OCEAN DRILLING PROGRAM

LEG 193 SCIENTIFIC PROSPECTUS

ANATOMY OF AN ACTIVE, FELSIC-HOSTED HYDROTHERMAL SYSTEM, EASTERN MANUS BASIN

Dr. Fernando Barriga
Co-Chief Scientist
Departamento de Geologia da
Faculdade de Ciências de Lisboa
Edificio C2, Piso 5 Campo Grande
1749-016 Lisboa
Portugal

Dr. Ray Binns
Co-Chief Scientist
CSIRO Division of Exploration
and Mining
P.O. Box 136, North Ryde
NSW 2113 Australia

____
Dr. Jack Baldauf
Deputy Director of Science Operations
Ocean Drilling Program
Texas A&M University
1000 Discovery Drive
College Station TX 77845-9547
USA

____
Dr. D. Jay Miller
Leg Project Manager and Staff Scientist
Ocean Drilling Program
Texas A&M University
1000 Discovery Drive
College Station TX 77845-9547
USA

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This Scientific Prospectus is based on precruise JOIDES panel discussions and scientific input from the designated Co-Chief Scientists on behalf of the drilling proponents. The operational plans within reflect JOIDES Planning Committee and thematic panel priorities. During the course of the cruise, actual site operations may indicate to the Co-Chief Scientists and the Operations Manager that it would be scientifically or operationally advantageous to amend the plan detailed in this prospectus. It should be understood that any proposed changes to the plan presented here are contingent upon approval of the Director of the Ocean Drilling Program in consultation with the Science and Operations Committees (successors to the Planning Committee) and the Pollution Prevention and Safety Panel.

Technical Editors: Karen K. Graber and Lorri L. Peters

ABSTRACT

The PACMANUS (Papua New Guinea-Australia-Canada-Manus) hydrothermal site in the Manus backarc basin of Papua New Guinea is notable for its distinctly siliceous volcanic host rock (dacite) and for the fact that its massive sulfide chimneys are particularly rich in copper and gold relative to those at typical basalt-hosted hydrothermal fields in midocean and backarc spreading centers. Its geological and tectonic setting at a convergent margin is effectively destined to become continental crust—hence it is a closer analog of ancient ore body environments than other modern hydrothermal fields drilled by the Ocean Drilling Program, all of which have been at divergent plate margins.

Geochemical and isotopic studies of seabed samples from the PACMANUS field imply an important role for magmatic sources of metals and mineralizing fluids. The predominance of metals leached from wall rocks by circulating seawater in high-temperature reaction zones adjacent to magma bodies— the well-established model for better-studied spreading ridge hydrothermal systems—might not apply for systems at convergent margin or island arc settings. Further clarification of such differences and of their implications for both fundamental and applied science issues demands information from the third dimension.

Leg 193 at the PACMANUS area represents a start toward satisfying this need. We will examine the internal anatomy of the system—volcanic architecture; lateral and vertical variability in wall rock alteration and sulfide mineralization patterns, including possible subsurface massive sulfide horizons; volcanological and structural controls on fluid pathways; and the relationship between all processes involved. This expedition will also provide the first tests for the presence of a deep biosphere in a convergent margin hydrothermal system, with special interest attached to subsurface hyperthermophilic microbes.

Four "bare rock" sites are planned for achieving our scientific objectives. Two sites are located at outflow zones of the hydrothermal system at, or close to, sites of focused and diffuse venting, respectively. One site is at a likely seawater inflow zone for the system, and one site is at a "background" position for providing comparisons between mineralized and unmineralized settings.

INTRODUCTION

The variety of modern seafloor hydrothermal settings characterized adequately in three dimensions will be greatly expanded by drilling below an active vent field associated with felsic magmatism at a convergent plate margin. Subsurface wall rock alteration and mineral deposition processes, fluid pathways, and sources of metals and ligands for this latter environment are expected to differ significantly from those at basaltic midocean ridges previously tested by the Ocean Drilling Program (ODP) during Legs 106, 139, 158, and 169. The differences profoundly influence chemical and energy fluxes in the global ocean, and on a practical level they are highly relevant to the increasingly difficult problem of maintaining mankind’s mineral resource inventories.

Felsic volcanic sequences and their associated intrusions, presumed to have erupted in convergent margin (island arc) settings, have long been recognized as especially prospective for a range of valuable ore styles, including massive sulfide deposits rich in both base and precious metals and porphyry copper-gold deposits. Understanding how such ore bodies were created in the past, by deciphering the interplay between igneous, structural, hydrothermal, and hydrologic processes in a close modern analog of such a setting, will improve the capability of future exploration geoscientists to recognize favorable signals of prospectivity in ancient sequences.

