CRUISE SUMMARY

RV FRANKLIN

FR 03/2000

Title

BINATANG 2000. Microbes from Hydrothermal Vents: Applications in Mining and Mineral Processing

Itinerary

Departed Cairns 0645hrs, Friday April 14 2000
Arrived Rabaul 0850hrs, Thursday 4 May 2000

Principal Investigators

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Honouring David Dekker who passed away 17th July 2000

Scientific Objectives

1. The principal aim is to collect samples from actively-forming seafloor hydrothermal deposits in the eastern Manus Basin, PNG, from which microbes will be extracted and cultured for use in a new CSIRO multidivisional research initiative "Biological Applications in Mining and Mineral Processing". Dr Franzmann leads this activity. These collections were authorised by a contractual agreement between CSIRO Exploration and Mining and the responsible government authority PNG BioNet.

2. A second objective is to deploy and test several deep-submergence geophysical sensors being developed in CSIRO to facilitate future seafloor mineral exploration and mining. This was led by Dr Dekker.

3. Finally, geological investigations arising from results of the PACMANUS cruises (1991-97) will be conducted (led by Dr Binns), including

- Surveys of two sites where there are strong indications of as-yet undiscovered hydrothermal fields
- A repeat survey of the exceptionally intense SuSu Knolls hydrothermal plume to delineate changes since 1993-1997 measurements
- Further collections of diffusely vented fluids using the VUNL (constructed for FR-09/97) at the Snowcap, North Su and South Su sites
- Photography of proposed ODP drill sites
- CTD -transmissometer surveys to test for possible hydrothermal activity near faults within sediment-filled grabens in St Georges Channel (en route from Cairns, if there have been no delays in transit)

Cruise Objectives

With *Franklin* positioned over known hydrothermal sites at PACMANUS, DESMOS, and SuSu Knolls (Fig. 1), rock, sulfide and sediment samples will be collected by

- Chain-bag dredge
- Smith-McIntyre grab
- Small gravity corer

All samples are to be brought on board as quickly as possible. After they have been examined and sub-sampled by microbiologists, they will be studied and sub-sampled by the geologists (on deck and in the container lab). Most samples will be preserved by freezing. No extensive culturing is proposed on board.

In addition, the microbiologists will take subsamples of fluids collected by VUNL (vent funnel, deployed on CTD cable) from above vent fields, and also samples collected within bouyant hydrothermal plumes using the CTD rosette/transmissometer. These will be processed and chemically analysed in the wet lab and chemistry lab.

Finally it is planned that lines or nets, to which will be affixed many small metal or ceramic plates for collecting microbes, will be laid within the vent fields using moorings, floats and an acoustic release. These will be released for return to surface a day or two later, and the plates preserved for study ashore. Geological or geophysical surveys will not be possible at a site while these collectors are in place.

Cruise Track

See Figures 1 and 2.

Cast-off Cairns	06:45 Friday 14th April 2000
Passed Jomard Entrance	09:23 Sunday 16th April
Commenced operations, St Georges Channel	01:03 Tuesday 18th April
Commenced operations, Bismarck Sea	18:54 Tuesday 18th April
Operations ended	20:12 Wednesday 3rd May
Tied-up Rabaul	08:50 Thursday 4th May 2000

Principal Scientific Equipment

- SIMRAD EA500 scientific sounder
- DGPS navigation (Fuguro Omnistar – Ashtec G8)
- Neil Brown CTD rosette with Seatech transmissometers (2) and Niskin bottles
- Recording Seabird SBE-19 CTD with Alphatrack-2 transmissometer
- Lister chain-bag dredges (2) with 500kg depressor weight
- Small gravity corer: 1 m, 120kg
- Smith-McIntyre grab
- Bottom-tow digital video camera system (Panasonic)
- Geoacoustics Geochirp sub-bottom sonic profiler
- Geometrics G880 Cs marine magnetometers (2)
- Trailed array of Wenner resistivity electrodes
- Bottom-tow computer logger
- Yeokal submersible data logger
- VUNL-2 – vent funnel for fluid collection at seafloor
- "Binatang Masin" (2), microbe collection moorings with extendable arms and pumped filters.

Results

Binatang-2000 (named from the *Tok* Pidgin word for "bugs") was a very different but most successful expedition for the participants, achieving all major and most subsidiary goals.

We demonstrated that with accurate ship handling and precision dredging at previously surveyed sites, voluminous samples of sulfide chimneys can be collected from which hyperthermophilic microbes formerly active at elevated temperature were

extractible. A more than sufficient quantity of such samples, plus microbes from lower-temperature deposits and from floc particles in buoyant hydrothermal plumes (especially the intense SuSu plume), were obtained by the microbiology party to supply the new three-year CSIRO multi-division research program on biomineral processing. Each conceivable kind of microbe-bearing material was sampled at least several times. Of particular interest were samples taken from the outer oxidising surfaces of apparently active chimneys, where relatively aerobic conditions are inferred. Some of these samples, protected in the interior of dredge hauls, were reported as being anomalously warm on recovery, while fluids trapped in others were distinctly acid. On-board optical microscopy demonstrated bacteria and archaea presence in these samples; this has since been confirmed by laboratory studies ashore.

Two moorings (*Binatang* Masins), with a variety of metal and plastic collector plates fitted to extendable arms, were each deployed twice during the cruise at four active hydrothermal sites. On recovery, the plates had not collected or retained any significant amount of microbial material dispersed from the vents. However, floc and ferruginous oxides were filtered from seawater by a small pump which operated at the bottom of the mooring unit for three of the deployments.

We also overcame many practical difficulties and successfully deployed to bottom a progressively more complex towed array of geophysical instruments and other monitors. Principal parameters measured included total magnetic intensity, horizontal magnetic gradient, resistivity properties and electromagnetic response of the sub-seafloor, sub-bottom chirped acoustic profiles, system orientation, depth, altitude, and ambient temperature. Compared to photographic tows on previous cruises, poor return signals from the altitude-measuring pinger created trouble in maintaining flying height, as a result of which some damage was caused to the instrumentation by minor collisions with bottom. This, fortunately, was repairable in all cases. Modifications to the ship's scientific sounder preventing automatic slaving to a printer meant that pinger altimetry data were often not recorded. This will compromise interpretation of some geophysical data.

An apparently faulty batch of flood lamp bulbs, and the commonly excessive flying height adopted for safety while altimetry problems were experienced, prevented video recording of the bottom traversed in most of the geophysical tows. However, the limited photographic record and more particularly our recordings of ambient temperature by a small CTD attached to the system proved that the geophysical array was accurately towed several times across the Roman Ruins active hydrothermal field, once across the Satanic Mills and Tsukushi active chimney fields, and once across the Snowcap field of lower-temperature diffuse venting. It was also towed across a field of hydrothermal deposits thought from previous cruises to be inactive. On two traverses, temperature anomalies were noted when crossing this site, formerly known as "*Field C*". This means we have established yet another active hydrothermal site (the seventh) at PACMANUS. In honour of our late colleague this has been re-named the *Dekker Field.*

As expected, the geophysical signals are mostly noisy. Processing and interpreting the enormous amount of data collected is expected to take most of the coming year. Except that flying height and damage to the resistivity array during collisions may

have affected electrical and electromagnetic measurements, we have conducted the first-ever successful deployments of a multipurpose geophysical array across active and inactive seafloor hydrothermal deposits. The nature of their geophysical signatures will not be known until processing is further advanced. Nevertheless, this exercise has established a significant level of experience to guide future CSIRO research related to exploration and assessment of seabed mineral deposits.

Among geological outcomes, a highlight receiving worldwide publicity in the print and electronic media was the chance collection of the largest sulfide chimney specimen ever recovered from a submarine hydrothermal site. Weighing close to a tonne and 2.7 metres tall, this structure named *Bikpela* (Big Fellow) is composed almost entirely of the zinc mineral sphalerite. Analysis of a typical specimen has revealed 53% Zn and 0.15% Ag. Irrespective of its size, the sample provides key evidence supporting our hypothesis that two hydrothermal fluids with very different compositions are contributing to the PACMANUS mineralising system.

In the first of the two prospective hydrothermal sites investigated away from PACMANUS, a systematic grid of 16 sediment samples was collected from West Su Basin, where a geochemically anomalous ooze cored in 1997 suggested presence of sediment-hosted hydrothermal activity. Two CTD tow-yos were also made to supplement 1997 casts. While the latter hint at a hydrothermal source located somewhere in the Tumbo volcanic edifice northwest of West Su Basin, the sediment samples on the eastern side contained the more abundant dark layers. Post cruise analyses of these are under way to test metal contents and the significance of organic material, possibly bituminous in some samples. Sandy layers in the sediments comprise clasts of both fresh and altered lava and phenocryst mineral grains very similar to those of the thicker "hyaloclastite apron" at SuSu Knolls. Some altered grains contain sulfides, which provide a possible alternative explanation for the previously detected geochemical anomaly. While no obvious sign of a sediment-hosted hydrothermal deposit was found, a program of geochemical and sedimentological analysis is intended on these samples to further elucidate the cause of the anomaly. A basic geoscience by-product will be a superbly detailed assessment of the recent sedimentological history of this small basin remote from terrestrial influences.

The second prospective area, northern Pual Ridge to the north of PACMANUS, was extensively surveyed with eight CTD tow-yos and six static casts. Results of these and nine casts over PACMANUS established that there is almost certainly a deeper hydrothermal plume in this vicinity (around 1750m deep), apparently separate from that of PACMANUS (1650m), as suspected from earlier cruises. Locations where critical measurements would establish this conclusively were identified for future attention. Three bathymetric features representing possible sources for the deeper plume were dredged. Two yielded andesite and rhyodacite lava respectively, with no sign of hydrothermal activity. The third (Northwest Pual) yielded vesicular dacite lavas showing a style of siliceous alteration not previously encountered in the Manus Basin. Although remarkable in itself and offering a new interpretation for a phenomenon ("quartz eye tuffs") known from ancient massive sulfide orebody environments, the third site was probably not the deeper plume source. Further

processing of CTD and hydrocast data will be conducted in an attempt to narrow down the true source for future investigation.

This laboratory work will include analysis of particulates filtered from seawater samples taken within the plume. Together with samples from PACMANUS and SuSu Knolls collected on this and previous cruises, we now have the material for a major study of hydrothermal plume characteristics in a back-arc environment. A hydrocast near the end of *Binatang-2000* in the Marmin Knolls region confirmed previous indications of a hydrothermal site in the vicinity, but it established convincingly that there was no brine pool above 3m from the floor of a distinctly enclosed basin within the Marmin volcanic edifice.

A remarkable change in orientation was observed for the intense plume emanating from North Su at SuSu Knolls. Within a period of only six days this appears to have rotated some 30° or more, implying major deep ocean turbulence. Exceptional video footage of billowing "clouds" was obtained while flying in and out of the plume, close to its source.

Dredging and grabbing of volcanic rocks and hydrothermal deposits at PACMANUS and SuSu, undertaken primarily to collect microbes, provided no major geological surprises. Interesting recoveries included:-

- exceptionally cupriferous bornite-rich chimney samples as well as zincian *Bikpela* from Roman Ruins
- nontronite and Fe-oxyhydroxide deposits from Roman Ruins and Rogers Ruins, possibly representing the mounds upon which chimneys are built
- mineralised gastropods encrusted with Fe and Mn oxides respectively from two sites in the Tsukushi field.

Native sulfur was more commonly encountered this cruise, as a consequence of the focus on hydrothermal sites. One operation at Snowcap recovered large samples of a submarine sulfur lava flow, possibly the first to have been identified on Earth although pools of molten sulfur were previously known from Japanese submersible dives at DESMOS to the east of PACMANUS.

For the first time we located *Sonne Pimple* exactly – previously it was only known from side-echoes to the north of PACMANUS. It is a 25m high andesite mound 300m across at its base, which rises to 1655m, the same elevation as the main crests of Pual Ridge. As a possible hydrothermal site, it deserves further examination.

More rhyolitic pumice ash beds were encountered in sediment cores from the eastern part of the Eastern Manus Basin, but none were found in the west, which precludes an earlier hypothesis about their source on the westernmost extensional fault. A fragment of buried wood suitable for radiocarbon assessment of sedimentation rates was found, the first in 57 sediment cores from the region

Five deployments were conducted with a re-designed funnel (VUNL-2) for sampling diffusely-vented fluids at hydrothermal sites by "pogo-ing" the system and collecting waters by Niskin bottle when temperature anomalies were seen. Both microbe collection and geochemical studies of the fluids were intended. Lasting up to nearly 6

hours, these deployments proved both exhausting and frustrating. Interesting sites were indeed encountered but too often the sampling system failed or the anomaly vanished before the system could be lowered and triggered. However one anomalous sample each at Snowcap (turbid with detectable H_2S) and North Su was collected, and these will add to the previous geochemical database for samples collected with VUNL-1 in 1997.

Because of the defective lamp bulbs which often failed spontaneously or after mild crashes, and the problems experienced on this cruise (but not previously) with pinger altimetry, no useful photography was acquired at proposed Ocean Drilling Program sites at Snowcap and Roman Ruins. This is not a serious issue, since previous photography has persuaded the ODP panels to approve Leg 193 at PACMANUS late in 2000 (a major outcome of the *Franklin* cruise series in the eastern Manus Basin).

Two sedimentary basins in St Georges Channel (between New Britain and south-eastern New Ireland) were tested by CTD and sediment corer on this cruise and as a piggyback activity on the preceding cruise FR02/2000. Neither showed obvious hydrothermal signals, but a core taken near the Wide Bay Fault bounding 3500m deep South George Basin has apparently bituminous layers which might represent hydrocarbon seepage. Laboratory studies have been initiated.

