hebrides back-arc troughs widens and deepens toward the north, and is bounded eastwards by a continuous but irregular ridge Duff Ridge. A succession of conical seamounts lying along the edge of the platform from 10°30'S to 13°S likely represents the active New Hebrides volcanic arc. The back-arc troughs domain is relayed northwestards by ENE trending scarps and a deep trough (named the Santa

Cruz Trough) between the Reef and Ndende islands, inside the New Hebrides platform. The active Tinakula volcano sits on the western end of this trough. Right lateral and extensional motion are inferred along the Santa Cruz trough.

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Bathymetric map of the North Fiji Basin and the New Hebrides Island Arc

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We present a new bathymetric map of the North Fiji Basin and the New Hebrides Arc (8°S-24°S, 163°E-180°) at the scale of 1/1,000,000 in four sheets and contour interval of 200 m. This map, based partly on previous maps[1,2,3], includes all the multibeam bathymetric data collected during numerous cruises during the past ten years, especially data acquired since 1993 by the French *R/V L'Atalante* (SOPACMAPS 1, 2 and 3 cruises, NOFI cruise, ZoNéCo 1, 2 and 3 cruises and Calva cruise). This map, covering partly the EEZs of Fiji, Tuvalu, Vanuatu, Solomon Islands and New Caledonia allows the active tectonic elements of the area to be distinguished.

References

[1]Chase, T.E. et al. 1983. Topography of the Vanuatu region. USGS.
[2]Monzier, M.; Maillet, P. et Dupont, J. 1991. Carte bathymétrique des parties méridionales de l'arc insulaire des Nouvelles Hébrides et du bassin Nord-Fidjien. ORSTOM, Paris.
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Structure and deformation of north and central Malaita, Solomon Islands: Tectonic implications for the Ontong Java Plateau - Solomon Arc collision, and for the fate of oceanic plateaus

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The island of Malaita, Solomon Islands, represents the obducted southern margin of the Ontong Java Plateau (OJP). The basement of Malaita formed during the first and possibly largest plateau-building magmatic event at c.122 + 3 Ma. It subsequently drifted passively northwards amassing a 1-2 km thickness of pelagic sediment overburden. A major change in OJP tectonics occurred during the Eocene, possibly initiated by the OJP passing over the Samoan or Raratongan hot spot. Extension facilitated increased sedimentation and basin formation (e.g. the Faufaumela Basin) and provided readily available deep-crustal pathways for alkali basalt and subsequent Oligocene alnoite magmas, with related hydrothermal activity producing limited Ag + Pb mineralisation. Eocene to Mid-Miocene sediments record the input of arc-derived turbiditic volcaniclastic sediment indicating the relative closeness of the OJP to the Solomon Arc. The initial collision of the OJP and Solomon Arc at 25-20 Ma was of a "soft docking" variety and did not result in major compressive deformation on Malaita. South-directed subduction of the Pacific Plate briefly ceased at this time but resumed intermittently on a local scale from ~15 Ma. Subduction of the Australian Plate beneath the Solomon Arc commenced at ~7.8 Ma. Increased coupling between the Solomon Arc and the OJP led to the gradual emergence of the OJP at 5-6 Ma through to 4 Ma. The most intense period of compressive to transpressive deformation recorded on Malaita is stratigraphically bracketed at between 4 Ma and 2 Ma, resulting in estimated crustal shortening of between 24% and 46%, and the inclusion of 1-4 km of basement OJP basalts within the larger anticlines. Basement and cover

sequences are deformed together in a coherent geometry and that there are no major decollement surfaces: the large asymmetrical fold structures of Malaita are likely to be the tip regions of blind thrusts with detachment surfaces between 1-4 km beneath the cover sequence. Mid-Pliocene deformation records the detachment of the upper parts of the OJP, with initial material movement direction towards the NE and later obduction of an upper allochthonous block of the OJP southwestwards over the Solomon Arc. A model is presented whereby an upper 5-10 km thick flake of the OJP is obducted over the Solomon Arc to form the Malaita Anticlinorium, whilst deeper levels are presently being subducted. The important implication is that even very large and thick oceanic plateaus may not survive subduction completely intact.

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Understanding the volcanological record of Savo Island, Solomon Islands

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Savo Island is the surface expression of a c.1500 m high stratovolcano with a basal diameter of 9-10 km. Only the upper 465 m is above sea level forming a circular island some 6 km in diameter. The island is covered in dense tropical vegetation with a radial drainage system centred on an asymmetrical crater some 1 km in diameter.

Two historical eruptions have been recorded in 1568 and between 1830 and 1840 AD. A recent carbon 14 age on a wood fragment extracted from a pyroclastic flow has yielded an age of 270 $\pm$ 45 years BP, and analysis of oral historical records at least a fourth event termed the 'Toghavitu' eruption which is reputed to have been a most destructive cataclysmic eruption. Destructive mudflows are also recorded. Savo may have an eruptive periodicity of circa 100 - 300 years and is currently in a quiescent solfatoric stage.

Figure 1 is a geological map of Savo which summarises the most recent volcanological research. The most recent volcanic deposits are acid andesite - dacite, poorly sorted, block-rich, pyroclastic flow deposits which form six distinct pyroclastic flow fan deposits (PFFD's), mainly situated in the north of the island. The fan deposits have flat to gently seaward dipping upper surfaces. The PFFD's represent a major aggradational phenomenon which has significantly enlarged the subaerial extent of Savo. The PFFD's have an upper, proximal, valley confined section, a lower, medial, coastal fan section, and a submarine, offshore distal-fan section. The PFFD's can be divided into younger and older fans on the basis of drainage density. Although in detail the PFFD's are lithologically highly variable the predominant lithofacies is a massive to crudely bedded, very poorly sorted ash with lapilli plus block, pumice-free, unwelded deposit. There are some interbedded laharic sequences. Abrupt lateral facies variation are the norm. We interpret the PFFD's as the result of the explosive collapse of de-gassed exogenic dacite lava domes which produce nueés ardentes - Peléean or Montserratian like pyroclastic flows. Emplacement temperatures are considered to be moderate to low.

Approximately 50% of the island is covered by medial flank block and ash flow deposits (MFBA's) and comprises the bulk of the land between the central crater and the sea. Relative to the PFFD's, the MFBA's are massive, relatively homogeneous, coarse grained, and very poorly sorted. The MFBA's are acid andesite - dacite in composition, and contain blocks up to 2.5 m long. Like many Savo deposits the MFBA's contain abundant gabbroic to ultrabasic xenoliths. The MFBA's are interpreted as proximal-medial pyroclastic flow deposits.

Two dacite domes/intrusions are located within the modern crater, and these may have formed during the most recent eruptions.

The upper parts of the larger rivers expose basalt - andesite lavas which form a volumetrically small proportion of the exposed volcanic sequence.