The western margin of the oceanic Pacific plate displays numerous convergent segments or subduction zones. Most of these zones show evidence of seafloor hydrothermal activity at one or more sites in their vicinity (Fig. 1). The Manus Basin in the Bismarck Sea north of Papua New Guinea is the first location other than a midocean spreading axis where hydrothermal "chimney" deposits and associated vent fauna have been discovered (Both et al., 1986). This site, now called Vienna Woods, on the basaltic Manus spreading center, near the apex of a wedge of backarc oceanic crust (Fig. 2). In contrast, eastern Manus Basin has a more complex geological construction involving creation of continental crust, and it accordingly shows closer affinities to ancient ore body settings. It contains the PACMANUS hydrothermal field, discovered in 1991 (Binns and Scott, 1993), where the host volcanic sequence is conspicuously siliceous. Now thoroughly surveyed, the PACMANUS area is where Leg 193 will address the issues raised above.

As well as elevated hydrothermal temperatures, Leg 193 faces technical challenges such as bare-rock commencements in rugged volcanic terrain and the uncertain drilling characteristics of vitreous and/or altered dacitic lavas. These constraints have been adjudged by ODP to be worth confronting, given the exceptional opportunity to address the prime scientific objectives.

BACKGROUND

The Manus Basin is a rapidly opening (~10 cm/yr) backarc basin set between opposed fossil and active subduction zones (Manus Trench and New Britain Trench, respectively; Fig. 2). It lies within the complex zone of oblique convergence between the major Indo-Australian and Pacific plates.

On the now-inactive Manus Trench or its antecedent, volcanism above Eocene-Oligocene subduction of the Pacific Plate under the Indo-Australian Plate formed an island arc represented by exposures on New Ireland, New Hanover, Manus, and parts of New Britain (e.g. Hohnen, 1978; Stewart and Sandy, 1988). Paleomagnetic measurements (Falvey and Pritchard, 1985) indicate that these islands have been relocated to their present positions by an imperfectly understood sequence of backarc developments (Exon and Marlow, 1988). In the late Miocene or Pliocene, when arrival of the Ontong Java Plateau blocked subduction at the Manus Trench, convergence switched to the New Britain Trench. Here the Cretaceous oceanic Solomon microplate is moving under what is now the South Bismarck microplate (a unit separated from the Pacific plate by more recent backarc processes). Above the north-dipping Wadati-Benioff zone associated with the New Britain Trench, a chain of young arc volcanoes has formed along the concave northern side of New Britain (Bismarck or New Britain arc; Johnson, 1976).

The present-day configuration of spreading segments and obliquely oriented transform faults in the Manus Basin (Figs. 2, 3) is well established by bathymetric, sidescan, seismic reflection, gravity, and magnetics surveys (Taylor, 1979; Taylor et al., 1991) and by microseismicity (Eguchi et al., 1989), which defines left-lateral movement on the transform faults. In contrast to the wedge-shaped Manus spreading center, where new backarc oceanic crust has been forming since the 0.78-Ma Brunhes/Matuyama boundary (Martinez and Taylor, 1996), the rift zone of the eastern Manus Basin, which lies between the islands of New Ireland and New Britain and between two major transform faults (Figs. 2, 3), is a pull-apart zone of distributed extension on mostly low-angle faults approximately normal to the transforms. Martinez and Taylor (1996) infer ~80 km of extension across a 150-km-wide rift zone, concentrated mostly in the bathymetrically deeper portion of thinned crust that is coincident with an isostatic gravity high (Fig. 4). They argue that this extension is equivalent to that accomplished by a combination of backarc spreading and microplate rotation in the central portion of the Manus Basin (Fig. 3). Bathymetry, gravity modeling, and reverse magnetization indicate that basement of the eastern Manus Basin (called the Southeastern Rifts by Martinez and Taylor, [1996]) is arc crust equivalent to the Eocene-Oligocene exposures on New Britain and New Ireland. Reflection seismic traverses (B. Taylor and K.A.W. Crook, unpubl. data) across the eastern Manus Basin show essentially undeformed graben and half-graben fills up to 0.3 s, equivalent to about 1 m.y. at current sedimentation rates. This is consistent with rifting in the eastern Manus Basin covering a similar duration to spreading on the central Manus spreading center. The sediment fill is commonly tilted, denoting block rotation on listric master faults. Dredging of fault scarps where seismic profiles indicate exposure of lower, more deformed sequences has yielded fossiliferous calcareous mudstones and volcaniclastic sandstones ranging in age from early Miocene to the Pliocene-Pleistocene boundary. Although mainly of deeper marine origin, these are contemporaneous with the Miocene Lelet Limestone and Pliocene Rataman Formation that overlie the Eocene-Oligocene Jaulu volcanics of New Ireland (Stewart and Sandy, 1988) and with equivalent sequences on New Britain. Undated, mildly metamorphosed basalts dredged from inner nodal scarps near the active ends of the two transform faults (Fig. 5) may represent the presumed arc volcanic basement.