The greater detail in which geological results are reported above is a reflection of the fact they followed on from a series of four geological cruises to the area with *Franklin*, and four international expeditions involving CSIRO participants. In terms of technological potential, however, the microbiological and geophysical outcomes of the Binatang-2000 cruise, both representing first attempts, may well prove the more important in the longer term.

A number of technical problems were encountered early in the cruise. Mostly these were rectified without causing any loss of operational time, thanks to sterling efforts from CSIRO support staff and the ship's crew. Two persistent problems were erratic wire-out readings for the towing cable and difficulties with measuring and recording altitude of the geophysics package during bottom tows. The only equipment loss was the elderly Yeo-Kal submersible data logger, whose electronics were destroyed when it leaked on its first deployment. The weak links for several dredge hauls parted inexplicably during bites of less than 1 tonne tension.

Fewer macrofauna specimens, and no obvious new species, were collected during dredging operations on this cruise relative to some previous operations. The recoveries were frozen and sent from Darwin to CSIRO Marine Laboratories, Hobart where they will be identified and curated pending a decision on their ultimate transfer to a PNG collection.

Narrative

Arrival of scientists in Cairns commenced on Tuesday April 11th and equipment deliveries occurred during the week preceding sailing. One pallet from Hobart for FR03/2000 and several packages from USA for FR04/2000 had been lost. Thanks to great effort by Ron Plaschke, these were found and the last delivered to the ship late on the night before departure. A delayed shipment of chemicals from Sydney arrived about 10 minutes too late but was kindly transported to the ship by the pilot boat.

Friday 14th April: Day 1

Scientists having slept aboard overnight, Franklin cast off from Tropical Reef Shipyards on schedule at 06:45, and proceeded under pilot to the outer channel markers. After dropping the pilot, the ship anchored for about an hour while an oil leak in the engine was rectified. We then proceeded via Grafton Passage to commence a rough transit of the Coral Sea. A general muster was held at 10:30, followed by a safety address by the Master and a tour of the ship for newcomers.

Planning discussions and equipment preparation continued until strong SE winds and an easterly swell combined to cause confused seas that rendered conditions too uncomfortable for most scientists.

Saturday 15th April: Day 2

Continued our transit of the Coral Sea. As the wind swung to the east and then the northeast with abating strength, conditions improved and by afternoon preparations resumed. The first Science Meeting was held at 14:00. Leaders described their objectives and intended shipboard activities, and watches were decided.

Sunday 16th April: Day 3

With relatively calm conditions and excellent visibility of Louisade Archipelago scenery, we passed through Jomard Entrance at 09:23 and proceeded north to deep water near Pasamonte Island where trial operations were commenced.

CTD-Hydrocast Trial 1 without transmissometer was aborted when the CTD winch would not register wire out and tension correctly. This was repaired by Phil Adams while we continued steaming north.

CTD-Hydrocast Trial 2 started with a deployment to 250m but the rosette was returned to deck while the ship was re-oriented to prevent the wire drifting below the hull. A surficial southerly current of 1.5 kts caused difficulty in holding station and the rosette streamed out to starboard preventing any chance of correlation between wire-out and CTD depth. The operation became solely a test of leaks in the Niskin bottles, which were fired at the 750m salinity minimum. The microbiologists tested their new protocols on the recovered waters.

After some delays fixing the GO-block on the stern A-frame (which had been damaged in port), and also in finding suitable attachments for the beam and bridle system below which the camera cage and Geochirp were to be suspended, a flotation and balancing test was conducted of the front component of the geophysical deep tow system.

Geophysics Trial 1 involved placing the assembly over the stern while moving the ship ahead at 0.5 to 1 kt. The balancing of the system had been correctly set, but the combination was highly unstable, tending to tow with the beam highly oblique to the travel direction, and changing from side to side. After a burst of propeller power almost hurled the camera out of the water, the intended deployment to 100m as a pressure test was cancelled and the system returned to deck. Video footage of the deployment revealed a number of problems to be addressed.

The transit north was then resumed at full speed. At dinner, Jessie Wama's birthday was celebrated. At 18:30 a Science Meeting reviewed the operations and discussed the next day's plans.

Monday 17th April: Day 4

Transit continued across the Solomon Sea, in easterly wind and slight swell. Four heavy rain squalls in the early morning were followed by fine, sunny weather. Fire drill at 10:00. Equipment preparations included assembly of *Binatang Masins* (moorings with expandable collecting arms for trapping microbes at vent sites) and sediment corer, plus a major modification to the geophysical package whereby the main beam was fixed rigidly through the camera cage and the Geochirp suspended from it, replacing the cage tail fin. The GO-block was again removed, repaired and replaced. The scientific crew divided into three parties for training in the use of *trackPlot* and data logging, using dummy echosounder runs along the ships track. Lindsay Pender made some modifications to *trackPlot* based on the experience. The scientific sounder was noted to mark times some 48 seconds ahead of UTC.

To test the wire-out reading of the main GO-block, 200m of cable was streamed behind the ship. Although zeroed when the weight entered the water, readout was +30m when the weight returned. The tensiometer did not record. A larger eye was spliced on the end of the main cable.

Watches stood to at 14:00, commencing with a short Science Meeting. Equipment assembly continued, but insufficient daylight seemed likely for a planned trial deployment of the re-assembled geophysical package.

After traversing major fault blocks of the Solomon Sea plate, **Echosounder Traverse MES-27** started with a crossing of the New Britain Trench on the 150°20' longitude, then continued northwards between previous *Franklin* tracks. The trench floor appeared flat, at 8050-8056 metres depth.

Tuesday 18th April: Day 5

CTD-Hydrocast MH-63, with the old ORV transmissometer fitted, was deployed in 3500m-deep South George Basin near a graben at the foot of the Wide Bay Fault, to test for hydrothermal activity in a sediment-hosted environment. A giant but false 7% transmission anomaly at 750-800m was observed on the downcast but was absent from the upcast. A similar behaviour, subsequently shown to be an unexplained instrument malfunction (possibly in the temperature correction circuitry), was seen during Hydrocast MH-62 which had been undertaken on our behalf during FR02/2000 at North George Basin. Smaller 0.1-0.2% anomalies at 1550, 1700, 1820 and 2450m were deemed too high above bottom to be hydrothermal plumes. However they were sampled for later characterisation of particulates.

Sediment core MS-50 was taken nearby, just north of the graben, as a further test of hydrothermal activity. A relatively strong current to the west was encountered during this operation. The main winch tensiometer and wire-out meter failed completely during this operation, so the deployment was conducted using crossovers of direct and reflected signals from a pinger attached to the wire 100m above the corer. A 31 cm core was recovered, of brown ooze overlying 3 beds of dark grey sandy mud and clay. The sand appeared volcanic in origin. Two thin layers of black organic matter, possibly bituminous and indicative of an oil seep or hydrothermal cracking, occurred in the sandy unit. Laboratory analyses for base and trace metals indicative of hydrothermal activity will be conducted on this core.

Echosounder Traverse MES-28 was a short leg sailed westwards to recross the Wide Bay Fault, establishing that there is no offset on this structure.

Turning north, the foot of the fault scarp was again crossed, at the start of a transit up St Georges Channel. The flat floor of South George Basin deepened gently northwards on this line - a new observation. At 14:10 we rounded Cape Gazelle and swung into Blanche Bay to observe occasional fumerolic events on Tavurvur Volcano before continuing north. A brief stop was made over Tavui Caldera to successfully test the tensiometer and wire-out meter (fixed with parts from the hydro winch) by deploying a lead weight on the main cable. Several modern game-fishing boats were operating in the vicinity.

Geophysics Trial 2 tested flotation characteristics of the modified system, with the steel beam holding the GeoChirp now rigidly fixed to the camera cage. With the towing point over the centre of gravity, the system kited to one side, indicating the attachment should be moved forwards. The system was lowered to 500m as a pressure test of the video and computer housings and the CTD.

CTD-Hydrocast MH-64 commenced a series of operations designed principally to collect microbe samples from the diffuse venting sites of North and South Su, and the chimney site at Suzette. This single dip, about 800m east of North Su crest, was deployed to test for and sample the SuSu plume seen on previous cruises. Although the transmissometer again recorded a spurious downcast hump from 500 to 1500m, a narrow 15% anomaly was superimposed on this at 1195-1200m. This is between the

two 1996 plumes, and slightly lower than the single 1997 plume. Samples collected from the plume smelled of H_2S, and an archaea was noted in one filter.

Video Tow MCV-55 was a south-easterly "move and hover" traverse across the crest of North Su, designed principally to check for activity and to locate a suitable site for deployment of the first *Binatang Masin* (microbe-collecting frame). The camera frame had the GeoChirp sub bottom profiler (with hydrophone array) attached but no other geophysical equipment. Difficulties were experienced observing crossovers of the pinger signal, and in maintaining a good flying height since the direct ping signal was equivalent to about 8 metres on the sounder chart. Numerous crashes occurred. The video lamp blew after 1 hour. Zones of shimmering water, white and red deposits, plus temperature and transmission anomalies were recorded at the crest, which is bordered by 70m high scarps. The camera passed into thick fog – the North Su plume – after descending the south-eastern scarp to about 1200m. Two lumps of porphyritic dacite were recovered on the frame, which smelled of H_2S when brought aboard.

Wednesday 19th April: Day 6

In calm conditions, **Grab MG-36** tested the Smith-McIntyre grab and the reconstructed hydrowinch meters with a deployment at North Su to one active vent site on the quickly-calculated MCV-55 camera track. About 200g of dark grey gritty sediment, with shell fragments and native sulfur particles, variously described as smelling of H2S or ammonia, were recovered.

With a new ORV transmissometer as well as the North Ryde recording CTD-transmissometer fitted, **CTD-Hydrocast MH-65** was to be a repeat of MH-64 moved about 200m north, but it was aborted after an electronic short circuit.

Dredge MD-120 was a south-easterly haul aimed at the crest of North Su to collect microbial samples. It recovered a large load of weakly to moderately altered vesicular dacite with some ferruginous crusts and native sulfur blebs. When first lifting the depressor weight for this dredge, the steel eye broke out, having rusted through within the lead. The second weight was fitted, with a parallel chain for extra safety.

Grab MG-37 was intended to be a second test of a possible *Binatang Masin* site on North Su, but a transcription error in its waypoint led to its sampling a point about 800m east of Suzette. A full load of sediment with three layers was recovered: a thin layer of khaki ooze with undisturbed worms on the surface overlying laminated then massive dark grey silty sediment.

Two dump sites were established respectively east and west of SuSu Knolls
Dump A 3°48.5'S 152°08.0'E
Dump B 3°47.5'S 152°02.0'E
and residue from MD-120 was discarded at the former.

Dredge MD-121 was hauled southeast at the Suzette chimney site in order to sample microbes. After being briefly anchored, it recovered a modest load of gritty, sulfidic

sediment, live and dead gastropods (*Alviniconcha and Ifremaria*), and about 20 massive sulfide fragments, possibly from the one baritic chimney.

With a continuing smooth sea, **Grab MG-38** was a precise deployment at the site originally intended for MG-37 on North Su. It recovered a few small rocks and gritty sulfidic sediment whose particles typically had a white sulfur coating. An approximately 10% too low wire-out reading relative to depth was noted on this deployment – a problem requiring attention that evidently developed after MG-37.

Dredge MD-122 was hauled south-east across a known hydrothermal field on South Su. It returned after only one small bite with a quarter full of dark grey gritty and sulphurous sediment, layered in parts, plus a few pale ash layers, a fragment of altered dacite, and a bivalve.

Grab MG-39 was the first of a series to collect near-surface sediments from ***West Su Basin***, for geochemical and consequent studies to track down the possible sediment-hosted hydrothermal source of a Zn-Cu-Ba anomaly in MS-43 (PACMANUS-IV, 1997). A full load, with 15mm of khaki ooze overlying layered grey silty and sandy sediment was recovered. Planned deployment following this of the first *Binatang Masin* (microbe collection system) was postponed since transducers for its acoustic release, damaged during transport from Hobart, were being examined still. So **Grabs MG-40 to MG-47** were undertaken covering a grid in West Su Basin. Comparable stratigraphies to MG-39 were recovered, some with a bituminous organic layer at about 10mm depth.

Thursday 20th April: Day 7

By early morning *Binatang Masin* was still not ready, so we decided to conduct a trial geophysical tow in West Su Basin.

There was about an hour's delay while final adjustments were made to the geophysical package consisting of the camera cage and GeoChirp profiler linked by steel beam. Magnetometers and the resistivity array were not attached. After aborting the first deployment since the pinger had not been turned on, **Geophysics Tow MP-01** was conducted easterly at approximately 1 knot across the floor of West Su Basin (depth 2100m). On entering the water the system appeared to be towing correctly. A lag of the system behind ship of 352m was calculated at the "second cross-over" (1288m depth). Approaching bottom, great difficulty was experienced recognising the reflected pinger signal on the echosounder monitor. In case the towed system was kiting beyond the footprint of the broad-beam transducer, ships heading was changed either side of east, without significant improvement. The deployment was eventually terminated because we had no idea where the system was towing relative to the ship and the seafloor. On recovery, the video lamp had blown but the pinger was operating. In retrospect, the CTD record indicated the system never approached closer than 50m to bottom. A faint transmissometer anomaly at 1230m during the return to surface recorded the SuSu plume about 5 km west of North Su. The Yeo-Kal submersible data logger had been attached to the camera cage for this operation as well as the North Ryde CTD. However the former leaked and its circuitry was destroyed, so the intended cross-calibration of depth and temperature measurements

by the two instruments was permanently frustrated. Post-processing of the tow navigation instrument indicated a 30-45° yaw during the tow.