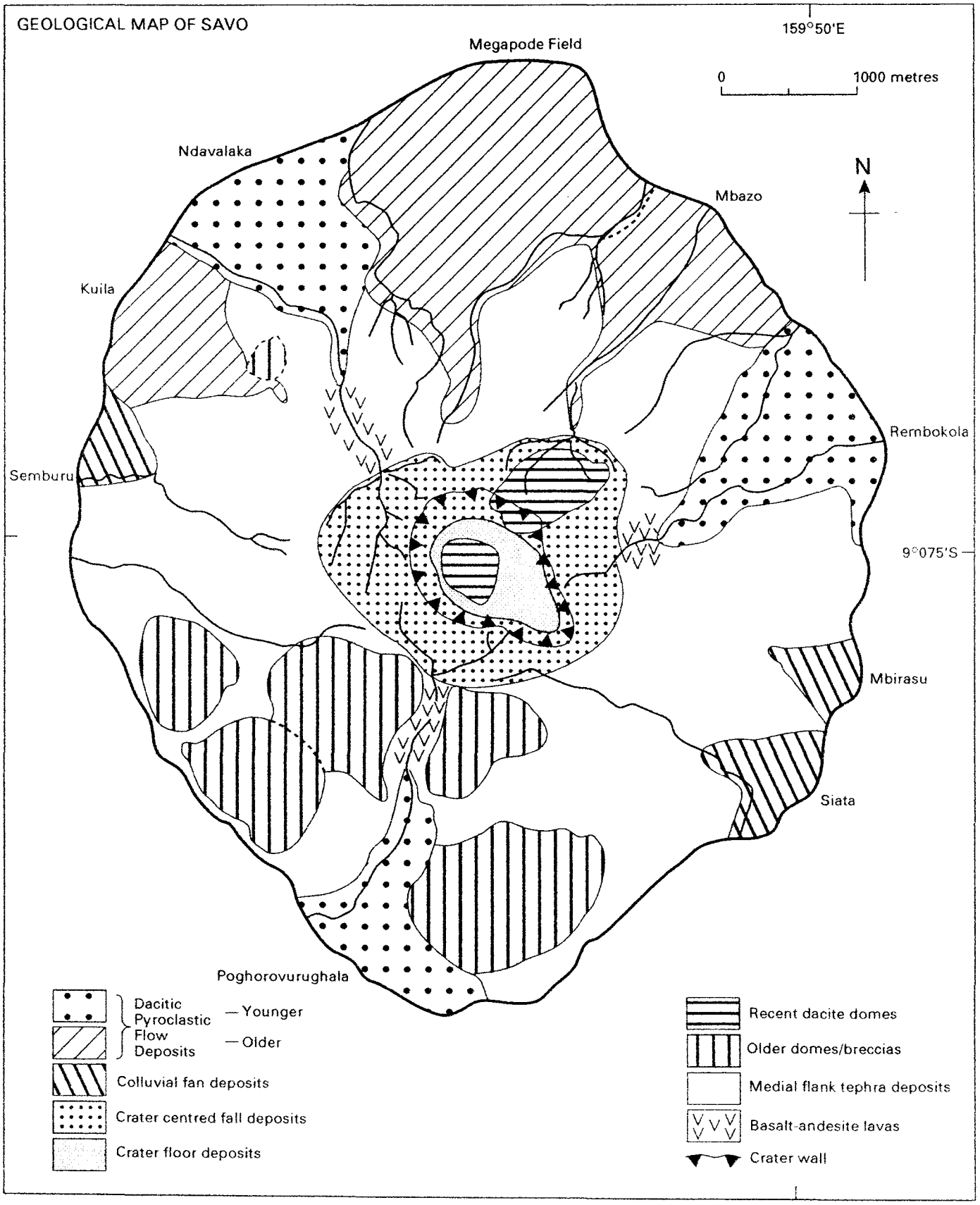
Crater wall andesitic - dacitic tephra deposits are dominated by relatively well bedded and sorted fall and locally surge deposits which form a concentric zone around the crater. Many sequences display typical fall characteristics such as mantled and parallel bedding with alternating lapilli- and ash-rich layers.

Three fluvial-volcaniclastic dominated fans have been recognised. Laharic and other reworked tephra sequences also form an integral part of some pyroclastic fan deposits.

Six older flanking domes are recognised which are predominantly located in the southwest quadrant of the island. The largest domes measure some 1.5 km in diameter, forming steep sided mounds some 240 m high. The predominant lithology is a coarse, poorly sorted, welded (locally tectonised) gabbro or microdiorite which can grade locally into more ultrabasic compositions. These older domes are interpreted as paleo-vent fills.

An understanding of the volcanic deposits of Savo and an interpretation of these deposits in terms of volcanic processes is an essential prerequisite for producing a volcanic hazard assessment. It appears that the most recent eruptions on Savo are highly explosive block-rich ash flows, which although initially valley confined, can very quickly overwhelm the associated coastal fan plains on which the bulk of the population of Savo lives. This theme is developed further in a separate paper at this STAR Session (see abstract by Petterson et al).

Figure 1


GEOLOGICAL MAP OF SAVO
159°50'E
Megapode Field
0
1000 metres
N
Ndavalaka
Mbazo
Kuila
Rembokola
Semburu
9°075'S
Mbirasu
Siata
Poghorovurughala
Dacitic Pyroclastic Flow Deposits
— Younger
— Older
Colluvial fan deposits
Crater centred fall deposits
Crater floor deposits
Recent dacite domes
Older domes/breccias
Medial flank tephra deposits
Basalt-andesite lavas
Crater wall

Towards a volcanic hazard assessment of Savo volcano, Solomon Islands

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An analysis of the volcanic facies exposed on Savo and the production of a volcanic/geological map has been developed to produce a first draft of a volcanic hazard map (see abstract by Petterson et al at this STAR Session). It is stressed that this is still very much work in progress and requires further development.

The most acute volcanic hazard on the island is linked to future explosive block-rich ash flows and associated fall deposits, although the pyroclastic flows are the most dangerous. The nature of these Peléean-type pyroclastic flows means that once they are triggered by a dome collapse, lateral blast, dense volcanic plume collapse etc. they can move at high velocity down topographic exit routes from the central crater to the coastal plain. Although nuées ardentes deposition has been the predominant process by which the Savo coastal plains have formed they can also destroy the subsequent anthropogenic development which have taken place on the coastal plains.