Built on this nascent continental crust, and probably controlled by subtle, relatively recent changes in the extensional stress field, a series of high-standing neovolcanic edifices (eastern Manus volcanic zone; Binns and Scott [1993]) extends enechelon across the trend of the rift faults (Fig. 5). Because these edifices do not significantly disturb the negative regional magnetization derived from basement, they are considered to be superficial features (Martinez and Taylor, 1996). The neovolcanic edifices range from central eruptions of more mafic lavas (basalt and basaltic andesite) to linear ridges formed by fissure eruption of andesite, dacite, and rhyodacite. The westernmost volcanic feature in Figure 5 is a low axial ridge with midocean ridge basalt (MORB) affinity set within a deep trough (Fig. 4). This is probably a failed spreading center; however, the other edifices are distinctly but variably potassic and have trace element and isotopic affinities comparable to subaerial arc volcanoes of New Britain (Binns et al., 1996a; Woodhead and Johnson, 1993), rather than to the MORBs at the Manus spreading center (Woodhead et al., 1998) or the adjacent East Sherburne volcanic zone (Fig. 3). The eastern Manus volcanic zone appears to be a submarine segment of the New Britain arc displaced from the main subaerial chain and erupted in the rifted backarc region.

The PACMANUS hydrothermal field targeted by Leg 193 is located near the crest of Pual Ridge, a 500- to 700-m-high felsic neovolcanic ridge with negligible sediment cover (Figs. 4, 5). This ridge is externally constructed of stacked, subhorizontal lava flows 5-30 m thick, with negligible to minor sediment cover along the crest. Whether this "layer cake" character persists internally is an open question. Dacite and some rhyodacite block lavas with rough surface topographies predominate, but there are also some smoother sheet flows and lobate flows of dacite (Waters et al., 1996). Consanguineous lobate flows of andesite occupy the lower reaches of Pual Ridge, whereas the 2100-m-deep valley to its east is floored by lobate flows of basaltic andesite (Fig. 5).

PACMANUS Hydrothermal Field

Isolated hydrothermal deposits have been photographed along 13 km of the main crestal zone of Pual Ridge (Binns and Scott, 1993; Binns et al., 1995, 1996b, 1997a, 1997b). The more significant active deposits occur in the center of this zone between two low knolls on the ridge crest (Fig. 5). Lavas in this central area are exclusively dacitic to rhyodacitic (65%-71% SiO_2). Based on extensive bottom-tow photography and manned submersible observation (Fig. 6), four principal fields of hydrothermal activity, including sulfide chimneys, and several smaller sites have been delineated and named (Fig. 7). Much of the information cited below is unpublished and is derived from cruises listed in the caption of Figure 6.

Roman Ruins (1693-1710 m water depth, 150 m across) contains many closely packed simple columnar chimneys as high as 20 m, and some complex multispired chimneys with numerous conduits. Commonly, these coalesce into wall-like constructions with north-south orientation. Many chimneys are broken (seismic effects?) and some show later regrowth. Fallen chimneys form a 10-m-high pediment for the active structures, including black smokers and diffuse venters of clear fluid. A smaller, deeper (1730-1740 m) field to the north, Rogers Ruins, is linked to Roman Ruins by a zone of Fe oxyhydroxide deposits. Numerous small occurrences of Fe oxyhydroxide and Mn oxides are common throughout the PACMANUS field.

Satanic Mills (1708-1720 m water depth, 200 m across) is an equivalent-sized field of more scattered deposits marked by clouds of black smoke from predominant multispired hydrothermal constructions. Both black to gray smokers and vigorous venters of clear fluid are in close proximity. East of this field there are north-south dacite fissures encrusted with fauna that emit clear fluid and are interpreted as juvenile vents soon to become smoker fields. To the south, the area of active venting is linked by a zone of altered dacite with diffuse venting and scattered Fe and Mn oxide deposits to the smaller Marker 14 field, which at 1745 m depth is the deepest hydrothermal site so far recognized at the PACMANUS site. Deflections of bathymetric contours beyond both the Roman-Rogers and Satanic-Marker lines suggest that both fields are located on north-northwest-trending fracture zones.

The Tsukushi field (1680-1686 m water depth) at the southwestern end of the PACMANUS field contains numerous actively venting chimneys up to 30 m high, many very slender, but some as large as 10 m in diameter. No chimneys were sighted when this field—discovered during a 1996 *Shinkai-2000* submersible dive—was traversed by a sea-bottom camera in 1993 and by a *Shinkai-6500* submersible dive in 1995. Additional large chimneys were present in 1998; hence this field might be very young. Iron oxyhydroxide and Fe and Mn oxide crusts are common in the zone extending northeast from Tsukushi.