Sediment core **MS-51** was deployed very accurately at the selected *Binatang Masin* mooring site on North Su, intended to acquire a subsurface sample. No core was recovered, but 100-150 gm of rock chips were caught, mostly moderately altered dacite with native sulfur. A few apparently abraded fragments of very altered dacite with sulfides were also present, implying that some transport of material has occurred on the surface of North Su. Wire-out reading on recovery was –57m, indicating a further problem with the main GO-Block.

Because this result, relative to the photography of MCV-55, suggested the MS-51 site was northwest of the vents, **Grab MG-48** was deployed about 60 metres to the southeast – the aim being to sample the selected site thoroughly before it became sterilised by the *Binatang Masin*. It recovered only about 20 gm of fresh and altered dacite plus fragments of native sulfur, so may not have been offset sufficiently far.

Having achieved the near-impossible in repairing a damaged acoustic release, the first *Binatang Masin* mooring, **MBM-01**, was dropped on target at North Su. Its recalculated position assuming vertical fall – *3°48.045' 152°06.113'* – was about 140 metres southeast of the crestal hydrothermal field, a little further than intended but nevertheless within the very intense plume observed at the end of MCV-55. Later, however, that plume was found to have moved to a north-east direction.

Dredge MD-123 was hauled southeast across the Suzette chimney field to collect more samples for microbe extraction. After becoming anchored briefly, presumably on a chimney, an excellent haul was returned of about 1 tonne of sulfidic sediment and numerous chimney fragments. The latter were dominated by chalcopyrite-bornite, with dark orange-brown oxide surfaces that were extensively sampled for aerobic microbes.

CTD-Hydrocast MH-66 was a single dip to sample the SuSu plume, placed about 300m SE (down-current?) of the crest of North Su, using the new ORV transmissometer and with the North Ryde CTD and transmissometer also fitted. Both instruments recorded an extremely strong transmission and relatively thick anomaly (25% on ORV, 18% on North Ryde instruments) from 1200 to 1270m, possibly with a second plume or nephel layer at 1300-1308m which was only 14-22 metres above bottom. Unfortunately the CTD did not acknowledge when Niskin bottles were fired, so the cast was terminated and samples discarded with the intention of repeating the dip. However when returned to deck the cause of the problem was not obvious, so after discarding excess material from MD-123 at Dump B we commenced a transit west towards PACMANUS with the intention of sampling the intervening sediment basin *en route*.

Friday 21st April: Day 8 (Good Friday)

Gravity Core MS-52 was taken on the south-eastern side of the large basin south of DESMOS, for stratigraphic comparison with cores on the western side and to check

for the presence of ash layers. The pinger was attached 100m above the corer. Good direct and reflected signals were obtained, confirming that the problems experienced on MP-01 were not caused by a faulty pinger. A 34 cm core was recovered of brown to greyish ooze, with a pale ash layer at 31 cm.

Dredge MD-124 was the first operation at PACMANUS for the cruise, a southeasterly haul aimed at collecting microbes from chimneys on the fringe of the Snowcap diffuse hydrothermal field, proposed site for the second *Binatang Masin* deployment. The site was observed by Chris Yeats on *Shinkai 2000* in 1998. After two good bites, the haul consisted of two parts, an early recovery (back of chain bag) of altered dacite and sulfide-bearing breccias with mussels, galatheids and tubeworms, and fresh glassy dacites at the front of the bag being collected late. Many samples of the latter auto-spalled on deck. Altered dacites were of two types, hard and soft, with some composite samples.

Two dump sites used on previous cruises, plus a third, were defined for excess material from operations in the PACMANUS vicinity:

Dump C to west	*3°43.0'S 151°38.0'E*
Dump D to west	*3°42.7'S 151°37.0'E*
Dump E to east	*3°45.5'S 151°41.8'E*

CTD-Hydrocasts MH-67 and 68 were each single dips placed down-current (NE) of the Roman Ruins and Snowcap hydrothermal sites respectively, to confirm activity and to collect microbes and geochemical samples near the "eye" of the PACMANUS plume as defined by previous cruises. The new ORV and North Ryde instruments were installed. Transmission anomalies of 0.3 and 1.8% respectively were recorded near bottom at 1660m and 1560-1670m respectively. The three operations conducted with both CTD-transmissometer assemblies show the uncalibrated North Ryde Alphatrack transmissometer yields anomalies that are 78% those of the ORV Seabird instrument, starting from different background values (77 versus 88% transmission). At 1000-1670m, depths measured by the North Ryde Seacat CTD are 99.6% those of the ORV's Neil Brown instrument. These cross-calibrations being consistent, the North Ryde unit was not attached for subsequent hydrocasts. A short transit was made to dump site C to dispose of excess material from MD-124.

To collect further microbe samples, **Grab MG-49** was deployed very accurately close to the MD-124 site for proposed *Binatang Masin* mooring. It recovered a quarter-full intact load of gravely to sandy sediment, smelling strongly of H_2S, with two 15cm tube worms upright on the surface. The sediment was composed of pale altered dacite and dark sulfide grains, mainly pyrite, plus some glassy grains.

Dredge MD-125 was aimed at a nearby point, another possible mooring site defined by submersible photography. After only weak bites it returned two kinds of material, fresh dacite glass and large samples of an unusual vermicular material with yellow sulfur veins which, on later examination proved to be pieces of a formerly molten sulfur lava flow. What appeared to be veins were crustiform crystals of pure sulfur, while the dark vermicular interior was the chilled margin grading into impure crystalline sulfur. This may be the first recorded submarine sulfur lava on Earth! Severe errors in the wire-out readings were again experienced.

Grab MG-50 aimed at the same site, returning a quarter load of fresh glassy dacite fragments in brown ooze, with two worms on the surface. Excess material from MD-125 was then dumped at site C, after which the GO-Block was removed to repair the wire-out metering. Minor repairs to the CTD were also required, so at this stage we were restricted to grab operations.

Grab MG-51 was aimed at an actively venting field of Fe-oxyhydroxide spires near the Tsukushi site, photographed by Chris Yeats in 1998. It returned almost empty, with a few grams of brown ooze. A repeat deployment was deferred because the crew were working on the GO-Block. Meanwhile, we steamed slowly to the next hydrocast site as the CTD was readied for deployment again.

CTD-Hydrocasts MH-69 and MH-70 were single dips, deployed under clear conditions with negligible wind and current. They straddled the MH-67 site in order to define the direction in which currents were carrying the PACMANUS plume. Only small transmissometer anomalies were observed, about 0.3% in MH-69 at 160m and 0.5% at 1670m in MH-70. These results were to some extent inconclusive.

Saturday 22nd April: Day 9

Allowing time overnight for the main GO-block to be replaced, **CTD-Hydrocast MH-71** was the first tow-yo of the cruise, run in an east-southeast direction from the north-eastern arm of Pual Ridge to Yuam Ridge. This and subsequent tow-yo's in the northern Pual Ridge area were intended to survey a deeper plume detected on previous cruises, in order to establish whether it was separate from the PACMANUS plume, and if so to delineate its likely source. A pinger was attached to the cable as a back-up in case of altimeter malfunction, which proved a mistake since the cable was consequently kinked and needed to be re-terminated. Moderate transmissometer anomalies were observed in the valley between the two ridges.

Grab MG-52, a repeat of MG-51, was aimed at a field of Fe-oxyhydroxide spires near the Tsukushi chimney field, observed by *Shinkai-2000* submersible. It recovered a little brown ooze, and thirteen hairy snail shells (*Alviniconcha*) thickly covered with black manganese oxide crusts.

Dredge MD-126 was a precision operation commenced in very calm conditions after a wind change. It was aimed at recovering more chimney samples from the Roman Ruins field. After landing slightly off target, about 40m southwest of the intended position, it was hauled in a south-westerly direction. Following a number of good bites not exceeding 0.8 tonnes, it returned upended with the first weak link (5/16'' bolt) broken and the second (1/4'' shackle) severely deformed. Recovery included a large segment of glassy dacite sheetflow with upper and lower surfaces, smaller fragments of the same, around 6 fragments of old sulfide chimney clogged with Fe oxide (probably from the basal mound), one chimney fragment broken from a larger structure, and a 15cm lump of Fe-oxyhydroxide with filamentous-granular texture. Presumably we skirted the edge of the chimney field. The new GO-block used for this operation appeared poorly calibrated for wire-out measurements, ***true wire-out***

being 1.12 times the nominal value on the meter (this calibration factor was confirmed and not changed significantly for the remainder of the cruise).

Grab MG-53 aimed at another possible *Binatang Masin* site on Snowcap, identified by *Shinkai-6500* submersible, expecting altered dacite and possibly bacterial mat. The jaws were held part open by a piece of dacite, so only a small load of glassy dacite, dark brown mud, and an abraded pumice pebble was recovered. The deployment was accurate so this unexpected result downgraded the site.

Geophysics Tow MP-02 was conducted without the video camera since the lamp problem had not been solved, and without the magnetometer system which was still being assembled. It provided the first experience of deploying the resistivity array. It was designed as a northeast to southwest tow along the crest of Pual Ridge, expecting to cross a previously photographed inactive hydrothermal site ("Field C", re-named Dekker Field after the cruise). An improved reflected pinger signal was received, allowing better flying, although the ping length had not been reduced to its shortest setting. Flying height varied from a few metres to 20 metres. One crash was well recorded by the inertial navigation package (dekkermeter). Although Field C was apparently crossed, no temperature anomaly was recorded. The North Ryde transmissometer failed early in the tow.

MBM-02, mooring of the second *Binatang Masin*, was successfully achieved on the Snowcap diffuse hydrothermal field. The recalculated position (*3°43.684'S 151°40.192'E)* is close to the MD-124 and MG-49 positions and to an outcrop of altered dacite with shimmering vent observed by *Shinkai-6500* submersible, so the mooring was perfectly positioned to collect ambient microbes.

Dredge MD-127 was another attempt to collect active chimneys from the Roman Ruins field. It was accurately placed near the field centre and hauled in a southeast direction. On hauling it soon became anchored and remained so for 1 hour 45 minutes of attempts to release it while the ship was moved back over the deployment position. On recovery, the weak link was intact but the cable was severely kinked for 50m above the dredge. In retrospect, extra cable was paid out too fast once the dredge had hit bottom, and it probably looped around a giant chimney which acted as a bollard. Discussions were held regarding procedures to avoid this happening (see MD-128). A few fragments of oxidised chimney and one very fresh chalcopyrite-bornite chimneylet, plus galatheids, a white shrimp and a red prawn were recovered in the dredge bag.

CTD-Hydrocast MH-72 was another single dip placed to extend the line of stations designed to assess direction in which currents were carrying the PACMANUS plume. Another 0.3% transmissometer anomaly was recorded at 1638m depth, similar to other dips on the line, so the results were again equivocal.

Sunday 23rd April: Day 10 (Easter Sunday)

CTD-Hydrocast MH-73 was the second tow-yo in the plume survey at northern Pual Ridge. With northwest winds and storm activity, it was sailed from southeast to northwest. Two distinct levels of plume, 1680 and 1775m approximately, were

recorded and sampled. An illuminated passenger vessel passed close during this operation.

Allowing time to reterminate the main cable after removal of the damaged section, **CTD-Hydrocast MH-74** was another traverse in this series, placed closer to PACMANUS. A wind change to strengthening easterly required a change of waypoints but a southeasterly haul was achieved. Dual transmission anomalies becoming weaker and more confused eastwards were again observed. Following this operation, during which a whale was sighted, the damaged cable from MD-127 were discarded at dump C.

Geophysics Tow MP-03 was sailed magnetic east (098° true as read from a chart, although the subsequent AGSO 2000.0 Reference Field indicates 096° decreasing at 0.5° per year) across southern Pual Ridge to intersect MP-02 at inactive hydrothermal Field C (Dekker Field). All equipment except the magnetometer was installed. Difficulty was again experienced recording a good reflected signal of the pinger, and the tow was mostly flown too high for photography (unfortunately as the lamp did not blow). Both the camera and dekkermeter indicated this tow flew with a considerable yaw for some unknown reason. A small 0.05°C temperature anomaly suggestive of activity was recorded by CTD when the estimated system position was *3°44.10'S 151°39.80'E*. This is on the western fringe of Field C (Dekker Field), about 300m east of its presumed centre. The transmissometer was inoperative.

A trial shallow dip of the new **VUNL-2** vent funnel attached to the CTD cable was conducted. The Niskin bottle fired on command, but the system hung slightly off vertical so instruments were moved to balance the system.

Grab MG-54 repeated MG-51 and MG-52 as the third attempt to sample Fe-oxyhydroxide spires near Tsukushi, with its waypoint moved 20m north. The first attempt did not trigger the grab, nor did a second, **MG-54R**, during which 15-20 kt NE winds affected station-holding. These conditions forced postponement of a planned VUNL deployment. Adjustments were made to the trigger mechanism.

Dredge MD-128 was intended to sample chimneys from the Rogers Ruins hydrothermal field. Although deployed close to its intended target, it returned a quarter load of glassy black dacite-rhyodacite with ferruginous coatings and fracture fillings. The first weak link had broken, even though only weak bites were experienced.