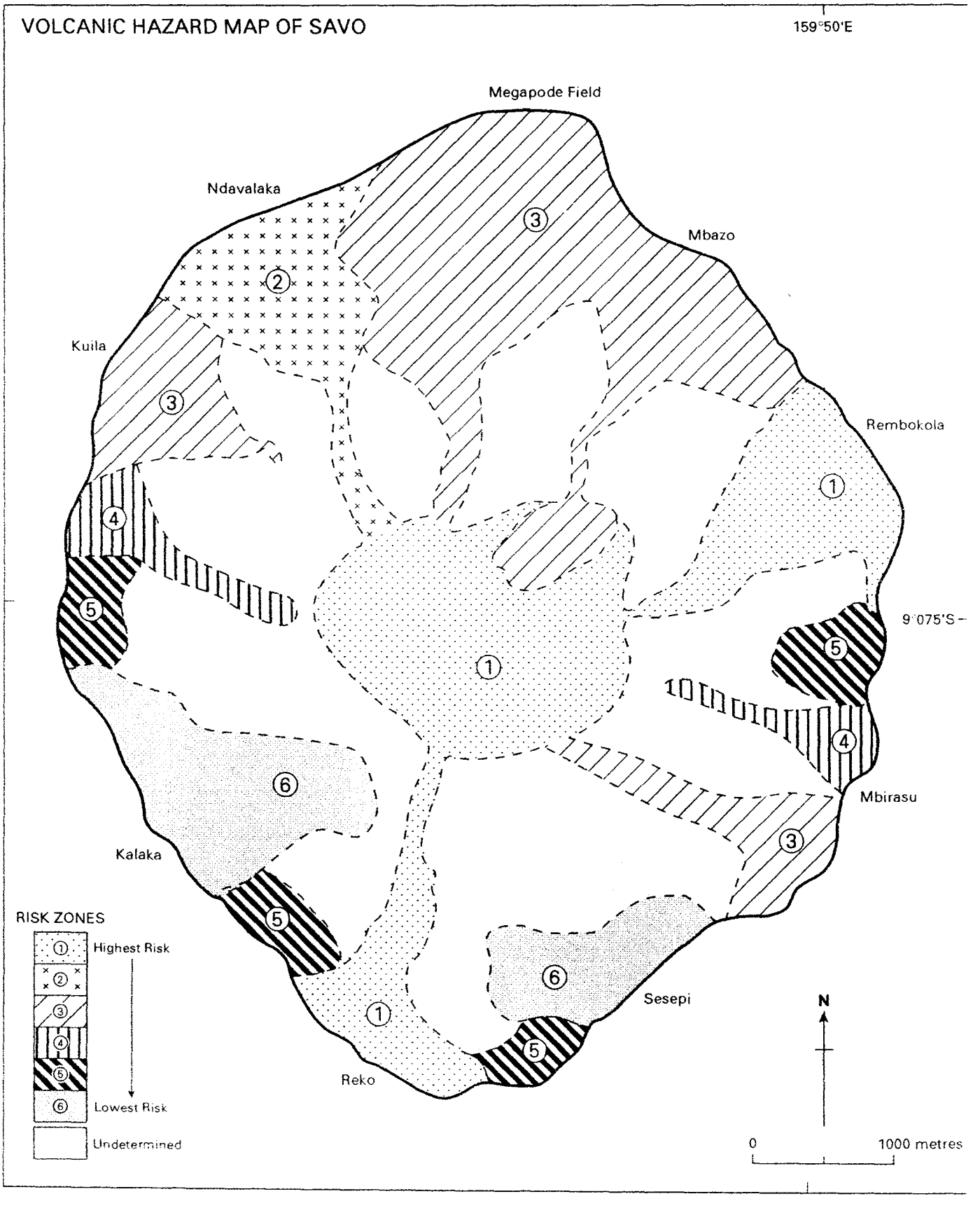
The coastal plains of Savo are by far the most important areas of population and economic activity. All of the 2500 - 3000 inhabitants of Savo live adjacent to the coast with the highest population density in the north of the island. The northern pyroclastic flow fan deposits are also the most important areas of agriculture, livestock rearing, and megapode egg collection (an important economic activity on Savo).

A first attempt semi-quantitative hazard assessment of Savo is presented in Figure 1. This map shows six zones which vary between the highest (Zone 1) and the lowest (Zone 6) risk zones. Zone 1, corresponds to the areas of most recent pyroclastic flow activity, the most likely exit routes of a crater-centred pyroclastic flow, and the central crater area. Zones 2 and 3 are also relatively high risk zones and correspond to the sites of older pyroclastic flows and laharic fans and more difficult exit routes from the central crater. Zone 4 is a lahar-risk zone, but may, in extreme cases be subject to pyroclastic flow activity. Zone 6 is the lowest risk or 'safest' zone which comprises areas which are on the lee-side of the numerous older volcanic domes. Zone 5 is an intermediate low risk zone between Zones 6 and 4. The implications of this hazard assessment will be discussed.

As with all hazard assessments the map depicted in Figure 1 is a product of the application of the principle of uniformitarianism and relies on the assumption that future volcanic activity will be similar to past activity. An extremely high explosive eruption and/or unpredictable lateral blast activity would significantly alter the prediction parameters.

If time permits the talk will also mention the calculations of Dr John Latter relating to the possible effects of different volume eruptions to the nearby areas of Guadalcanal (including Honiara), and the Florida and Russell Islands.

Figure 1


VOLCANIC HAZARD MAP OF SAVO
159°50'E
Megapode Field
Ndavalaka
Mbazo
Kuila
Rembokola
9°075'S
Mbirasu
Kalaka
Sesepi
Reko
RISK ZONES
Highest Risk
Lowest Risk
Undetermined
N
0
1000 metres

Interannual north-south oscillations in sea level in the tropical Pacific

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Empirical orthogonal function (EOF) analysis of 43 island and coastal tide gauge records from 1975 to 1997 from the tropical Pacific reveal two modes of interannual sea level oscillation. The first mode accounting for 39% of the non-seasonal variability characterises the east-west mass transport associated with the El Nino-Southern Oscillation (ENSO) events in 1976-77, 1982-83, 1986-87, 1991-92 and 1997-98. The second mode accounting for 18% of the non-seasonal variability shows a north-south oscillation with an amplitude of 80 to 200 mm. The second mode precedes El Nino or La Nina events by up to ten months. This signal displays a north-south asymmetry about the meteorological equator and is strongest in the western and central Pacific with a maximum at about 8°N and a minimum at about 5°S.

A combined EOF of tide gauge, heat storage (HS400), and sea surface temperature (SST) data reveal similar temporal patterns in all fields. The spatial first modes of sea level, HS400, and SST all show a typical ENSO signal: an anomalously high and warm tongue of water protruding westward from the South American coast along the Equator. The second mode is a precursor to El Nino: it is not an artifact of the EOF analysis created by the ENSO signal's propagation. The sea level and HS400 spatial patterns are very similar showing north-south asymmetry. The second mode's anomalously warm SST's are associated with a eastward shift of the confluence of the intertropical and south Pacific convergence zones from Indonesia to the International Dateline. The EOF analysis generally shows sea level is higher/lower in warmer/colder regions. The first and second mode together describe eastward propagation of mass and heat.

The second mode's north-south asymmetry suggests and oscillation in the intensity of the subtropical gyres, which affects sea level, HS400, and SST throughout the tropical Pacific. This mode of interannual sea level change has a magnitude greater than the seasonal cycle, but less than ENSO.