Snowcap (1654-1670 m water depth), the other major active hydrothermal site at PACMANUS, is very different in character. It occupies the crest and flanks of a 10- to 15-m-high hill, 100 m x 200 m in size, bounded on its eastern side by a north-northeast-striking fault scarp 60-80 m high. Outcrops of altered dacite-rhyodacite lava and hyaloclastite predominate, locally covered with patches of both sandy sediment and metalliferous hemipelagic ooze (only millimeters thick). Gravity corer and grab operations revealed the sand to be altered lava disaggregated by bioturbation or hydrothermal fragmentation. Typical alteration assemblages at Snowcap are dominated by cristobalite, with lesser natroalunite, diaspore, and illite-montmorillonite with traces of pyrite, marcasite, chalcopyrite, enargite, and native sulfur. These reflect relatively low-temperature interaction between dacites and a highly acid, relatively oxidized hydrothermal fluid (advanced argillic alteration), indicating that SO_2-bearing magmatic components were present in the fluid.

Diffuse low-temperature venting (6°C; compared with 3°C ambient seawater) is extensive across the gently undulating to flat crest of Snowcap knoll. More intense shimmer occurs at the edges of the occasional Mn oxide encrusted outcrop of altered dacite. The diffuse vent sites are marked by white surficial patches, probably including both bacterial mat and methane hydrate deposits. Around the southwestern fringe of the Snowcap knoll, there are several small fields of actively smoking and inactive chimneys, aligned in north-south-trending clusters.

Orifice temperatures measured at black or gray smokers and sulfide chimneys venting clear fluid are comparable for the Satanic Mills, Roman Ruins, and Tsukushi fields, ranging between 220° and 276°C. End-member vent fluids are very acidic (pH 2.5-3.5), show high K/Ca values (reflecting equilibration with dacite wall rocks), are high in Mn and Fe relative to midocean ridge fluids, and have variable salinities (Gamo et al., 1996; Auzende et al., 1996; Charlou et al., 1996). The variable salinities imply subsurface phase separation, meaning hydrothermal temperatures exceed 350°C at indeterminate depths below the chimney fields. This is supported by mineralogical evidence of phase separation (Parr et al., 1996). End-member gas compositions of 20-40 mM CO_2, 20-40 µM CH_4, and R/R_A(He) = 7.4 denote significant contribution to the hydrothermal fluids from arc-type magmatic sources (Ishibashi et al., 1996). Douville et al. (1999) ascribe unusually high fluorine contents in the fluids to magmatic sources. Temperatures of 40° to 73°C have been measured in shimmering clear fluid emitted from Fe oxyhdroxide deposits in the Tsukushi-Snowcap zone.

A very high thermal gradient of 15°C/m was measured at a sediment pocket on Snowcap adjacent to a 6°C shimmering water zone. Fluids collected near this location by a funnel sampler are similar to seawater in composition but are enriched in Mn, Fe, and Al. All outcrops of altered dacite in the vicinity of the shimmering water are heavily encrusted by Fe and Mn oxides.

Chimneys collected from Roman Ruins and Satanic Mills are comparatively rich in precious metals (average = 15 ppm Au and 320 ppm Ag), and are composed predominantly of chalcopyrite and sphalerite, with subsidiary pyrite, bornite, tennantite, galena, and dufreynosite (Scott and Binns, 1995; Parr et al., 1996). Barite is the principal gangue, but anhydrite substitutes in some samples. Chimneys at Roman Ruins typically contain less Cu than those at Satanic Mills. Fewer samples have been recovered from Tsukushi and the southwestern side of Snowcap, but these are virtually devoid of Cu and Au and contain more Pb and Ag. Their gangue includes appreciable amorphous SiO_2 as well as barite.

PACMANUS chimneys have elevated contents of "magmatophile" trace elements (e.g., As, Sb, In, Tl, and Te). Sulfur isotope ratios near zero ‰ $\delta^{34}S$ (Gemmell, 1995, Gemmell et al., 1996) indicate a larger magmatic-sourced component than occurs at midocean ridge hydrothermal sites and mature backarc spreading axes. Direct evidence for the importance of magmatic fluids is in Cu+Zn-rich gas-filled cavities within glass melt inclusions in phenocrysts of Pual Ridge andesites (Yang and Scott, 1996), as well as in the gas compositions of collected vent fluids (see above).