Monday 24th April, Day 11

CTD-Hydrocast MH-75 was another tow-yo, sailed northwest on a line closer again to PACMANUS in order to survey the deeper North Pual plume. A complex variation in transmission profile was recorded, dominated by a 1% peak at 1750m.

Dredge MD-129 was another attempt to sample chimneys at Rogers Ruins. It landed about 40m west of its target and returned a modest load of glassy dacite very similar to that of MD-128.

The first deployment for this cruise of the new vent funnel, **VUNL MV-05**, covered a quadrangular area on the crest of Snowcap where submersible sightings of shimmering water were numerous. Good weather and expert ship handling allowed 12 "pogos" of the funnel, two of which registered temperature anomalies of 0.1°C (both with VUNL sensor and with the more sensitive recording CTD). The first, pogo 9, coincided with a side echo suggesting proximity to a rock outcrop (good places for vents). The second was sampled. The recovered fluid was slightly turbid and smelled of H2S (analysed at 0.06mMol/cubic meter). The filters were strongly coloured with brown particulates. Following this operation, excess rocks from recent dredges were discarded at site C.

CTD-Hydrocast MH-76 was a single dip placed just northeast of the Satanic Mills, hydrothermal site. It was intended to test the likely "eye" of the PACMANUS plume. A triple-layer plume was recorded, with three peaks each about 1% intensity at 1588, 1630 and 1659m depth (bottom at 1682m). All peaks were sampled.

Geophysics Trial 3, a test deployment of the magnetometer assembly, followed to confirm its stability and flotation characteristics. Shortly after demonstrating suitable flotation, the magnetometer package was damaged in the propeller wash during an unexpected surge to keep the ship on station. It was recovered safely and repairs initiated.

Geophysics tow MP-04 was intended to trial the complete system with an easterly-flown crossing of Pual Ridge repeating the MP-03 traverse. Lacking the magnetometer, the traverse was moved 0.2 nm north to a "barren" crossing where no hydrothermal deposits are known. A replacement pinger with 2ms pulse was substituted, and this considerably improved the ability to fly the system close to bottom, although the tow was terminated when signal was lost, and recognising direct and reflected pinger signals at the start of the tow was essentially a matter of luck. Only 8 minutes of video was recorded at the start of the tow, before the lamp blew. This confirmed that good images were possible at 3m separation, but none at 10m separation using the new system. Significant and variable yaw was also recorded during the tow. No temperature anomalies were encountered.

Dredge MD-130 was another attempt to collect active chimneys for microbe extraction from the Roman Ruins field. During deployment to bottom, however, the ship drifted 300m northeast. After modest bites during a southeasterly haul, a third of a bag of vesicular dacite was recovered, including many excellent samples of lavas with "woody pumice" rinds. The samples were particularly prone to auto-fragmentation on deck, apparently caused by retention of high pressure fluids in fractures.

Tuesday 25th April, Day 12 (Anzac Day)

CTD-Hydrocast MD-77 was another tow-yo in the survey of the North Pual plume, towed southeast across Pual Ridge close to the position of Sonne Pimple. A single transmissometer peak was recorded throughout, strongest (about 1.2%) in the trough west of Pual Ridge where it was 1750m deep at the anomaly centre but shallowed to 1700m at its edges. Over the northern part of Pual Ridge there was a suggestion that

the plume shoaled to 1665m. This profile provided some support for the concept that topography significantly influenced the depth and intensity of the PACMANUS plume, but the critical evidence had insufficient spatial resolution.

Grab MG-55 was the fifth attempt to sample Fe-oxyhydroxide deposits from the spire site near Tsukushi. It instead recovered a sample of sphalerite-rich chimney with thick Mn crust, probably extinct, and a number of smaller Mn crust fragments.

Dredge MD-131 repeated MD-130 as a further attempt to sample active chimneys at Roman Ruins. It was accurately deployed, and left bottom after only a few nibbles while hauled southeast into a light easterly breeze. It recovered a one-tenth but exceptionally significant load. Besides pieces of a very fresh chalcopyrite-bornite-(enargite-sphalerite) chimney, probably from the one structure, and small pieces of stained and altered dacite, there was an abundance of blue-green (reduced) and red-brown (oxidised) nontronite, of clayey Fe-rich material, and of harder Fe-oxyhydroxide. These samples are thought to represent a section though the layered mound material distributed between chimneys. One chimney sample in the centre of the haul was reported to be anomalously warm on deck, and it yielded a condensate when placed in a plastic bag.

CTD-Hydrocast MH-78 was a single dip placed just down-current (northeast) from Roman Ruins in order to sample the plume for microbes and geochemistry. A 0.7% transmission anomaly close to bottom was detected and sampled.

Dredge MD-132 was another attempt to collect active chimneys at the Roman Ruins field for microbe sampling. The ship drifted 100m SE during deployment to bottom, and after gentle bites the haul consisted of boulders and gravel-sized fragments of vesicular dacite with glassy rinds, some with Fe-staining. At this point the EA-500 scientific sounder, which had become 30 seconds fast, was reset to ships GPS time.

Echosounder traverse MES-29 was the first (north-easterly) of two orthogonal tracks set to delineate the crest of Sonne Pimple, from previous cruises an elusive feature which is a possible source for the deep north Pual plume. The apparent crest was defined, and also a second, deeper "pimple" 0.7 nm to the north east. The sounder trace along the crest-line indicated a stepped series of subhorizontal terraces, confirming 1994 data from *Sonne*.

CTD-Hydrocast MH-79 was the first of two single dips placed northeast of Sonne Pimple (approximately 300m northeast) to examine any connection between the PACMANUS plume and the North Pual plume. A 1% transmission anomaly was detected at 1730-1735m depth, hugging the seafloor.

Echosounder traverse MES-30 was the south-easterly cross track to locate the crest of Sonne Pimple. This was accurately established as a 25 metre high feature rising above Pual Ridge, with crest at *3°42.548'S 151°41.476'E* at a depth of 1655m and about 300m in basal diameter. Surprisingly, since it did not show on 1990 multibeam bathymetry, the crestal depth is equivalent to the two main knolls of Pual Ridge. The traverse showed terraces at 1705 and 1755m on the eastern flank of Pual Ridge at this vicinity, but no equivalent features on the western flank. Also, a low knoll (another

lateral volcano?) was detected (crest 1790m) at the foot of the eastern flank. Camera tows MCV-30 and MCV-47 from earlier cruises passed 120m and 70m respectively west of Sonne Pimple crest at depths of 1690 and 1680m, while dredges MD-53 (east haul) and MD-99 (southeast haul) commenced hauling from positions 200m west and 65m southwest of the crest respectively. These results confirm that we have correctly characterised Sonne Pimple as a small andesite edifice. Although dredged samples possess manganiferous crusts indicative of nearby hydrothermal activity and a need for further photography, the crest is too high to be the source of the 1750m deep plume of northern Pual Ridge.

CTD-Hydrocast MH-80 was the second single dip near Sonne Pimple, placed about 400m southwest from this newly defined feature. A bottom-hugging plume (0.8%) was recorded at 1670m. Higher resolution surveys of this locality seem critical to resolving the relationship between the PACMANUS and North Pual plumes.

Dredge MD-133 was planned as another deployment to sample microbes from active chimneys. The original target was the Satanic Mills field, but operations this close (300m) to *Binatang Masin #2* were not permitted by the Master so it was moved to Roman Ruins. Recalling problems of MD-127, the target for this SE haul was placed near the SE fringe of the field. Nevertheless, on hauling, the dredge quickly became anchored. It was freed after 50 minutes of hauling and paying cable while the ship was manoeuvred back towards the hang-up point. Tension readings indicated a substantial load, and on emerging from the water a giant chimney was precariously balanced across the yoke of the dredge. It was quickly and carefully brought inboard by bosun Billy Highes and winchman Graham McDougall. The end of the chainbag was draped over the chimney top, so we achieved a bullseye. Descent of the lead weight to one side evidently forced the dredge yoke down the chimney. The chimney, named ***Bikpela Binatang*** *(Big Bug)* or, subsequently, just ***Bikpela*** was a tapered cylinder 2.7 metres long, 2.0 m in circumference at the base and 1.3 m at the top. Its weight, estimated by the Master at 800kg was later measured at RAAF Darwin (damp) as 970 kg, implying a mean density of 1.5 gm/cc. The chimney was composed mainly of pale sphalerite, and had a thin black Mn oxide crust. Fluid dripping from the chimney on recovery was sampled for microbes and geochemistry. Its acidity (pH 5.8 near the chimney centre, 6.1 near top) indicated the structure was active. No smell of H2S was noted. The chimney possesses lateral fluting of the "beehive diffuser" type and lacked a central conduit. Small orifices were present, however, on some lateral protuberances. The basal fracture on which the chimney broke was brightly coloured with orange-red and yellowish Fe oxide staining. Fragments of glassy volcanic indicated the chimney was basically torn out by its roots and not broken off. Microbe samples were taken from many locations on the chimney, and also from its interior using a cordless electric drill. The chimney was removed from the dredge yoke using a sling and the ship's crane, then stored at the starboard scupper on wooden pallets, wrapped in cook's cheesecloth and plastic sheet. It was dampened down with seawater every few days until the ship berthed at Darwin after FR03/2000 and FR04/2000. Small pieces of stained dacite, several live gastropods and some galatheids were present in the chainbag of the dredge.

Wednesday 26th April: Day 13

Geophysics Tow MP-05 was towed west across the Roman Ruins site, with no camera or magnetometers fitted. Deployment to bottom was accomplished quickly and good reflected pinger signals allowed relatively easy flying, averaging 10m above bottom. To make sure Roman Ruins was reached, ships speed was increased half way through the tow to 1.5 kt, but this caused the pinger signal to deteriorate. Pronounced temperature anomalies (to 0.6°C) were encountered towards the end of the tow. Assuming a 350 metre lag, this was the Roman Ruins site. Unfortunately, altimetry records for the crossing were lost because the printer had not been phased down with the monitor display. On recovery, the first float of the resistivity array was entangled with the GeoChirp.

CTD-Hydrocast Tow MH-81 was a southeasterly tow-yo placed to cross the northeastern-most part of Pual Ridge. This showed two main levels of plume, one at 1680m persisting for the whole tow, and one at 1750-1780m in the central section over Northeast Pual Ridge. The strongest anomaly, 2% at 1750m occurred on an upcast close to two small rises on Northeast Pual Ridge. Filters obtained on this tow had a more yellow deposit than previous cast to the south.

Having commenced a transit back to SuSu Knolls to recover the first *Binatang Masin*, **Sediment Core MS-53** was taken from a small basin east of Umbo Knolls, to test for ash layers and metalliferous horizons. A 48.5 cm core was recovered, containing eleven clayey beds of which three were pale volcanic ash. A wood fragment recovered at 37.3-37.5 cm will provide a rare opportunity for radiocarbon dating and measurement of sedimentation rate.

Recovery of *Binatang Masin* **MBM-01-R** at North Su required both acoustic releases to be fired. The floats surfaced very close to the deployment position but drifted some 200m east before recovery. The recovery operation proceeded smoothly except for a shackle jammed in the main winch roller. Apart from some brown stains on the frame below the pump, the mooring appeared unexpectedly clean. The filter pump had leaked and only a small sample was recovered.

CTD-Hydrocast MH-82 was a single dip placed about 300m southeast of the presumed source of the plume from North Su, effectively replacing MH-66 for which the Niskin bottles malfunctioned. A 20% transmissometer anomaly was recorded, peaking at 1150m. A profile of samples was taken for microbial and geochemical studies. An eruption plume from Tavurvur volcano at Rabaul was observed during this operation.

Grab MG-56 was another sample point in the grid covering West Su Basin. Despite a somewhat unusual behaviour recorded by tensiometer, the grab returned half full of undisturbed sediment with worms standing from the surface. The surface material, unconsolidated volcaniclastic sand, was underlain by laminated mud and ooze with organic-rich layers. An SO_2 smell was reported by the microbiologists.

Geophysics Trial 4 over West Su Basin successfully tested the re-built and strengthened magnetometer system, which floated level just below surface with the ship proceeding between 0.5 and 1 knot. Recovery procedures using a block on the A-frame were also improved.

Grab MG-57 sampled another grid point in West Su Basin, returning half full with layered ooze, here with brown-khaki ooze overlying volcaniclastic sand. Dark organic-rich bands were again present.

Sediment Core MS-54 was taken at another sample point in the West Su Basin grid, on its southern margin close to the presumed transfer boundary fault. Despite an operational error which resulted in the corer being held only 8m above bottom before its final drop, 67.0 cm of core was retrieved. About 16 cm of unconsolidated volcaniclastic sand overlay clayey ooze with bituminous layers and a possible volcanic ash.

Thursday 27th April: Day 14

CTD-Hydrocast MH-83, a westerly tow-yo located just north of the presumed transfer boundary fault of West Su Basin, aimed at locating possible sediment-hosted hydrothermal activity. A 0.1% transmissometer anomaly at 1225m ascribed to North Su was observed in the east but declined rapidly. Another apparent faint plume at 1690m became progressively more intense westwards, peaking at 0.2%. Together with previous cruise results (MH-59, MH-60, MH-64) a source to the west for this latter plume is indicated, possibly within the Umbo to Tumbo volcanic edifice zone.

Dredge MD-134 was another attempt to sample microbes from chimneys at the Suzette site, hauled west into a moderate current. After becoming anchored with several 1.2 tonne spikes, the dredge returned with its first and second weak links broken. About 2 kg of black sulfidic silt, a few fragments of oxidized chalcopyrite-barite chimneys, and barnacles, a galatheid plus portions of tubeworm were in the fishnet bag.