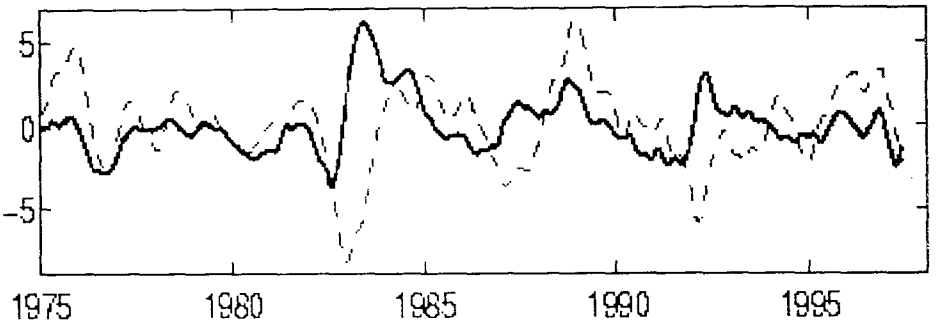

Figure 1: Time series for first (dashed line) and second (solid line) sea level EOF modes.

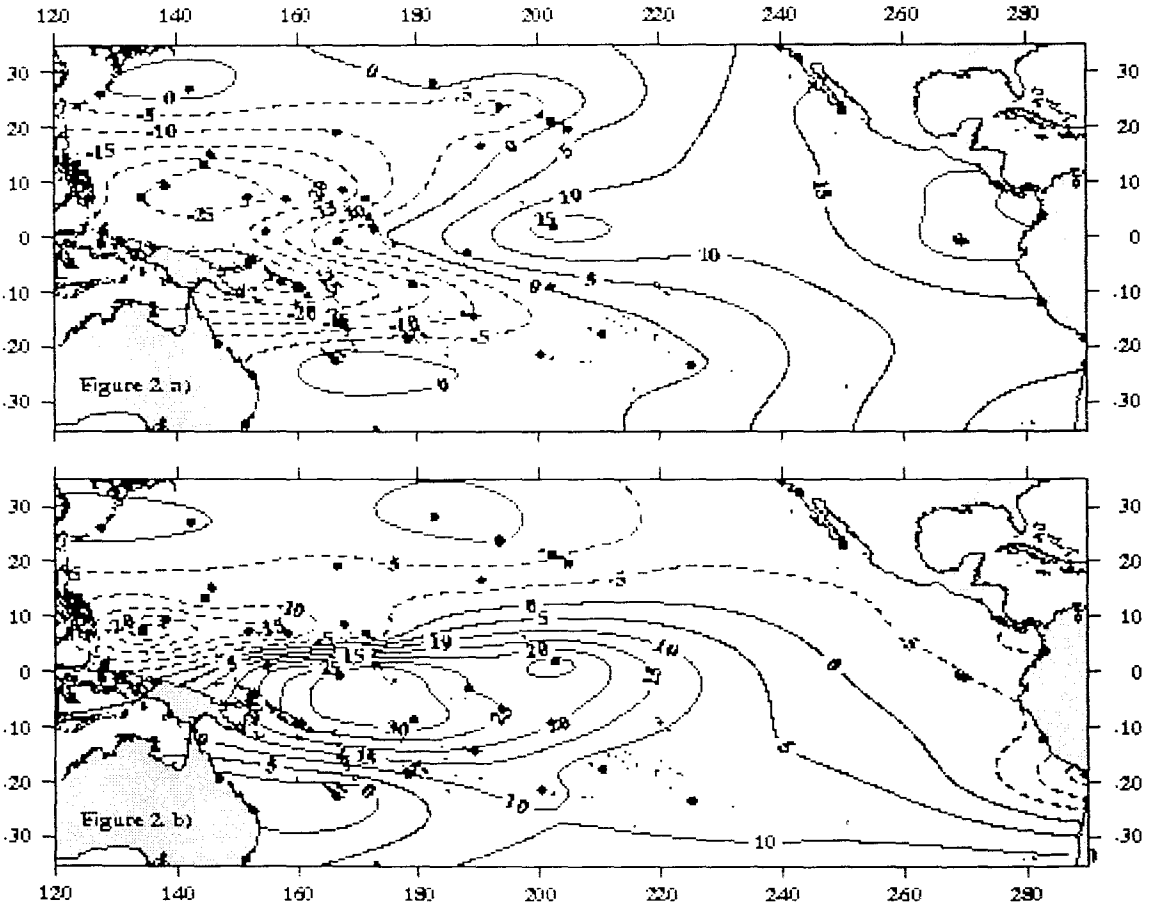

Figure 2: Spatial patterns for a) first and b) second sea level EOF modes. Solid dots indicate 13 tide gauges.

Pacific Cities: seismic hazard mapping in Port Vila

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Port Vila Harbour was surveyed in May 1997 as part of the Pacific Cities project. Bathymetric and seismic reflection profiling was carried out across the inner embayments and the seaward extension into Mele Bay.

Sea-floor characteristics of the Port Vila Harbour area are mapped out as a planning tool for potential reclamation and construction of offshore structures. The detailed bathymetric chart of the wider region will form the principal input into an upcoming storm surge and tsunami modelling program that will also investigate the potential for seiching in the harbour - a phenomenon recorded in the oral history of the area. The physiography of the harbour is closely controlled by horst and graben structures that have been traced onshore during a recent mapping program for Pacific Cities, aimed at providing a microzonation of earthquake site-response parameters. Sedimentation patterns in the harbour, derived from seismic profiling, can be usefully compared with the record of onshore, co-seismic Holocene uplift described in earlier work[1].

Geologic and physiographic data is accumulated on a MapInfo GIS database, with further work, including interactive overlays of infrastructural/population data and a variety of hazard scenarios planned for inclusion in the near future.

Reference

[1]Howorth, 1985. Baseline coastal studies, Port Vila, Vanuatu: Holocene uplift record and evidence for recurrence or large earthquakes. CCOP/SOPAC Technical Report 51.

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The Laser Airborne Depth Sounder (LADS)

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The latest generation of technology for shallow water hydrographic surveying is the Laser Airborne Depth sounder (LADS) System.

The technology which underpins the LADS System was pioneered by the Australian Defence Science and Technology Organisation (DSTO) over a 15-year period commencing in the early 1970's.

This earlier work proved the concept of measuring ocean depths from an airborne laser and established a number of system parameters. The work was sponsored by the Royal Australian Navy (RAN) Hydrographic Service to search for a faster and more cost-effective method of surveying Australia's vast continental shelf.

In 1989, Vision System Ltd was contracted by the Department of Defence to design and manufacture a fully engineered LADS System based on DSTO's earlier research.

In 1993, LADS entered service with the RAN and has been in routine operational service since that time surveying areas of the Great Barrier Reef, Coral Sea, Torres Strait and Arafura Sea, and has conducted survey operations in Indonesia.

In its 4½ years of operation, LADS has successfully surveyed over 10,000 square nautical miles of Australia's continental shelf.

As the sole licensee to the Commonwealth of Australia, Vision Systems established a subsidiary, LADS Corporation Ltd (LCL), in 1995 to continue to supply maintenance and logistics support to the RAN and to market LADS worldwide.

Based on the success of the RAN LADS, LCL has invested in a new generation system, LADS Mk II, which has considerable system and performance advantages over its predecessor.