The PACMANUS hydrothermal field supports an exceptionally abundant vent macrofauna dependent on chemosynthetic bacteria, broadly similar to those of other southwest Pacific sites (Hashimoto et al., 1999). At Snowcap, dredged samples of altered dacite possess microscopic tube worms (unidentified species) along internal hairline fractures. These, and their presumed symbiotic bacteria, imply the presence of a subsurface biosphere that will also be investigated by the scientists aboard Leg 193. ODP is currently negotiating with the Papua, New Guinea Office of Environment and Conservation regarding permission to undertake investigations in this unique environment.

SCIENTIFIC OBJECTIVES

The overall aim of Leg 193 is to delineate, effectively in three dimensions, the subsurface volcanic architecture, the structural and hydrologic characteristics, and the deep-seated mineralization and alteration patterns of the PACMANUS hydrothermal field (Fig. 8). From these data and subsequent laboratory analyses of samples and structural data, the following specific scientific objectives will be pursued. Unlike ODP legs in sedimentary sequences, we are less able to predict in detail the lithologies and structures that will be encountered; hence, we must stand prepared to "expect the unexpected."

1. Assess the manner in which fluids and metals derived from underlying magmatic sources, and from leaching of wall rocks by circulated seawater, respectively, have combined within the PACMANUS hydrothermal system. This will be approached by applying geochemical and isotopic modeling to the vertical and lateral variations in hydrothermal alteration styles and sulfide mineral occurrences including subsurface massive sulfide deposits established by the drilling. Related subsidiary objectives include comparison of exhalative and subhalative mineralizing processes, assessing the consequences of fluid phase separation, and seeking explanations for the elevated contents of Cu, Zn, Ag, and Au in massive sulfide chimneys at the PACMANUS seafloor.

2. Delineate probable fluid pathways within the system and establish a hydrological model by measuring and interpreting variations in physical properties and fracture patterns of fresh and altered bedrocks.

3. Determine whether the construction of Pual Ridge is simple "layer cake," with potential older exhalative or subhalative massive sulfide horizons concealed by younger lavas or, alternatively, whether inflation of the volcanic edifice by lava domes or shallow intrusions is the predominant process in this submarine felsic volcanic environment.

4. Develop a petrogenetic model for Pual Ridge igneous rocks and seek evidence pertaining to the nature of the possible underlying source for magmatic components in the hydrothermal fluids.

5. By combining the above models, develop an integrated understanding of the relationship between volcanological, structural, and hydrothermal phenomena in the PACMANUS system for comparison with equivalent hydrothermal phenomena at midocean ridges and for providing a new basis for interpreting ancient ore environments.

6. Establish the nature, extent, and habitat controls of microbial activity within the hydrothermal system, and interpret the differences encountered in diversity and biomass in terms of nutrient supplies and environmental habitats interpreted in the context of the geochemical and hydrologic understanding of the total hydrothermal system.

PROPOSED SITES

The above scientific objectives will be tackled with a program of as many as four sites, the strategy for which is illustrated in reference to expected subsurface geology in Figure 8. These localities will explore (1) two outflow sites under a zone of low-temperature diffuse venting (Site PCM-2A) and as close as possible to a site of focused high-temperature venting (PCM-3A), (2) a background position (PCM-1A) away from known activity, and (3) a likely inflow site (PCM-4A) where faulting should facilitate entry of seawater to the system. Figure 8 shows that even though major advances in knowledge will be made during Leg 193, we will not have penetrated to the enigmatic source regions for metals and fluids. Hence, answers to the major scientific questions will require much subsequent laboratory analysis and interpretation of data.

Rough volcanic topography over most of the PACMANUS field and closely packed chimneys within the high-temperature vent fields severely constrain the number of drilling sites suitable for use of the hard-rock guide base (HRGB). Alternate drilling locations within <150 m (<10% water depth) of primary targets were identified from submersible video footage but will be occupied only if drilling conditions at primary targets become intractable and sufficient time remains in the operational schedule to drill additional targets.

The priority order in which the sites are described below, and their target depths, may change at sea, depending on results progressively obtained and technical factors such as whether the hammer-drill system, drill in-casing, or diamond drilling capabilities are available. The two outflow sites will provide a comparison between alteration/mineralization and fluid pathways beneath a zone of focused high-temperature venting (PCM-3A, Roman Ruins chimney field) and a zone of diffuse venting (PCM-2A, Snowcap field). Nearby, the third site on the crest of Pual Ridge (PCM-1A) will provide an unaltered "reference" volcanic section as well as indications of possible shallow seawater influxes in the upper sections and a variety of possible outcomes in the lower sections. In effect, this drilling strategy achieves the assessment of vertical and lateral heterogeneity of the ore-forming hydrothermal system.