Vent Funnel (VUNL) Deployment MV-06 followed, being a traverse on the north-western crest of North Su where MCV-55 had recorded hydrothermal activity. Three pogos were conducted, the last being sampled. A relatively steep gradient of temperature with depth confused recognition of temperature anomalies, but the Niskin bottle was fired soon after lowering to bottom, on the third pogo, following an apparent 0.2°C anomaly, having just climbed a 40m high scarp. The temperature anomaly dropped just before the bottle was fired, but possibly the desired fluid was nevertheless collected.

Tempted by these results, a second deployment **MV-07** was conducted using the same waypoints. Excellent weather and expert ship handling characterised this 5 hour operation, during which time the funnel was moved to and fro over the apparent crest of North Su. Twelve pogos were conducted. Several brief temperature anomalies up to 0.8°C (at the crest) were noted, though these declined when the funnel was lowered to bottom. The tensiometer recorded three brief hang-ups. On the final pogo a decision was made to collect an ambient sample, but frustratingly after such a long

operation the bottle did not fire. On recovery, the pinger mounting had been deformed, the Niskin release mechanism damaged, and the CTD cable kinked above VUNL, needing repair.

Following this exhausting operation, we transited to the DESMOS caldera to deploy *Binatang Masin No. 1* at the Onsen hydrothermal site. **MBM-03** accomplished this with great precision, the deployment site where the mooring was dropped being within 5 metres of the waypoint near the foot of the caldera wall.

Returning to PACMANUS, **Geophysics Tow MP-06** repeated the tow track of MP-05, with magnetometer attached as well as resistivity array and GeoChirp, but no video camera since the lamp failure problem had not been solved. The initial deployment into the water was a successful test of magnetometer flotation characteristics with newly-strengthened frame. The intended track was sailed accurately, and the system was well flown 10-12m above bottom initially, rising to 15-25 metres later to avoid collisions with chimneys. A pronounced 0.15°C temperature anomaly was recorded from 00:20-00:28hrs while crossing the Roman Ruins field, when the cage was 20-25m above bottom. A noisy light transmission anomaly (4-6%, at 1665 to 1675m depth) was also recorded here. Recovery of the magnetometer was somewhat precarious, requiring a better plan for future tows.

Friday 28th April: Day 15

CTD-Hydrocasts MH-84 and **MH-85** were single dips at north-east Pual Ridge to fill in the plume survey and help locate the source of the deeper 1760m plume. Both dips showed strong dual plume signals at around 1670 and 1760m, the deeper being stronger (approaching 2%). Water samples for microbiology and chemistry were taken across the plumes.

Dredge MD-135 was another attack on Roman Ruins to collect chimney samples for the microbiologists. A strong southwest current required a last-minute change from southeasterly to south-westerly haul. The tensiometer pattern was unusual and indicated a period of "rumbling" on bottom before actual bites. The dredge recovered a third of a bag of chimney fragments, mostly beehive structured but some with barite-lined orifices.

CTD-Hydrocast MH-86 was another single dip over far north-eastern Pual Ridge in the deep plume survey. A dual plume signal was again obtained, but this time the lower anomaly was less deep (1700m) and weaker than the higher (1650m). Samples were taken from the two peaks.

Dredge MD-136 was a final attack on Rogers Ruins before its planned sterilisation by *Binatang Masin*. Once more the recovery was of hackly dacite sheetflow, including a 0.5 metre lump. No sulfides were recovered, but a bluish bloom on the dacite cracks and vesicles suggests proximity to the vent field.

Recovery of *Binatang Masin* **MBM-02-R** from the Snowcap site was successfully conducted after having spent 6 days on bottom, although one collector arm did not fold back when the system was acoustically released off bottom. Small grains of

sulfides were present on the last two flaps of this arm, suggesting it may have rested against a chimney. The filter was well covered with tan deposit.

Geophysics Tow MP-07 was a south-westerly tow along the crest of Pual Ridge, placed to pass over Roman Ruins and to continue to crossing earlier east-west tracks. All equipment except the video camera was fitted. Two pronounced temperature anomalies were recorded, of 0.11°C crossing Roman Ruins (20:50h, 12m flying height), and 0.32°C crossing the Tsukushi field (21:42h, sounder record not preserved). A very noisy transmissometer low was spread across both these sites. Rough topography but no temperature anomalies were noted when crossing Field C. The system was deployed well and the track sailed accurately. A minor crash occurred (with a chimney?) while crossing Tsukushi, and this may have caused the magnetometer to overtake the cage. When recovered, the magnetometer was draped over the cage with tangled cables.

Saturday 29th April: Day 16

With the site no longer sterilised *by Binatang Masin*, **Dredge MD-137** was deployed on the Satanic Mills hydrothermal field and hauled to the southwest. Although accurately placed, there was one very strong bite, and the dredge returned with its weak link broken. Pieces of dacite and a few tubeworms were recovered in the bag. This operation was immediately repeated as **Dredge MD-138**, which recovered more dacite (some altered and with Mn crusts), plus several fresh Cu-rich chimney fragments possibly from the one structure. Some fresh sulfide lumps were reportedly unusually warm when picked from the centre of the load when upended on deck. Vent fauna was also recovered, including gastropods, galatheids, shrimp, barnacles and a scale worm.

CTD-Hydrocast MH-87 was conducted as a single dip providing more information on the deeper plume over northeast Pual Ridge. The dual plume anomaly at this site consisted of a stronger (2%) signal at 1700m underlain by a weaker one at 1750m. Plume peaks were sampled. Excess material from the two previous dredges was disposed at Dump Site E after this operation.

Following the success of MD-138, **Dredge MD-139** was yet another south-westerly haul intended to collect chimneys from the Satanic Mills site. It recovered a good load of dacite (some with Fe oxide staining), and a variety of chimney fragments. Microbe collection focussed on one large part-oxidised chimney with Cu-rich centre and Zn-Ba rich outer part, with an unusual outer coating of soft white material and a strong H_2S smell. The coating is possibly a sulfate mineral, and may explain the white colour of beehive chimneys as photographed on bottom.

CTD-Hydrocast MH-88 was a single dip placed southwest of Tsukushi to see whether bottom currents had removed any plume from that direction. Surprisingly, a quite strong (0.7%) plume anomaly was observed near bottom, peaking at 1608 metres. The plume peak was sampled.

With spare daylight before the deploying *Binatang Masin*, **Dredge MD-140** was again aimed at collecting deposits from the so far elusive Rogers Ruins field. Hauled

southwest and placed with accuracy, the haul was successful. A quarter-bag load of oxide deposits was recovered, including green nontronite, a khaki (nontronitic?) clay, and orange-yellow to brown Fe-oxyhydroxide deposit, some with black Mn crusts. A few cobbles of dacite with Fe-Mn staining were present, but no macrofauna.

Binatang Masin No. 2 was then deployed accurately onto the centre of the Roman Ruins site, as operation **MBM-04.**

Geophysics Tow MP-08 was next conducted, an easterly track designed to cross the Snowcap site. All equipment except the camera was fitted. With wind rising and a current setting to the northeast, some difficulty was experienced holding course and speed during the initial deployment, which had to be repeated after the magnetometer raft capsized. Difficulty was experienced obtaining suitable pinger signals, so deployment to bottom was slow and first contact was at about 1725m depth after the system had passed beyond Snowcap. The track then descended the eastern flank of Pual Ridge to about 1760m depth, crossing the Marker 14 site. No temperature anomaly was noted. The "Dekkermeter" navigation system indicated the cage experienced major yaw deviations while close to bottom. The transmissometer failed halfway after showing no anomaly.

Dredge MD-141 was aimed at a location on northeastern Pual Ridge where hydrothermal deposits had been photographed during PACMANUS-III in 1996, possibly a source for the deeper plume though probably a little too deep (1930m). Although not far from PACMANUS, a very different southerly-setting current required a last-moment change to a northerly haul. The dredge was placed accurately on target. After some gentle bites it became hung up, requiring a drift back to deployment site before recovery without breaking the weak link. A large haul of sloppy brown ooze with a high proportion of small lava fragments (talus or hyaloclastite) was recovered. On top of the haul were a number of bigger blocks of similar rhyodacite lava, presumably from the anchor site. Except for slight Fe oxide staining on one fracture surface, and a single bivalve, there was no evidence for hydrothermal activity.

Sunday 30th April: Day 17

CTD-Hydrocast MH-89 was another single dip in the "fork" of north Pual Ridge, extending the deep plume survey. The well developed plume showed a strong 1.5% plume anomaly at 1695m, and a weaker anomaly at 1740m. Both were sampled.

Dredge MD-142 was aimed at a low knoll on north-eastern Pual Ridge which was another possible source of the 1750m plume. After hauling north into the current, a half bag load of aphyric andesite sheetflow fragments with some khaki ooze was recovered. There was no evidence of hydrothermal activity. One sample contained a xenolith of porphyritic lava.

CTD-Hydrocast MH-90 in the fork area continued the survey of the deeper plume of northeast Pual Ridge. A broad (composite) 1.4% anomaly peaking at 1730m was recorded. The peak position was sampled. Excess dredge material and damaged

cable were dumped at site E after this operation, and the main towing cable was re-terminated.

Vent funnel deployment MV-08 was then conducted at Snowcap, within an area west of previous MV-05 and south of the MBM-02 site. Nine pogos were conducted during which five brief anomalies around 0.5C° were noted. A sample was attempted on the final pogo when there was a prolonged 0.1C° anomaly. Again, frustratingly, the bottle did not fire.

Dredge MD-143 was deployed on the Tsukushi site as a southwest haul, aiming to collect chimneys for microbiological and geochemical studies. The dredge quickly became anchored, apparently (from the sample recovered) on a large chimney. To free it the ship was sailed back over the deployment site. In a small 5 kg recovery, around 50 gastropods of various sizes and in various stages of encrustation by Fe-Mn oxides were recovered, together with fragments of Fe-stained dacite and a few sulfide chimney fragments.

CTD-Hydrocast MH-91 was a single dip placed further southwest from PACMANUS along the crest of Pual Ridge than MH-88, again attempting to close off the PACMANUS plume. The transmissometer yielded a false anomaly at 400-650m, symptomatic of a fault similar to that experienced with the old instrument (during MH-63 and 64), but a broad genuine 0.6% plume signal was recorded between 1580 and 1680m.

Dredge MD-144 repeated the attempt to sample the Tsukushi chimney site, also being hauled to the southwest. The dredge again became anchored, probably on a chimney, but was freed relatively quickly. It returned with a broken weak link, and a small 2kg haul of glassy dacite with Fe staining, and several fragments of sphaleritic massive sulfide. One dacite sample contained an unusual pale grey ooze in vesicles which proved especially rich in microbes.

CTD-Hydrocast MH-92 was a southeasterly tow-yo between Marmin Knolls and Pual Ridge to further examine anomalies recorded to the north on MH-77. A single-peak narrow plume at 1680-1700m was observed, strongest (1.3%) in the middle of the track.

Monday 1st May: Day 17

With increased confidence allowing a night deployment, back-to-back **Geophysics Tows MP-09** and **MP-10** were two west to east crossings of Pual Ridge at the positions of Field C (Dekker Field) and of Snowcap respectively, with a modified resistivity array providing higher resolution. The magnetometers were also fitted, but no camera or GeoChirp. The latter was still undergoing repair after being damaged on the previous tow, and the former was not used since the last remaining lamp bulb was being held in reserve. Tow MP-09 over Field C was successful, recording a 0.05C° temperature anomaly at 3:32:30 just after crossing the crest – approximately the same position as the anomaly of MP-03. Difficulty in recording the pinger signal was experienced on MP-10, and several crashes apparently occurred. The system returned with two resistivity electrodes torn off, and one guard rope for the magnetometer

broken. Dacite fragments were embedded in the magnetometer nosecone. No temperature anomaly was recorded over Snowcap, but the system may have been too high above bottom.

Following a transit east to SuSu Knolls, **CTD-Hydrocast MH-93** was intended as a single dip just southeast of the North Su crest, designed to resample microbes from the 20% plume near the site of MH-82. To our great surprise, only a small plume signal (0.5%) at 1120m was observed before the CTD approached close to bottom at 1185m. The CTD was raised to 700m and the ship moved about 250m further southeast for a second dip **(MH-93A)**. This also yielded only a small plume, so the CTD was raised to 1000m and the ship again moved another 250m southeast for a third dip **(MH-93B)**. Here the sharp plume anomaly had increased to 0.9%, still far less than the result obtained 5 days earlier. Speculation ensued regarding whether the North Su vents had ceased operation, since such a rapid change in deep current direction seemed unlikely. However to check the latter possibility, a grid of further dips was planned.

While a squall with 30kt winds blew up, a deck test was conducted of the response time of the temperature detector in VUNL-2. The time constant was measured at only 10 seconds, indicating the shorter pogos would be permissible in future deployments.

Dredge MD-145 was intended to be another sampling attempt on Suzette chimneys for the microbiologists, but the deployment was aborted when the dredge had been lowered to 500m, because the weather prevented holding station with sufficient accuracy. For the same reason a planned VUNL dip was cancelled, and we commenced the grid of CTD dips to test whether the North Su plume had changed orientation.