LADS Mk II is capable of surveying 19 square nautical miles (65 square kilometres) per hour, and can measure water depths form 0 to 70 metres at optional sounding densities from 10m x 10m to 3m x 3m.

Accuracy of LADS soundings is to S44 IHO standard for Hydrographic Survey - 4th draft, Order 2. Further, LADS is much more cost-effective than surveying using conventional acoustic techniques particularly in complex or shoal areas.

The light density digital data produced by LADS has many applications including:

- nautical charting,
- coral reef and fisheries management,
- offshore exploration,
- territorial sea and EEZ delineation,
- ports and harbours development,
- oil spill management programs,
- low water line surveys,
- resource management programs,
- scientific modelling.

This paper will describe the LADS technology, its operation with the RAN and LADS Mk II, and it is hoped the paper will help to identify potential applications for LADS in the South Pacific.

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Fine aggregate resources of small, Pacific Island nations: problems of supply, impact of extraction and development

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Small limestone islands of the western Pacific, such as Cook Islands, Kiribati, Marshall Islands, Samoa, Tonga and Tuvalu are experiencing increasing problems with sources of fine grade construction material, that is sand and gravel. For sustainable economic development to continue, alternative supplies must be found and used. At present most fine grained aggregate is extracted from the beaches. However, as the beaches are destroyed, this source is becoming exhausted. Local studies from Tonga indicate that the active beach, used for fine aggregate has a lifespan (at present rates of usage) of the order of years rather than decades. The effects of beach degradation impact upon coastal protection and is thus in conflict with the use of the beach (and coastal zone generally) for recreational purposes. Thus the coastal hinterland becomes more prone to erosion and to inundation during cyclones and tsunamis. The beach becomes less of a tourist attraction, a consequence that may have severe impact upon the nations' economy. Economic development may be hindered as a consequence of reduced availability of sand and gravel.

Alternative sources of fine aggregate have been found offshore, but these are not being used as extensively as they might. The reasons why the offshore alternatives are not used have been identified as: technical; financial; operational; and attitudinal.

However, upon examination, these obstacles to accessing the offshore resources may be more apparent than real. Local studies show that offshore resources are economically competitive, if not cheaper, than those onshore. Extraction may not be as environmentally damaging. Nevertheless, there needs to be a wider realisation of the availability and benefit of using the offshore resources. It is a `quantum jump' in technology, but his should not be perceived as a disadvantage. Experience from `old world' countries has led to the formulation of extraction procedures, that allow for the environmentally acceptable and sustainable development of alternative offshore sand and gravel resources. It may be that these procedures, applied within the region may assist in the increased use of the offshore aggregates. If the problems are common to many nations then a regional approach may be appropriate. It is the objective of this STAR presentation to discuss fine aggregate availability in this context.

Some effects of tropical cyclones Gavin and June in 1997 on the terrestrial and coastal environments of the Fiji Islands

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This paper investigates the principal effects of tropical cyclones Gavin and June on the physical environment of the Fiji Islands. These cyclones, which entered Fiji waters in March and May 1997 respectively, were the first severe tropical depressions to traverse Fiji since cyclone Kina in 1993. Media reports indicated that Vanua Levu, the Yasawa Islands, the Mamanuca Islands and the northern and western districts of Viti Levu were the most severely affected. Hurricane force winds, intense rainfall and storm waves caused a number of damaging effects on the natural environment, including intensive and widespread flooding, landslides and coastal erosion. These effects in turn caused the loss of several lives and much human suffering, while badly damaging roads and infrastructure.

Different tropical cyclones cause contrasting geographic patterns in landscape change on Pacific islands. This depends on the strength and duration of the storms, the proximity of the storm tracks to land, maximum precipitation intensities and total rainfall amounts, antecedent weather conditions, the hydrological storage capacities of the vegetation and soils, and many other factors influencing the environmental susceptibility of the islands concerned.

Spatial patterns in the environmental responses to cyclones Gavin and June are assessed using satellite images of the southerly progression of the storms and corresponding data on rainfall, river flood hydrographs, landslide occurrence, storm surges and reports of beach degradation. Field observations at some of the worst affected areas give indications as to the magnitude of these physical effects.

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Refining plate motions and locating hot spots using a newly recognised geometric relationship between hot spots and seamounts

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Knowledge of past changes in both the rate and direction of motion of the lithospheric plates permits reconstruction of the past locations of bathymetric and topographic features on the surface of the Earth, in turn providing insight into paleoceanographic and paleoclimatic factors which may have influenced the accumulation of natural resources at these locations. Hot spots and the seamounts produced by them provide both geometric and temporal evidence for changes in plate motion.

An age-independent, geometric relationship is presented that links hot spots to the seamounts they produce and so permits the use of undated seamounts to refine plate motions. This technique, dubbed hot-spotting, also has the potential to rigorously assess hot spot fixity and to locate extinct hot spots. Furthermore, by convolving seamount shapes with their flowlines, images of cumulative volcano amplitude (CVA) can be obtained, where local maxima at flowline intersections both reveal the location of hot spots and provide an estimate of volcanic flux. The latter providing additional information on factors that may have influenced paleoceanographic/paleoclimatic change. Here we use the hot-spotting technique to examine Pacific hot spots in general and the Hawaii and Louisville hot spots in particular.

Application of this method indicates a recent change in plate motion, and suggests a relocation of the Louisville hot spot to the Hollister Ridge, south of the Eltanin Fracture Zone.

Groundwater recharge in low, coral islands: results of the UNESCO-SOPAC study on Tarawa Atoll, Kiribati

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Sustainable water extraction from shallow fresh groundwater lenses is crucial to lowlying coral atoll Pacific nations, where lenses are the principal source of freshwater. Overpumping can draw underlying seawater into lenses. These shallow groundwaters in permeable coral sands are also easily contaminated by surface wastes. Local communities, with land overlying freshwater reserves, are often required to change landuse practices so that their neighbours can have potable water. Such requirements touch sensitive community concerns and can generate conflicts. Safe extraction limits are governed by the amount of rainfall recharging the groundwater. Recharge is difficult to estimate because the amounts of water intercepted by tropical vegetation, lost by evapotranspiration, removed from groundwater by trees and stored in the soil are known only approximately. This UNESCO-SOPAC-sponsored study aims to quantify recharge processes, to understand possible conflicts, to record oral traditions and community views on the impacts of pumping on crops and water and to provide training in the appropriate hydrology and social science.

Bonriki Island, Tarawa Atoll, Republic of Kiribati was chosen for the study. The Bonriki lens has been pumped since 1978 from lateral galleries, designed to lower the water table by less than 50 mm. Windspeed, air temperature and humidity, atmospheric pressure, solar radiation, soil moisture to 0.7 m, groundwater level at various locations and sap flow velocity in coconut trees were recorded at 15 minute intervals for the duration of the study. Measurements of the thickness of the freshwater lens used special, salinity monitoring wells. Groundwater chemistry was also studied. Raingauges recorded rainfall and interception and stem flow was measured. The project was discussed with the Bonriki community and the views of representatives were sought to collect oral history on changes.