Site PCM-2A

Proposed Site PCM-2A (water depth 1655 m) is located on the thoroughly explored crest of the Snowcap field (Fig. 7), at a site where there are few rocky outcrops and no obvious shimmering water. The anticipated immediate substrate is altered dacite. The site will establish whether the Snowcap field is underlain and perhaps inflated at relatively shallow depth by one or more zones of "subhalative" mineralization. Investigation of deeper levels will identify alteration and mineralization pattern vertical zonality and should reveal the subsurface structural conditions that govern diffuse rather than focused venting. The site depth is targeted nominally at 500 m to fit within our operational schedule, but high temperatures may preclude achieving this dpeth. However if drilling proves easy and new exciting phenomena are still being observed, we may consider deeper penetration here at the risk of deleting a lower priority site from the program.

Site PCM-3A

Proposed Site PCM-3A (water depth 1696 m) is located within the Roman Ruins hydrothermal field (Fig. 7), as defined by both submersible observations and by differential global positioning system (DGPS) navigated camera tow. The site is surrounded by chimneys, including black smokers, and will provide comparative data on alteration/mineralization patterns and fluid pathways beneath this focused high-temperature field. High temperatures are expected to limit the depth of penetration, making 300 mbsf a nominal though geologically desirable goal to allow assessment of telescoped alteration patterns. Again, if drilling conditions prove ideal and novel observations are being made, coring deeper than the nominal limit may be considered.

Site PCM-1A

Proposed Site PCM-1A (water depth 1720 m) is located on a mostly smooth-surfaced dacite sheet flow forming a very low rise 160 m from the Roman Ruins field (Fig. 7). The sediment cover is estimated to be a maximum of 10 cm. Presuming this site will be least affected by high temperatures, it is designated for the deepest hole (700 m). It would penetrate some 250 m below the base of Pual Ridge (i.e., below the collar of the 350-m-deep inflow zone at Site PCM-4A). Possible intersections at depth, relevant to science objectives, include

- shallow intrusive bodies clarifying growth mechanisms of Pual Ridge and also representing, in proxy, possible deeper-seated intrusive sources of hydrothermal fluids;
- a lateral expansion of the deeper alteration system below the two other outflow holes;
- deep-seated mineralized veins for isotopic assessments of changes with depth in the proportion of magmatic and seawater fluids (e.g., anhydrite and barite); and
- possible Eocene-Oligocene basement to Pual Ridge.

If operations at proposed Site PCM-2A do not yield sufficient material to adequately decipher the volcanic architecture of Pual Ridge, the priority of drilling Site PCM-1A may be enhanced.

Site PCM-4A

Proposed Site PCM-4A (water depth 2139 m) is located among the basaltic andesite sheet and lobate flows flooring the valley southeast from PACMANUS, in a lightly sedimented (20-50 cm) depression or collapse pit on the track of a submersible dive. While investigation of structural and mineralogical features at the inflow zone is a priority, this site is placed to intersect the following features with minimal penetration but reasonable confidence:

- the base of the basaltic andesite sequence, indicated by seismic profiling (Figs. 9A, 9B) at 150 m, and possible Eocene-Oligocene basement beneath this; and
- an interpreted low-angle extensional fault at 250 m, and basement below it.

DRILLING STRATEGY

One of the most technologically challenging aspects of this leg will be drilling in material with an as-yet undetermined response to conventional drilling tools. Penetration rates and bit life are virtually unknown, as are downhole conditions. Our original operational strategy was based on an attempt to pinpoint locations for deployment of an HRGB. In bare-rock environments where ODP has experience drilling, our proposed penetration depths would require more than one bit run; hence, they would require reentry capability. Instability of borehole walls could also limit depth of penetration, so hole preparation options that include casing operations must be considered.

Based on detailed examination of seafloor video images, the operations team for Leg 193, in consultation with the co-chief scientists, have determined that few of the proposed sites are suitable for deployment of an HRGB without risk; however, given the bottom conditions and shallow-water operations area and the expectation of good weather, calm waters, and undithered GPS navigation, we are confident it should be possible to conduct bare hole reentry (BHR) operations with assistance of the vibration-isolated television (VIT) underwater camera. Recent repeated success with similar BHRs bolsters our confidence. Possible innovations that might also be useful in this situation include the hammer drill (under development) or drill-in casing. An additional option includes drilling a large-diameter hole followed by deployment of a free-fall funnel. At least one target (proposed Site PCM-2A) could be suitable for jetting in a standard reentry cone, if hole instability in the pilot hole dictates a need for casing to reach our scientific objectives.