CTD-Hydrocasts MH-94, MH-95 and **MH-96** were located about 1 km from the crest of North Su, respectively to the northwest, northeast and east. The first two recorded only minor plumes at the North Su level (0.5%, 1.3% transmission anomalies) but the third located an intense 12% plume near 1175m. The results indicate that the North Su plume had moved clockwise some 30° to 45° during the week between measurements. Cast MH-94, which was about 500m southeast of Suzette, also detected a faint plume (0.3%) at 1450m, not seen on any other cast this cruise but strong in 1996. Samples taken from the upper plume peak in MH-94 and the intense plume in MH-96 (0.2ppm in water) smelled distinctly of H_2S.

Grabs MG-58 and **MG-59** collected sediment samples from two more points in West Su Basin for the geochemical survey. In the latter, 10 sediment layers were logged in a 105mm syringe-core, including several dark organic-rich layers.

Tuesday 2nd May: Day 18

CTD-Hydrocast MH-97 was a tow-yo of seven dips, extending the survey of West Su Basin further west from MH-83. The second last cast hit bottom on a ridge extending south from West Tumbo volcano. A faint plume was observed at 1650m, increasing westwards to 0.2% then falling slightly. The peak was sampled on the final cast. West Tumbo is the possible source of this plume.

Grabs MG-60 and **MG-61** collected two more sediment samples for the geochemical survey of West Su Basin.

Sediment core MS-55 was taken to establish stratigraphy in a small sub-basin west of West Tumbo volcano. An 80.5 cm core was recovered, with complex layering including two ash bands and numerous dark layers, possibly metalliferous.

Transiting to DESMOS with the intention of recovering the *Binatang Masin* deployed as MBM-03, a large rain squall was encountered with winds to 25 kts and choppy seas. These conditions were unsuitable so, with radar indicating calmer weather to the west, we proceeded to **MBM-04-R**, recovery of *Binatang Masin* at Roman Ruins, PACMANUS. Surfacing only 100m north-northeast of the deployment position, the collector was efficiently recovered. Although no floc or oxide was present on outer surfaces, or on the many pieces of rock and metal that had been added to the arms, the filter was thickly coated with brown material.

Returning to DESMOS where winds had dropped to 6 kts, leaving a slight swell, *Binatang Masin* **MBM-03-R** was also a successful recovery, again surfacing very close to the deployment point. One steel plate had been bent, but the filter pump had failed and no biomass was present.

Geophysics tow MP-11 was a north-easterly tow along the crest of Pual Ridge, designed to cross the Dekker site (Field C), then Snowcap and Satanic Mills, continuing then to link previous cross traverses near Roman Ruins. The video camera, CTD, magnetometers and resistivity array were installed, but no GeoChirp which was still not repaired. The camera operated well although much of the tow was flown too high. Increase in fauna was recorded crossing the Snowcap site. A prominent temperature anomaly (0.6°C) was recorded for some 30 metres when the system crossed high over the northeastern side of the Satanic Mills chimney field. Weaker anomalies occurred at recalculated positions between Satanic Mills and Snowcap, and about 100m southeast of Tsukushi. No anomaly was recorded crossing Dekker Field. The transmissometer gave faulty readings. On recovery, two electrodes were missing from the resistivity array, and fragments of dacite were embedded in one magnetometer housing.

CTD-Hydrocast MH-98 was a southeasterly tow-yo placed to join with MH-73 and plug the remaining gap in the northeast Pual Ridge plume survey. The transmissometer anomaly at around 1730m increased to a maximum of 3.6% near the eastern end of the tow, the highest value recorded in this survey. The "eye of the plume" corresponded closely to the site tested earlier, with no hydrothermal indications, by dredge MD-141.

Wednesday 3rd May: Day 19

With little time remaining, results of this NE Pual plume survey were evaluated and it seemed the only major unexplored candidate for its source was a ridge at the southern end of the north-western arm of Pual Ridge. Sidescan sonar imagery suggested this might be relatively younger than the main north-western arm. Accordingly, **Dredge**

MD-146 was hauled southwest into a moderate current along the crest of that target. After a series of gentle bites, the dredge returned with a large load of rather old-looking laminated rocks thought at first to be samples of basement, though this would have required major revision of our structural understanding of the region. Subsequent petrological study revealed these to be vesicular dacites showing an alteration style previously unrecognised in the eastern Manus Basin – vesicles were filled and groundmass glass replaced by tridymite (SiO_2 polymorph) along flow banding laminae. Apart from this unusual style of alteration, no other evidence of hydrothermal activity was present. The source of the deeper plume in the northeast Pual region remains unresolved. It may be near the end of camera-video tow MCV-29 made during 1996, an area deserving further study in future.

The remaining operations of FR03/2000 were in part dictated by the Master's request to move further from Rabaul and allow enough transit time to prepare the ship for arrival.

CTD-Hydrocast MH-99 was deployed into a small enclosed basin within the Marmin Knolls volcanic edifice. This had been partly tested by MS-1 in 1991 and MH-14 in 1993 as a site for possible accumulation of dense exhalative brines. However, the MH-14 tow-yo had not approached sufficiently close to bottom to rule out this possibility. In static MH-99 the CTD was deployed to 3 metres off bottom without detecting any indication of a brine pool. However, an unexpectedly strong 1.3% transmissometer anomaly at the top of a "plume fog" was recorded at 1660m. Combined with observations of earlier cruises, this suggests there may be present-day hydrothermal activity somewhere in Marmin Knolls, close to the site of MH-99.

Dredge MD-147, the last of this cruise, was deployed on the western slope of Kumul Ridge, a possible failed spreading ridge, to acquire samples for isotopic investigations into its mantle sources. After being anchored for 20 minutes the dredge was recovered with some 500kg of basaltic pillow segments with thin glass rinds. A little pale ooze was present in the sediment traps.

Finally, two sediment cores were taken from grabens near the westernmost extensional faults of the eastern Manus Basin. Besides providing material for stratigraphic and sedimentological investigations, these were intended to check for the thick ash layers expected if these were sourced from the apparently outcropping pumice dredged from the fault scarp MD-50 in 1996. Neither **Sediment Core MS-56** (70cm) in the westernmost graben, nor **Sediment Core MS-57** in the last but one graben (only 17cm) contained any obvious ash layer, casting doubt on the likelihood that the MD-50 scarp was a major source for ash layers in sediments.

CTD-Hydrocast MH-100 was intended to provide a reference profile of water samples from the westernmost part of eastern Manus Basin, remote from hydrothermal activity. It was also intended to test a new Seabird CTD acquired by the ORV Facility. With time running out, these plans were frustrated when the instrument failed to provide signals to surface, and the operation was aborted at 250m depth.

Thursday 4th May: Day 20

On completion of MH-99, the transit to Rabaul was commenced while scientists completed their packing of equipment and samples. The spectacular scenery of Volcano Peninsula was passed soon after dawn. The Rabaul pilot boarded at 08:00, and *Franklin* tied up at Simpsons Harbour at 08:50, to be greeted by FR04/2000 participants waiting on the wharf. Geophysical equipment and a selection of samples for the Geological Survey of PNG were off-loaded, but other equipment and samples remained on board for later discharge in Darwin.

Summary

Each of the Principal Investigators was highly satisfied with the outcomes of the *Binatang-2000* cruise (FR03/2000). We achieved some notable firsts by collecting microbes from hydrothermal vents using remote operations from a surface vessel, and by towing a prototype geophysical package across a sizeable hydrothermal field. These operations, and recovery of the *Bikpela* chimney, the largest ever returned to surface, have attracted worldwide attention to the capabilities of RV *Franklin* and to CSIRO research.

The hyperthermophilic microbe collections will provide plenty of future work for the new CSIRO research program on biomineral processing, where the ultimate aim is to develop cheap, safe and non-polluting ways to extract metals from ores, and perhaps to mine currently non-economic low grade ore deposits further down the track.

Data collected during deployments of the geophysical package will also provide much work ahead in processing and interpreting the results. Together with the experience gained, a considerable step forward has been made in positioning CSIRO to respond to the technological needs of a possible new industry. There is expanding commercial interest in the undersea mining of high grade polymetallic sulfide deposits, especially because this offers an environmentally more acceptable to large-scale bulk mining of low grade ores on land.

Contributing to the basic scientific understanding of hydrothermal ore deposits and to the use of this knowledge in land-based mineral exploration, and also to assessing the potential for economic ore deposits to occur under the ocean, the geological studies conducted during *Binatang-2000* have tidied up a number of "loose ends" remaining after the earlier PACMANUS I to IV program with *Franklin*. They have also provided tantalising indications that there are far more active hydrothermal fields in the eastern Manus Basin than we know so far. The results certainly justify planning further cruises to the region.

Acknowledgements

Once again, we are pleased to acknowledge the vital contributions made by the ship's officers and crew, and the onboard ORV Facility staff, to the success of this cruise - precision handling and efficient operation of the vessel, unflinching work on the

afterdeck and at the winch controls, maintenance and repair of instruments, and attention to the shipboard comfort of the scientists.

We are also grateful to Dr Lohi Matainaho of PNG BioNet, Ms Patricia Pepena of the PNG Marine Scientific Research Subcommittee, and Mr Tim McLennan of CSIRO for their invaluable effort to ensure that the objectives of this cruise could be achieved in an environment of increasing formal authorisation requirements.

Finally, we thank the Steering Committee of the ORV National Facility for granting this cruise, and all Facility staff who contribute to this exceptional Australian program.

Personnel

Scientific Party

Philip Adams	CSIRO Marine Research, Hobart	Electronics
Ray Binns *	CSIRO Exploration and Mining, Sydney	Geology
David Cousens #	CSIRO Exploration and Mining, Brisbane	Geophysics
David Dekker	CSIRO Exploration and Mining, Brisbane	Geophysics
Peter Franzmann	CSIRO Land and Water, Perth	Microbiology
Tim McConachy #	CSIRO Exploration and Mining, Sydney	Geology
Peter Nichols	CSIRO Marine Research, Hobart	Microbiology
Lindsay Pender ^	CSIRO Marine Research, Hobart	Computing
Mark Rayner	CSIRO Marine Research, Hobart	Chemistry
Jessie Wama +	Geological Survey of PNG, Port Moresby	Geology
Chris Yeats #	CSIRO Exploration and Mining, Sydney	Geology
Luke Zappia	CSIRO Land and Water, Perth	Microbiology

* Chief Scientist ^ Cruise Manager # Watch Captain + PNG Rep.

Ship's Crew

Neil Cheshire	Master
Arthur Staron	First Officer
John Morton	Chief Engineer
Ian Moodie	Second Officer
Greg Pearce	First Engineer
Andrew McLagan	Electrical Engineer
Bill Hughes	Bosun
Ron Culliney	Chief Steward
Gary Hall	Chief Cook
Terry Reid	Second Cook
Rod Heath	Able Seaman
Graham McDougall	Able Seaman
Simon Smeaton	Able Seaman
Phil French	Greaser