The study has shown that evapotranspiration averages about 2.6 mm/day, about 2/3 of potential evaporation, and is driven by solar radiation. Coconut trees transpire 100 to 150 l/day. This is approximately equal to a direct loss of about 1 mm/day from the groundwater lens. This loss rate agrees well with estimates from the thickness of the lens. Interception losses by coconut trees during light rains is around 0.8 mm. During heavy rains, the tree crowns concentrate flows up to 270% of the cumulative rainfall. Approximately 20% of the rain falling on the crown area becomes stem flow in vertical trees. Watertable monitoring shows that drawdown during pumping is only of order 20 mm, within design specifications, and less than the diurnal watertable fluctuation of approximately 60-100 mm due to tidal fluctuations. Tidal efficiencies at the watertable are about 5% and the tidal lag is approximately 2.5 hours, independent of horizontal position on the island. Recharge events can raise the groundwater elevation by up to 600 mm. Increases in elevation take at least 7 days to decay due to discharge from the edge of the lens. The community believes that vegetation, particularly coconuts, has declined since pumping began and seeks compensation from the government. The study found that compensation had led to a decline in the management of vegetation and in the replanting of coconuts. High concentrations of hydrogen sulphide were found in groundwater (up to 4 mg/l). Its impact on vegetation remains to be elucidated. Hydrogen sulphide is generated from dissolved sulphate, from the dissolution of the coral sand aquifer, and from labile organic matter which appears to come from surface sources such as wells and swamp taro pits.

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Towards a better understanding of reef flat and beach sediment processes, Kosrae, Federated States of Micronesia

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The shores of Kosrae, Federated States of Micronesia, can be divided into three types: sand and gravel beaches, mangroves and artificial beaches. Sand beaches occur on the west and most of the north coasts, and on parts of the east coast. Gravel beaches occur on the south coast and along parts of the east coast. Erosion is occurring on most parts of the north, east and south coasts, and along limited areas of the west

coast. Varied erosional phenomena show that shorelines have commonly retreated by 7 to 15 m in the last 45 years. Erosion on the west coast is mainly caused by natural processes but on the other coasts it is mainly related to human activities such as removal of sediments, engineering activities, channel closure and river diversion, and removal of mangrove trees.

The coastal sand and gravel contain little terrigenous material and are mainly of biogenic material derived from the reef and reef flats. In particular, the sand contains abundant tests of a single species of larger foraminifera, *Baculogypsina sphaerulata.* These tests are particularly concentrated in river mouth sites and their abundance, often good state of preservation and striking orange colour might suggest that they grew in these sites.

However, the foraminifera are actually living epiphytically on algae on the middle and outer reef flats, although they are much less abundant there than closer inshore. Their accumulation in the coastal sediments, and especially in the river mouths, is apparently a result of the range of coastal processes and island physiography combined with the hydraulic properties and relative durability to physical and chemical processes of the foraminiferal tests.

Damage to the foraminiferan tests during transport ranges from fragmentation and polishing of the tests through to loss of part or all of the spines through to very minor damage to external chamber surfaces. Commonly, the first signs of abrasion can only be seen using electron microscopy, making the transport processes difficult to evaluate. At the opposite extreme, rounding and polishing of the test may make identification difficult. A scale for degree of test damage is currently being developed, and this may help quantify the amount of transport of individual tests.

Without knowledge of the outer reef flat ecology, it would be easy to misinterpret the processes of sedimentation, with possibly serious consequences for any remedial measures required to lessen the coastal erosion. Further, because the *Baculogypsina* tests appear to be transported rather differently to other biogenic clasts, damage to areas of high foraminiferal productivity by construction, excavation or pollution of parts of the reef flats, may have consequences at distant areas on the coasts.

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GEOLOGY OF THE GOLD RIDGE EPITHERMAL GOLD DEPOSIT, GUADALCANAL ISLAND, SOLOMON ISLANDS

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Abstract - Gold mineralisation at Gold Ridge, central Guadalcanal, Solomon Islands is hosted within a distinctive volcaniclastic facies of a widespread epiclastic unit of the Lower Pliocene Epoch. High temperature, low sulphidadion epithermal mineralisation is characterised by a gold-pyrite association in quartz-calcite veins within illite-carbonate-quartz-pyrite alteration. The primary control on mineralisation is a set of extensional faults and associated low angle shears and tensional microfractures localised along a NE trending arc-normal fault zone. Exploration to March 1996 outlined proved and probable ore reserves of 19.54Mt at 1.65g/t for 1.035 million ounces of gold. A bankable feasibility study on Gold Ridge was recently submitted to the Government of the Solomon Islands. Pending agreements scheduled for completion in the short term, the project will become the first mining operation in the Solomon Islands.

INTRODUCTION

The Gold Ridge gold deposits are in the Malango mountains of central Guadalcanal Island in the Solomon Islands, at latitude 9°40' S, longitude 160°08' E about 30km SE of the national capital, Honiara (Figure 1). Access from Honiara is by 35km of sealed and 10km of unsealed road. The main project area covers about 5km^2 of steep jungle clad hills between 300m and 600m above sea level on the northern slopes of the central mountain range. The climate is warm and humid with rainfall ranging between 4,000-5,000mm per year in the project area.

Gold was traced to its bedrock source in 1936 by panning in the streams and tributaries north of the Gold Ridge project area. Substantial modern exploration by CRA, AMOCO, Cyprus and ARIMCO culminated in two feasibility studies in 1990 and 1992. Ross Mining purchased the project in March 1995 and completed a bankable feasibility in July 1996 following field and test work. Drilling in the project to date totalling 66,000m identified three ore bodies, Valehaichichi, Kupers and Dawsons within a diamond shaped hydrothermally altered zone 2.5km long by 1.4km wide.

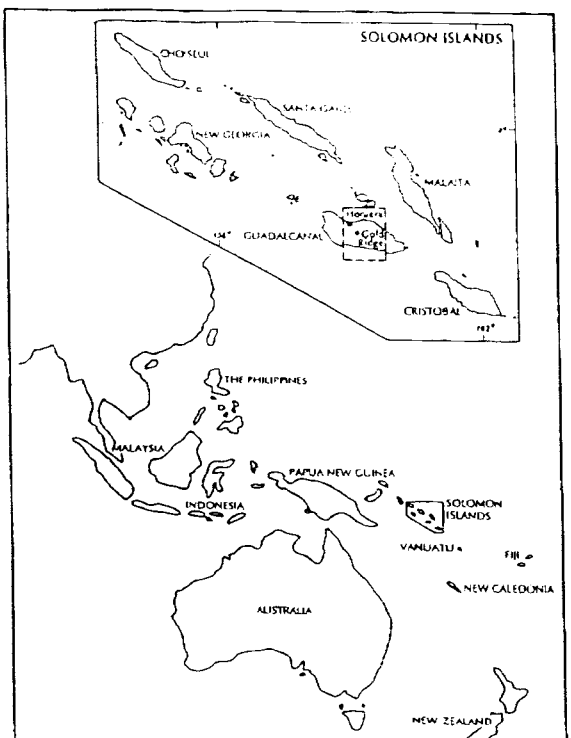

Figure 1: Location

Pending approvals from the Solomon Islands Government and the Gold Ridge Landowners Association, which represents the interests of the Gold Ridge people, construction is expected to commence early in 1997 and mining in mid 1998. A 2Mt per annum open cut gold mine is proposed with processing of ore at the same rate as mining in a treatment plant close to the mine site. The first gold pour is scheduled for the last quarter of 1997. Expected mine life on current ore reserves is 10 years at a production rate of about 100,00 ounces of gold per year.