Proposed Site PCM-2A at Snowcap is first priority for both scientific and technical considerations. It lies at the center of a large zone of relatively soft but coherent altered dacite. Possible high temperatures and hole instability being the chief constraints, this site would be drilled to a maximum depth of 750 m. The drilling plan is to spud directly on bedrock and drill with the rotary core barrel (RCB) for ~50 hr rotation time or ~250 meters below seafloor (mbsf), whichever comes first. The time/depth allocated for this operation may be adjusted by the operations manager, inasmuch as one objective of this operational scenario is to provide a baseline for future operations once we determine rate of penetration (ROP) and bit life characteristics. The hole will then be reentered with the advanced diamond core barrel (ADCB; maximum depth penetration of 300 m without reaming) and drilled to target depth of 500-550 mbsf. If time and drilling conditions are especially favorable, and if particularly important intersections occur at this target depth, we may consider deepening this hole to as much as 750 m with a third bit (either the RCB or ADCB).

The next priority will be proposed Site PCM-3A at the site of focused high-temperature venting. To achieve the planned penetration of 350 m, at least two bits and a BHR may be required. The drilling plan will be similar to that at Site PCM-2A, but initial RCB penetration will be reduced to as little as 50 m if the first hole demonstrates superior performance of the ADCB, which would be used to continue to the target depth of 350 m. If justified by timing and exceptional results at this depth, the hole could be deepened to as much as 650 m with a third entry using the ADCB following reaming. It is unlikely that scenario will arise.

The need for and priority of a reference hole at proposed Site PCM-1A will depend on whether the previous two drilling targets provide an adequate assessment of volcanic architecture or whether sampling to allow direct comparisons between altered rocks and their fresh counterparts becomes vital (for instance, if the altered rocks appear to not have been derived from the well-characterized dacite lavas at PACMANUS). This site is targeted at 750 m depth with the aim of sampling the entire volcanic sequence of Pual Ridge as well as characterizing the basement below the ridge. Since at least three (and likely more) bits will be required, this target depth cannot be achieved during this leg unless predicted penetration rates can be significantly exceeded. The operational strategy for drilling at Site PCM-1A will be determined by the success of coring operations at previous sites.

Deletion of Site PCM-1A from the drilling plan or revision of the target depth might allow inclusion of the inflow target (proposed Site PCM-4A). Achievement of target depth and scientific objectives of drilling at Site PCM-4A, through the inferred fault zone and into basement, may require multiple reentries and potential coring with the ADCB but might be accommodated by a single bit RCB hole drilled to bit destruction.

If hole stability becomes a major problem during drilling at any site but we recognize the need to continue coring on scientific grounds, we may need to stabilize the borehole wall with casing. After extensive discussions of operational strategy, and given the bottom conditions as documented in video surveys and reports from submersible surveys and camera tows, we will hold in our arsenal of seafloor reentry platforms conventional reentry cones equipped with casing hangers and will carry sufficient casing for borehole stabilization. Because casing operations are time consuming (to the detriment of coring operations) we will deploy these only if we determine that deeper penetration is more important to achieving our overall scientific objectives than additional hole commencements.

Recognizing that drilling conditions may be challenging in this terrain, we have identified several alternate sites with the same scientific objectives and drilling strategies as outlined above. In the event we cannot meet our scientific objectives at Site PCM-1A, two contingency targets have been identified. Both locations are near the Pual Ridge crest but are further removed from areas of high-temperature venting. We do not intend to occupy these sites in place of Site PCM-1A; they will be cored only if we cannot reach our scientific objectives at the primary site and there is enough time in the operations schedule to drill these targets. Proposed Site PCM-5A is ~600 m northeast of Site PCM-1A, whereas Site PCM-6A is ~300 m southeast of our primary target.

Two alternate sites for drilling below a focused high-temperature vent site (the scientific objective of drilling at Site PCM-3A) have also been identified (Fig. 7). Proposed Site PCM-7A is in the Satanic Mills chimney field, and proposed Site PCM-8A in the Tsukushi chimney field. We do not intend to investigare these locations in lieu of the primary target; however, one or both of these sites may be occupied if drilling at Site PCM-3A fails to provide adequate material for comparison with recovery at Site PCM-2A or if the alteration patterns in the high-temperature site prove to be so similar to those in the lower temperature site that the principal scientific imperative becomes to confirmation of this unexpected result by drilling additional sites.

ADDITIONAL OPERATIONAL CONSIDERATIONS

High-Temperature Fluids

The highest vent temperature measurement at PACMANUS black smokers (strictly "gray smokers") is 280°C; however, the number of such measurements is too limited to ensure this is the true maximum. Indeed, a variety of evidence mentioned above indicates that phase separation (boiling) of the hydrothermal fluids is occurring below the surface. There is no way of knowing how deep below the seafloor this occurs, so for safety purposes we must presume it is relatively shallow, and define the boiling point at the collar of the shallowest water depth site (Site PCM-2A, 1655 m). The end-member salinities of the PACMANUS fluids are variable but fairly close to seawater (650-800 mM, Ishibashi et al, 1996).