Ray Binns
Chief Scientist

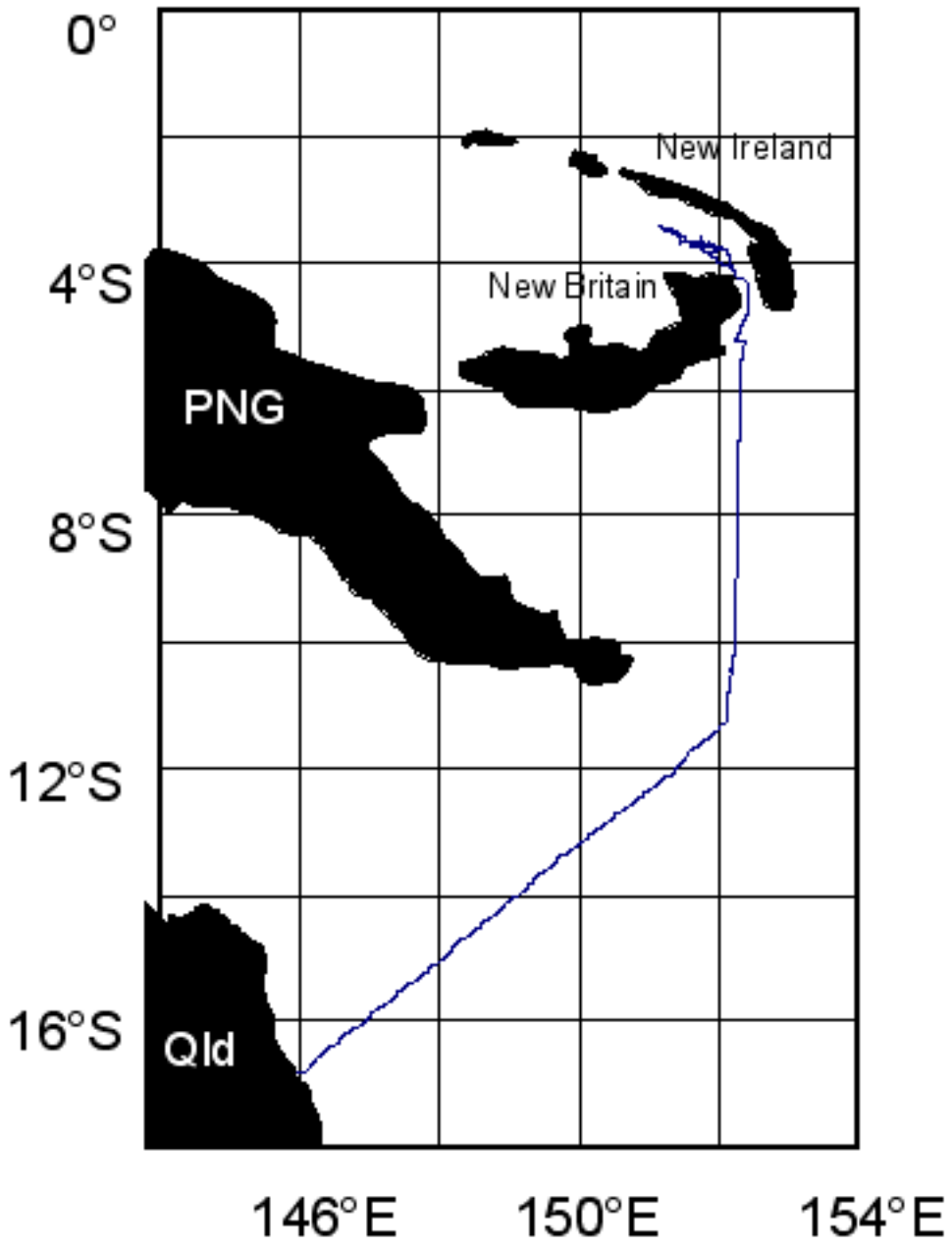

Fig. 1 Cruise track, FR-03/00

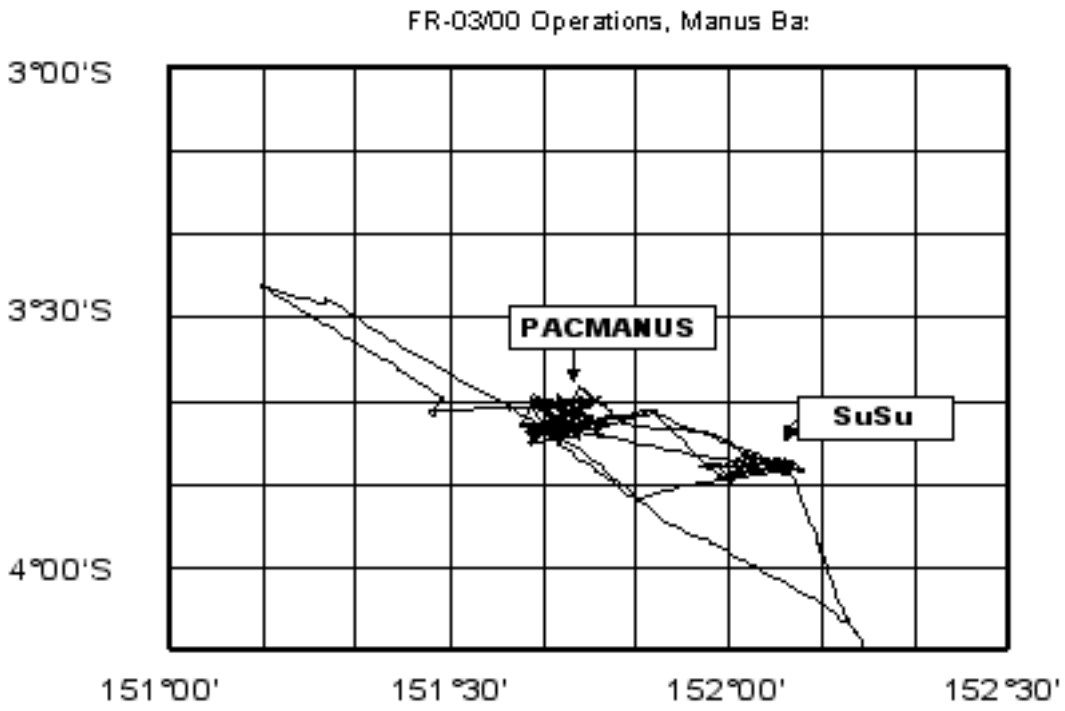

Fig. 2 Cruise track in the Eastern Manus Basin, FR-03/00

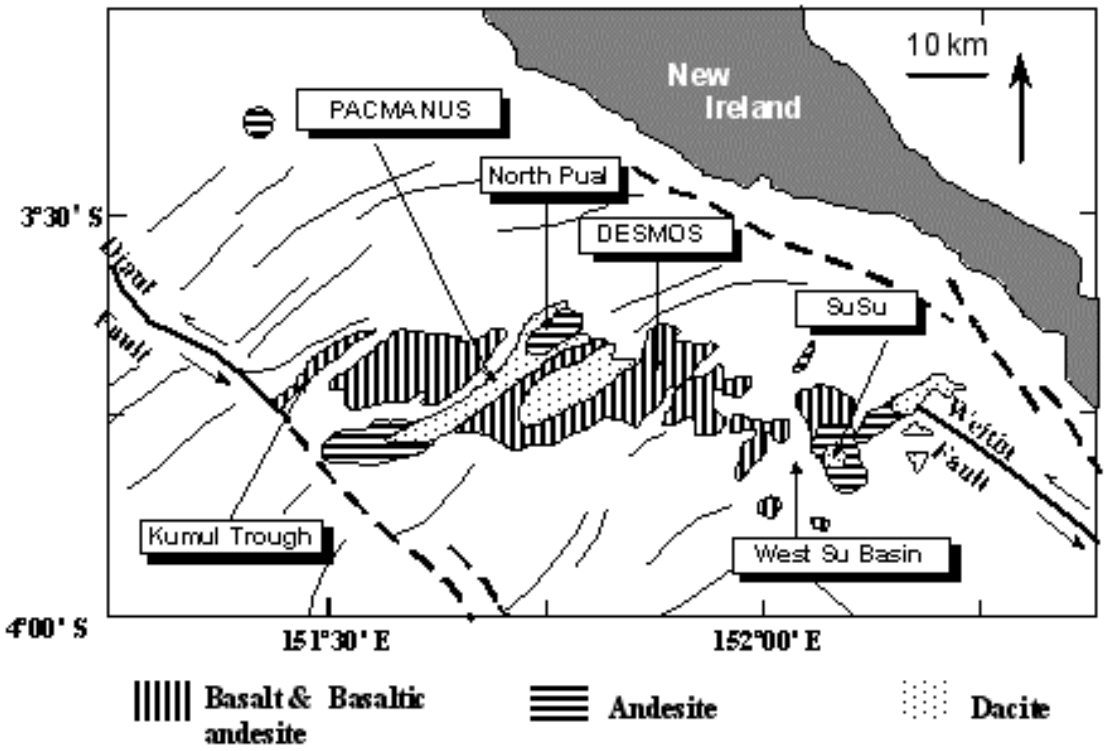

Fig. 3 Principal areas investigated during FR-03/00 in relation to seafloor geology, Eastern Manus Basin

APPENDIX: Station List

Positions cited are those of the ship. Times are local, GMT+10
Details of two piggyback operations conducted during FR-02/00 are included (MH-62, MES-26)

Dredges

Operation	*Date*	*Start time*	*End time*	*Start Latitude (S)*	*Start Longitude (E)*	*End Latitude (S)*	*End Longitude (E)*	*Start Depth (m)*	*End Depth (m)*	*Location*
MD-120	19/04/2000	4:06	5:08	3 47.910	152 05.930	3 48.150	152 06.090	1224	1240	North Su
MD-121	19/04/2000	8:17	9:28	3 47.390	152 05.664	3 47.467	152 05.642	1521	1525	Suzette
MD122	19/04/2000	13:14	14:29	3 48.560	152 06.250	3 48.80	152 06.350	1521	1525	South Su
MD-123	20/04/2000	19:43	20:41	3 47.330	152 05.610	3 47.62	152 05.670	1515	-	Suzette
MD-124	21/04/2000	5:49	7:03	3 43.676	151 40.161	3 43.907	151 40.350	1646	1729	Snowcap
MD-125	21/04/2000	14:04	15:05	3 43.683	151 40.165	3 43.885	151 40.390	1645	1735	SnowCap
MD-126	22/04/2000	8:47	10:19	3 43.236	151 40.498	3 43.585	151 40.261	1689	1653	Roman Ruins
MD-127	22/04/2000	17:58	21:10	3 43.230	151 40.473	3 43..261	151 40.540	1689	1688	Roman Ruins
MD-128	23/04/2000	21:30	23:09	3 43.149	151 40.408	3 43.133	151 40.805	1700	1663	Rogers Ruins
MD-129	24/04/2000	6:46	8:02	3 43.131	151 40.444	3 43.297	151 40.748	1701	1679	Rogers Ruins
MD-130	24/04/2000	21:28	23:18	3 43.193	151 40.485	3 43.191	151 40.759	1691	1662	Roman Ruins
MD-131	25/04/2000	9:35	10:46	3 43.246	151 40.488	3 43.477	151 40.738	1697	1716	Roman Ruins
MD-132	25/04/2000	13:05	14:07	3 43.148	151 40.464	3 43.299	151 40.768	1696	1665	Rogers Ruins
MD-133	25/04/2000	20:52	22:18	3 43.239	151 40.476	3 43.159	151 40.703	1690	1672	Roman Ruins
MD-134	27/04/2000	7:39	8:31	3 47.372	152 05.650	3 47.481	152 05.418	1521	1568	Suzette
MD-135	28/04/2000	8:05	8:53	3 43.250	151 40.498	3 43.413	151 40.348	1688	1667	Roman Ruins
MD136	28/04/2000	13:13	14:04	3 43.134	151 40.465	3 43.060	151 40.221	1700	1756	Rogers Ruins

MD-137	29/04/2000	0:55	1:55	3 43.532	151 40.444	3 43.793	151 40.091	1694	1667	Satanic Mills
MD-138	29/04/2000	3:20	4:30	3 43.599	151 40.325	3 43.812	151 40.112	1688	1671	Satanic Mills
MD-139	29/04/2000	9:34	10:22	3 43.603	151 40.336	3 43.815	151 40.119	1691	1673	Satanic Mills
MD-140	29/04/2000	13:10	14:01	3 43.142	151 40.448	3 43.220	151 40.388	1701	1688	Rogers Ruins
MD-141	29/04/2000	22:19	0:35	3 41.091	151 44.605	3 40.864	151 44.685	1922	1635	NE Pual Ridge
MD-142	30/04/2000	3:36	5:19	3 39.986	151 45.165	3 39.639	151 45.238	1804	1880	NE Pual Ridge
MD-143	30/04/2000	14:20	15:20	3 43.780	151 40.036	3 43.796	151 40.026	1669	1671	Tsukushi
MD-144	30/04/2000	18:16	19:56	3 43.776	151 40.016	3 44.082	151 39.572	1664	1651	Tsukushi
MD-145	01/05/2000	14:02	14:02	3 47.335	152 05.634	3 47.356	152 05.652	1509	1519	Suzette
MD-146	03/05/2000	5:35	6:29	3 40.396	151 41.913	3 40.741	151 41.574	1724	1841	NW Pual Ridge
MD-147	03/05/2000	10:38	12:13	3 41.490	151 27.839	3 41.207	151 28.255	2614	2550	Kumul Ridge

Grabs

Operation	*Date*	*Start*	*End*	*Start Latitude (S)*	*Start Longitude (E)*	*End Latitude (S)*	*End Longitude (E)*	*Start Depth (m)*	*End Depth (m)*	*Location*
MG-36	19/04/2000	1:13	2:00	3 48.04	152 06.11	3 48.05	152 06.08			North Su
MG-37	19/04/2000	20:03	21:12	3 47.12	152 06.06	3 47.06	152 06.08	1647	1650	North Su
MG-38	19/04/2000	5:03	11:22	3 48.00	152 06.06	3 47.97	1552 06.05	1159	1165	North Su
MG-39	19/04/2000	15:19	16:38	3 48.01	152 03.00	3 47.96	152 02.94	?	?	West Su Basin
MG-40	19/04/2000	17:04	18:13	3 47.50	152 02.50	3 47.50	152 02.51	2093	2093	West Su Basin
MG-41	19/04/2000	18:55	20:14	3 47.01	152 02.99	3 47.00	152 03.01	2073	2069	West Su Basin
MG-42	19/04/2000	20:50	22:13	3 47.00	152 01.97	3 46.97	152 02.00	2086	2087	West Su Basin
MG-43	19/04/2000	22:51	23:28	3 48.27	152 02.24	3 48.24	152 02.24	2092	2092	West Su Basin
MG-44	20/04/2000	1:52	3:01	3 47.51	152 01.48	3 47.50	152 01.50	2078	2078	West Su Basin
MG-45	20/04/2000	3:45	4:19	3 47.00	152 00.94	3 46.98	152 00.97	2049	2048	West Su Basin

MG-46	20/04/2000	5:40	6:15	3 48.00	152 01.00	3 48.00	152 01.00	2067	2069	West Su Basin
MG-47	20/04/2000	7:13	8:46	3 48.50	152 01.51	3 48.19	152 01.15	2088	2078	West Su Basin
MG-48	20/04/2000	17:19	17:41	3 48.02	152 06.11	3 48.03	152 06.10	1205	1185	North Su
MG49	21/04/2000	12:05	13:15	3 43.684	151 40.169	3 43.681	151 40.183	1642	1642	Snowcap
MG-50	21/04/2000	16:10	16:34	3 43.689	151 40.152	3 43.690	151 40.157	1643	1643	Snowcap
MG-51	21/04/2000	18:40	19:05	3 48.803	151 40.021	3 43.797	151 40.031	1662	1666	Tsukushi
MG-52	22/04/2000	6:12	8:03	3 43.782	151 40.025	3 43.772	151 40.032	1666	1666	Tsukushi
MG-53	22/04/2000	10:48	11:50	3 43.684	151 40.226	3 43.698	151 40.214	1645	1666	Dive 297 Site
MG-54	23/04/2000	18:10	19:34	3 43.761	151 40.021	3 43.769	151 40.034	1670	1668	Tsukushi
MG-54R	23/04/2000	19:55	20:30	3 43.771	151 40.030	3 43.722	151 40.009	1666	1653	Tsukushi
MG-55	25/04/2000	7:13	7:36	3 43.798	151 40.054	3 43.782	151 40.033	1668	1664	Tsukushi
MG-56	26/04/2000	17:40	18:19	3 47.503	152 03.511	3 47.504	152 03.521	2062	2068	West Su Basin
MG-57	26/04/2000	20:28	21:07	3 47.982	152 01.997	3 48.009	152 01.979	2089	2089	West Su Basin
MG-58	01/05/2000	20:48	22:10	3 48.510	152 00.515	3 48.492	152 00.539	2062	2060	West Su Basin
MG-59	01/05/2000	22:40	23:16	3 47.513	152 00.504	3 47.527	152 00.501	2034	2034	West Su Basin
MG-60	02/05/2000	4:42	6:20	3 47.904	151 58.858	3 47.899	151 58.855	1876	1880	West Su Basin
MG-61	02/05/2000	6:59	7:31	3 49.702	152 00.525	3 49.701	152 00.499	2037	2035	West Su Basin