REGIONAL SETTING

The Solomon Islands and Papua New Guinea are part of a continental island arc system formed by the collision of the N moving Australia-India Plate with the SW moving Pacific Plate. Subduction of the Pacific Plate beneath the Australia-India Plate resulted in partial melting of the Pacific Plate and diapiric rise of magmas into the domed Australia-India Plate. Fracturing of core rocks due to collision and subduction generated a set of lineaments trending ESE and NNE. These primary structural elements were reactivated through time by ongoing tectonism and are referred to as arc-parallel and arc-normal structures. Arc-normal faults are transfer structures that are being increasingly recognised as important first order controls on the localisation of magmatic activity and mineralisation (Etheridge & Henley, 1995). Several of the well known PNG mineral deposits (Ok Tedi, Porgera, Mt Kare) are located along transfer structures where they intersect with arc-parallel structures (Figure 2).

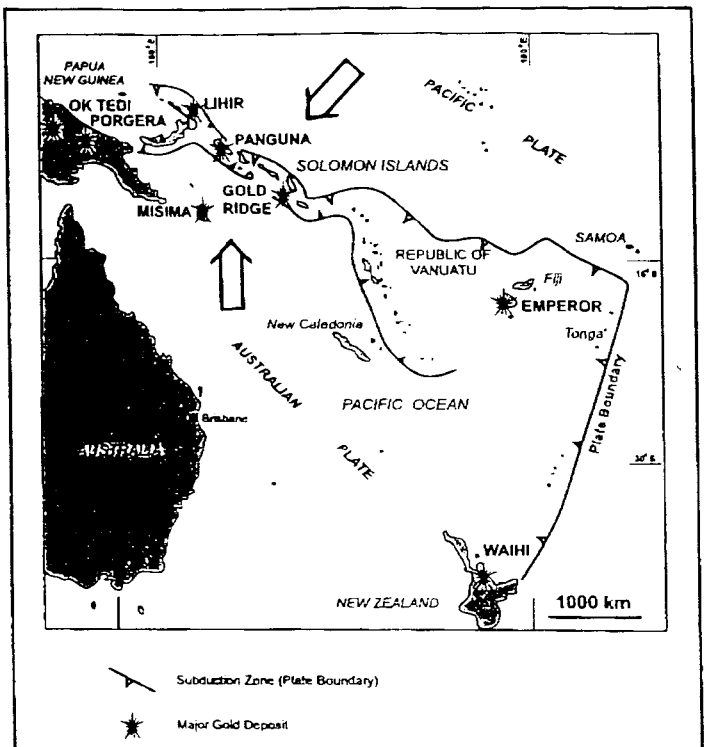

Figure 2: Tectonic Setting & Major Deposits

Gold Ridge comprises three closely spaced deposits within hydrothermally altered volcaniclastic rocks over an area of about 5km^2 astride the NNE to NE trending Melango fault (Figure 3). The Melango fault system corresponds to the short axis of the sigmoid-shaped island of Guadalcanal, presumably offsetting the uplifted Pre-Miocene oceanic basement to the SE from the younger rocks to the NW. In addition to localising the Gold

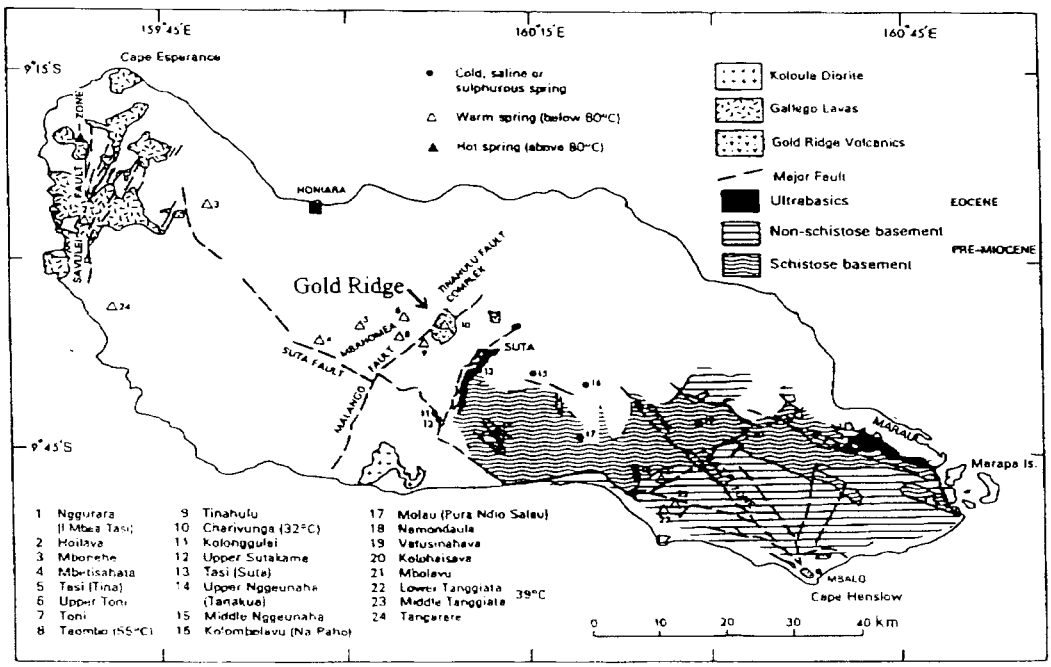

Figure 3: Map of Guadalcanal (after Hackman, 1980) showing hot springs and major faults.

Ridge volcaniclastics, the Melango fault system corresponds to a series of ultramafic and other basement fault blocks, minor volcanic accumulations and high level intrusives that include a porphyry prospect to the south of Gold Ridge. Etheridge & Henley (1995) recognised the influence of such deep seated arc-normal faults on the distribution of gold and gold-copper mineralisation in island arc settings in Indonesia, New Guinea and New Zealand, and consider these structures to be a key control on the distribution of large porphyry copper deposits in regions such as Chile.

The most likely structural setting for the Gold Ridge volcaniclastic sub-basin was a pull-apart basin along a step in the Melango fault system, which appears to have originated as a transform fault offsetting the Mio-Pliocene arc of Guadalcanal (Etheridge & Henley, 1995).

PROJECT GEOLOGY

Gold mineralisation at Gold Ridge is associated with argillic alteration (illite-carbonate-quartz-pyrite) and pervasive low order silica-pyrite alteration (quartz-illite-pyrite) usually as matrix infill. The three deposits are hosted by the Gold Ridge Volcanics (GRV) of the Lower Pliocene Epoch - a distinctive, shallow dipping volcaniclastic facies at least 500m thick (probably 900m) at the base of a more widely distributed epiclastic formation. An alteration map of the known mineralised zone with soil auger geochemical values plotted shows the strong association of gold with the argillic alteration (Figure 4).

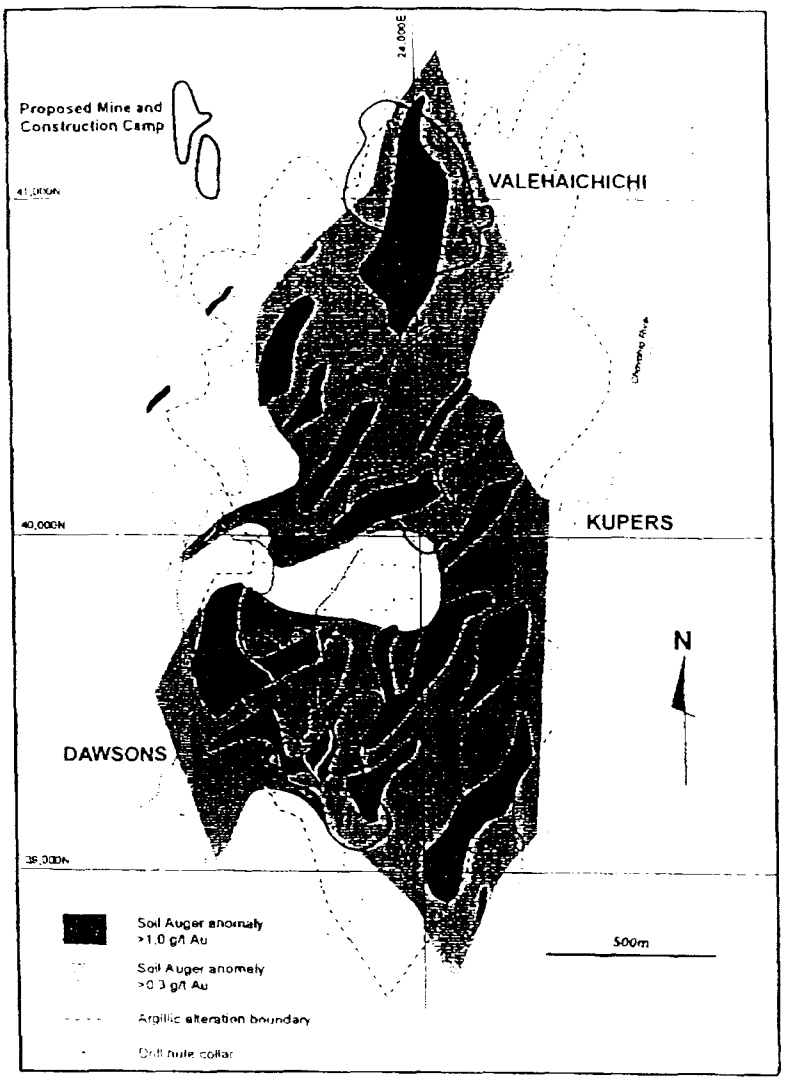

Figure 4: Alteration & Gold Geochemistry

The GRV sequence underwent pervasive argillic alteration characterised by illite and illite-kaolinite assemblages. Argillic alteration overprinted an earlier and more widespread propylitic alteration event

(chlorite-smectite-carbonate-quartz). Valehaichichi hosts the most intense and concentrated argillic alteration. Propylitic alteration survived at Kupers and Dawsons where argillic alteration is less intense. Primary porosity of shallow dipping, clast supported lithologies was an important factor in the lateral dispersion of gold mineralising fluids away from subvertical, narrow fissures that provided the conduits.

Steep dipping displacement zones trending NNW to NNE were recognised throughout the project area, although overall the GRV sequences are not significantly disrupted by faulting. Mapping and drill core orientations indicate broad, open folding caused by compressional tectonics. Anticlinal folding along a ENE to ESE trending axis was interpreted at Kupers, and a broad synclinal fold along a NNE axis at Dawsons. A combination of compressional and strike-slip deformation produced most of the moderate to shallow dipping secondary fractures and veins. Shallow dipping lithological controls as well as moderate to shallow dipping fractures and veins combine to impart a strong subhorizontal distribution to gold mineralisation (Figure 5).

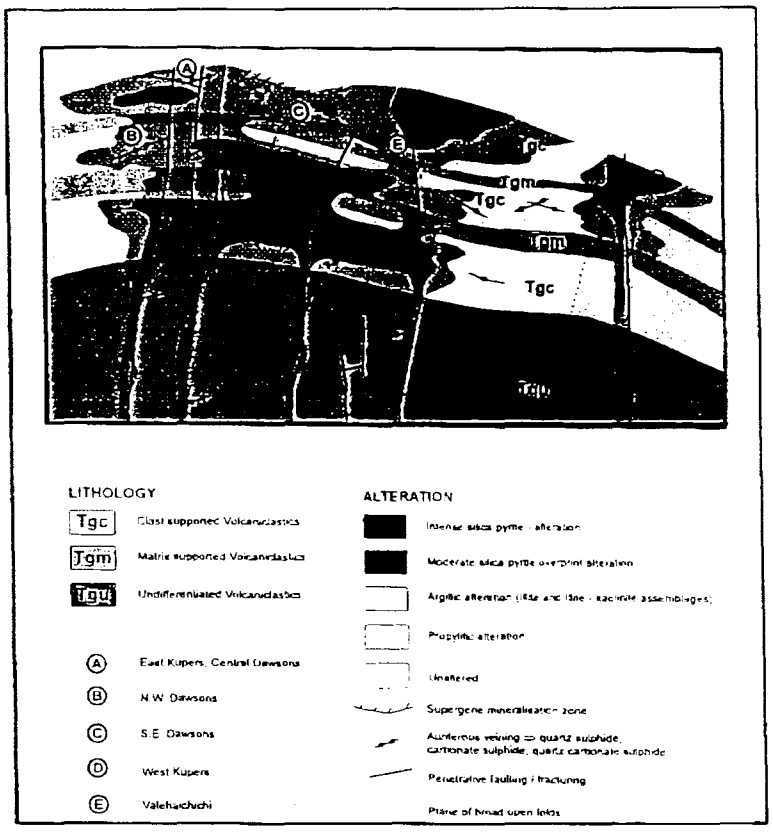

Figure 5: Schematic Mineralisation Model

Gold mineralisation at Gold Ridge is associated with argillic alteration and pervasive low order silica-pyrite alteration. High gold grades are most frequently observed in the following:

- Zones of high order silica-pyrite alteration.
- Quartz, quartz-carbonate and carbonate-sulphide veinlets (pyrite > sphalerite, galena, chalcopyrite).
- Zones of intense illite-kaolinite-pyrite alteration that are often fractured, locally crushed, or brecciated.

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