Cores

Operation	*Date*	*Start*	*End*	*Start Latitude (S)*	*Start Longitude (E)*	*End Latitude (S)*	*End Longitude (E)*	*Start Depth (m)*	*End Depth (m)*	*Location*
MS50	18/04/2000	17:30	17:40	10° 27.06´	152° 12.01´	10° 27.06´	152° 12.01´			St Georges Cha
MS-51	20/04/2000	16:15	16:28	3° 48.00'	152° 06.08'	3° 48.00'	152° 06.08'	1168	1176	North Su
MS-52	21/04/2000	1:42	5:00	3° 51.99'	151° 50.47'	3° 51.95'	151° 50.58'	2076	2075	East Basin
MS-53	26/04/2000	10:55	11:30	3° 43.70'	151° 57.02'	3° 43.68'	151° 57.01'	2158	-	Umbo Knolls

MS-54	26/04/2000	22:17	23:36	3° 48.41'	152° 03.00'	3° 48.40'	152° 02.95'	2078	2078	West Su Basin
MS-55	02/05/2000	9:12	9:50	3° 47.99'	151° 57.69'	3° 48.01'	151° 57.69'	2072	2072	W of West Su E
MS-56	03/05/2000	15:05	17:07	3° 26.40'	151° 09.89'	3° 26.40'	151° 09.89'	2448	2933	Far west EMB
MS-57	03/05/2000	18:18	19:44	3° 28.03'	151° 16.71'	3° 27.78'	151° 16.63	2527	2526	Far west EMB

CTDs

Operation	*Date*	*Start*	*End*	*Start Latitude (S)*	*Start Longitude (E)*	*End Latitude (S)*	*End Longitude (E)*	*Start Depth (m)*	*End Depth (m)*	*Location*
MH-62	04/02/ 2000			4° 31.1	152 29.7					North George E
MH-63	18/04/ 2000	1:04	3:23	5 15.084	152 24.942	5 15.002	152 25.000	3563	3563	South George E
MH-64	18/04/2000	18:54	20:17	3 48.08	152 06.49	3 48.14	152 06.33	1543	1412	North Su
MH-65	19/04/2000	2:50	3:08	3 48.00	152 06.50			?		North Su
MH-66	20/04/2000	22:05	22:36	3 48.08	152 06.15	3 48.10	152 06.20	1385	1289	North Su
MH67	21/04/2000	7:35	8:27	3 42.998	151 41.003	3 43.007	151 41.007	1657	1668	SnowCap
MH68	21/04/2000	9:38	10:24	3 43.644	151 40.310	3 43.657	151 40.297	1678	1678	SnowCap
MH-69	21/04/2000	21:10	21:40	3 42.744	151 40.743	3 42.759	151 40.757	1685	1684	Pacmanus
MH-70	21/04/2000	22:39	0:30	3 43.237	151 41.256	3 43.262	151 41.218	1690	1660	Pacmanus
MH71	22/04/2000	0:35	5:15	3 41.537	151 43.016	3 42.823	151 46.482	1860	1751	NE Pual Ridge
MH-72	22/04/2000	21:52	23:00	3 43.449	151 41.513	3 43.403	151 41.419	1786	1727	South East Pacmanus
MH-73	23/04/2000	3:46	6:21	3 42.742	151 47.000	3 39.996	151 40.987	1937	2063	NE Pual Ridge
MH-74	23/04/2000	6:21	12:43	3 39.996	151 40.987	3 44.330	151 40.466	2063	1909	NE Pual Ridge
MH-75	23/04/2000	23:52	5:32	3 43.509	151 44.444	3 39.308	151 39.151	2006	2344	NE Pual Ridge
MH-76	24/04/2000	15:56	17:13	3 43.441	151 40.469	-	-	1687		Satanic Mills
MH-77	25/04/2000	0:11	6:21	3 39.953	151 39.010	3 44.668	151 44.061	1884	1970	NE Pual Ridge

MH-78	25/04/2000	11:34	12:44	3 43.141	151 40.510	3 43.012	151 40.658	1690	1682	Roman Ruins
MH-79	25/04/2000	16:11	17:23	3 42.399	151 41.595	3 42.199	151 41.562	1714	1708	Sonne Pimple
MH-80	25/04/2000	18:29	19:23	3 42.696	151 41.293	3 42.596	151 41.320	1676	1676	Sonne Pimple
MH-81	26/04/2000	5:19	9:53	3 38.523	151 44.016	3 42.726	151 49.003	1887	2086	NE Pual Ridge
MH-82	26/04/2000	15:23	16:45	3 48.954	151 06.442	3 48.101	151 06.213	1237	1240	North Su
MH-83	27/04/2000	0:24	6:29	3 47.864	152 04.443	3 49.565	151 58.823	1860	2016	West Su Basin
MH-84	28/04/2000	3:40	5:05	3 40.683	151 45.338	3 40.698	151 45.338	1802	1807	NE Pual Ridge
MH-85	28/04/2000	5:34	6:54	3 40.901	151 44.609	3 40.938	151 44.594	1864	1859	NE Pual Ridge
MH-86	28/04/2000	10:32	11:31	3 39.547	151 46.186	3 39.506	151 46.246	1920	1952	NE Pual Ridge
MH-87	29/04/2000	8:04	9:23	3 40.003	151 44.676	3 40.049	151 44.669	1907	1896	NE Pual Ridge
MH-88	29/04/2000	11:14	12:21	3 43.874	151 39.938	4 43.864	151 39.890	-	-	Tsukushi
MH-89	30/04/ 2000	1:40	3:00	3 39.487	151 43.992	3 39.522	151 44.008	1982	1976	NE Pual Ridge
MH-90	30/04/ 2000	5:53	6:40	3 39.992	151 43.512	3 39.998	151 43.505	1942	1939	NE Pual Ridge
MH-91	30/04/ 2000	16:32	17::34	3 44.202	151 39.507	3 44.218	151 39.589	1654	1652	Pacmanus
MH-92	30/04/ 2000	21:20	23:52	3 40.740	151 39.007	3 42.254	151 41.341	2053	1700	Marmin Knolls
MH-93	01/05/ 2000	11:12	12:54	3 48.184	152 06.177	3 48.271	152 06.413	1212	1484	Su Su Plume
MH-94	01/05/ 2000	14:41	15:36	3 47.460	152.05.903	3 47.623	152 05.827	1557	1549	North Su
MH-95	01/05/ 2000	17:17	17:44	3 47.600	152 06.486	3 47.601	152 06.491	1648	1655	North Su
MH-96	01/05/ 2000	18:42	19:30	3 47.942	152 06.525	3 47.938	152 06.514	1544	1531	North Su
MH-97	02/05/ 2000	0:30	4:00	3 48.004	152 00.936	3 48.037	151 56.973	2048	2057	West Su Basin
MH-98	02/05/ 2000	23:49	3:42	3 39.409	151 41.652	3 42.554	151 46.045	20??	1659	NE Pual Ridge
MH-99	03/05/ 2000	8:00	8:58	3 41.091	151 36.293	3 41.091	151 36.304	2266	2266	Marmin Knolls
MH-100	03/05/ 2000	20:02	20:12	3 27.941	151 16.503			2527		West EMB

VUNLs

Operation	*Date*	*Start*	*End*	*Start Latitude (S)*	*Start Longitude (E)*	*End Latitude (S)*	*End Longitude E)*	*Start Depth m)*	*End Depth m*	*Location*
MV-05	24/04/2000	9:07	14:23	3 43.658	151 40.224	3 43.693	151 40.220	1643	-	Snowcap
MV-06	27/04/2000	9:47	11:55	3 47.913	152 06.071	3 47.957	152 06.105	1190	-	North Su
MV-07	27/04/2000	12:58	18:45	3 48.026	152 06.107	3 47.968	152 06.075	-	-	North Su
MV-08	30/04/200	9:50	14:00	3 43.692	151 40.167	3 43.702	151 40.195	1647	1644	Snowcap

Binatang D R
Masins deployment recovery

Operation	*Date*	*Start*	*End*	*Start Latitude (S)*	*Start Longitude (E)*	*End Latitude (S)*	*End Longitude (E)*	*Start Depth (m)*	*End Depth (m)*	*Location*
MBM-01D	20/04/2000	18:34	18:38	3 48.02	152 06.09	3 48.03	152 06.10	1182		North Su
MBM-02D	22/04/2000	17:03		3 43.677	151 40.207			1646		Snowcap
MBM-01R	26/04/2000	14:00	14:42	3 48.04	152 06.09			-		North Su
MBM-03D	27/4/2000	20:31	20:39	3 41.495	151 51.936	3 41.478	151 51.920	1846	1838	Desmos
MBM-02R	28/4/2000	15:46	17:12	3 43.602	151 40.082	3 43.613	151 40.222	1651	1672	Snowcap
MBM-04D	29/04/2000	16:38	16:44	3 43.235	151 40.522	3 43.264	151 40.479	1683	1688	Roman Ruins
MBM-04R	02/05/2000	0:00	16:45	3 41.48	151 51.920					Desmos
MBM-03R	02/05/2000	14:10	14:25	3 43.150	151 40.524					Roman Ruins

Video Tow

Operation	*Date*	*Start*	*End*	*Start Latitude (S)*	*Start Longitude (E)*	*End Latitude (S)*	*End Longitude E*	*Start Depth m*	*End Depth(m)*	*Location*
MCV-65	18/04/2000	20:35	23:57	3° 48.00'	152° 05.90'	3° 48.09'	152° 06.11'	-	-	North Su

Geophys Tows

Operation	*Date*	*Start*	*End*	*Start Latitude (S)*	*Start Longitude (E)*	*End Latitude (S)*	*End Longitude (E)*	*Start Depth (m)*	*End Depth (m)*	*Location*
MP-01	20/04/2000	10:13	13:50	3° 47.94´	151° 59.79	3° 48.20'	152° 03.12'	2060	-	West Su Basin
MP-02	22/04/2000	13:10	16:10	3° 43.467´	151° 40.271	3° 44.76'	151° 38.68'	1671	1796	Snowcap
MP-03	23/04/2000	14:21	16:44	3° 43.902´	151° 38.662	3° 44.22'	151° 40.29'	2013	1764	Pacmanus
MP-04	24/04/2000	18:41	20:50	3° 43.746´	151° 39.099	3° 44.03'	151° 40.44'	1897	1768	Pacmanus
MP-05	26/04/2000	0:37	4:22	3° 43.489´	151° 41.855	3° 43.18'	151° 40.20'	2011	1747	Roman Ruins
MP-06	27/04/2000	22:11	1:18	3° 43.488´	151° 42.010	3° 43.08'	151° 139.5'	2032	1928	Roman Ruins
MP-07	28/04/2000	18:51	0:50	3° 42.499´	151° 41.327	3° 43.66'	151° 40.06'	1678	1742	PualRidge
MP-08	29/04/2000	18:03	20:00	3° 43.542´	151° 39.435	3° 43.79'	151° 41.02'	1852	1825	Snowcap
MP-09	01/05/2000	1:30	4:00	3° 43.985´	151° 38.308	3° 44.20'	151° 39.18'	2073	1736	Field C -Snowc
MP-10	01/05/2000	5:57	7:42	3° 43.521´	151° 39.022	3° 43.73'	151° 40.57'	2044	1748	Snowcap
MP-11	02/05/2000	19:04	23:03	3° 45.032´	151° 39.002	3° 42.78'	151° 41.15'	1876	1672	Pual Ridge

E/S Profiles

Operation	*Date*	*Start*	*End*	*Start Latitude (S)*	*Start Longitude (E)*	*End Latitude (S)*	*End Longitude (E)*	*Start Depth (m)*	*End Depth (m)*	*Location*
MES26	4/02/2000	6:00	16:00	5° 20.48	152° 21.31	6° 19.4'	152° 15.03	-	-	St Georges Cha
MES27	17/04/2000	17:23	1:00	6° 31.18'	152° 19..9'	5° 15.06'	154° 24.14'	-	-	St Georges Cha
MES28	18/04/2000	7:45	9:43	5° 15.08'	152° 23.73'	5° 07.49	152° 18.47'	-	-	St Georges Cha
MES29	25/04/2000	15:00	15:26	3° 43.10'	151° 40.95'	3° 41.80'	151° 42.25'	1650	1750	Sonne Pimple
MES-30	25/04/2000	17:47	18:04	3° 42.203'	151° 41.100'	3° 43.003'	151° 41.900'	1717	1802	Sonne Pimple