According to Appendix 4 of Bischoff and Rosenbauer (1985), the two-phase boundary of normal seawater (3.2% NaCl) at a pressure of 166 bars (= 1655 m seawater depth) lies at 354°C. This temperature is lowered to 349°C for pure H_2O, representing the extreme (but unlikely) situation of a very low salinity hydrothermal fluid and the theoretical temperature limit that must not be exceeded in any hydrothermal aquifer drilled. The comparable values for Middle Valley and the Trans-Atlantic Geotraverse (TAG) hydrothermal mound are ~385° and 430°C respectively.

PACMANUS end-member vent fluids are relatively rich in dissolved CO_2 (20-40 mM) and methane (20-40 μM) so should gently effervesce before boiling or "flashing." Nevertheless, for Sites PCM-2A and PCM-3A, and probably PCM-1A as well, it will be necessary to adopt a protocol of frequent temperature measurements to ensure that a specified limit (e.g., 340°C), is never exceeded.

Hydrogen Sulfide and Radon Gas

Measured H_2S contents of PACMANUS vent fluids range up to 4 mM, and that of the calculated end-member fluid is 7 mM (Shitashima et al., 1997). These values are higher than those at Middle Valley (3 mM) and TAG (0.5 mM), and potentially hazardous levels of H_2S gas could potentially be released into the local atmosphere upon opening or cutting samples cored from hydrothermal aquifers. The same precautions of providing an H_2S detector, and of allowing relevant samples to degas before storing them in enclosed areas should be adopted as were applied during Legs 136, 158, and 169.

Barite is a significant gangue mineral in PACMANUS chimneys, and it contains detectable radium (Dickson, et al., 1995). The rare earth element abundance patterns of PACMANUS vent fluids indicate that subsurface precipitation of barite also occurs (Douville, et al., 1999). Direct radiation from barite-rich samples is not likely to present a health risk; however, release of radioactive ^{222}Rn gas by decay of ^{226}Ra is a potential hazard. Similar to Leg 169, all mineralized cores should be checked for radioactivity and those identified as hazardous should be marked as requiring proper venting to allow dispersal of radon prior to handling, if they have been stored in sealed containers.

SAMPLING STRATEGY

New sampling guidelines specify that a formal, leg-specific sampling strategy be prepared by the Sample Allocation Committee (SAC = co-chiefs, staff scientist, and ODP curator on shore or Curatorial Representative on board ship) for each prospectus. Modifications to the strategy during the leg must be approved by the SAC. The sampling strategy is here keyed to the new guidelines and will be refined as the sample requests are evaluated and considered by the entire shipboard party before reaching site.

Sampling Requests

Based on the Scientific Prospectus, each Leg 193 scientist (shipboard or shore based) should prepare and submit to ODP/TAMU (Texas A&M University) a sampling request for his/her postcruise research. These should be submitted to ODP at least three months before sailing. One month before sailing, a complete sampling program should be completed, including resolution of possible conflicts.

Dynamic Sampling Strategy and Critical Interval Definition

At the beginning of the leg, a meeting of the full shipboard scientific party will review the sampling requests and define the procedures and a tentative schedule for sampling sessions. Given the characteristics of the drilling targets and scientific objectives of Leg 193, it is foreseeable that sampling may have to be carefully planned, with a permanent revision of the sampling strategy according to findings. This will be particularly true at "critical intervals," such as veins, massive sulfide intercalations, and other intervals of high scientific interest or low recovery. These may require special consideration and special sampling procedures, such as a higher (or lower) sampling density, reduced sample size, or sampling techniques not available on board ship. These will be identified during the core description process and in the sampling protocol established by the interested scientists and shipboard SAC. It will be the responsibility of SAC members to identify and label critical intervals. Progress of the leg may justify reclassification of a former critical interval into the unclassified status.

Minimum Permanent Archive

The minimum permanent archive will be the standard archive half of each core.

Sample Limit

Shipboard scientists may nominally expect to obtain as many as 100 samples up to 15 cm^3 in size. Additional samples may be obtained upon written request to ODP soon after the cores return to the ODP Gulf Coast Repository. This guideline will be adjusted upward or downward by the shipboard SAC, depending on penetration and recovery during Leg 193. All sample requests must be justified in writing on the standard sample request form and approved by the SAC. Larger samples can exceptionally be collected, subject to written justification and approval by the SAC. Larger samples will be considered the equivalent of multiple samples in complete or partial increments of 15 cm^3.

Biological Sampling

Sampling for microbes and other living organisms and for biogenic molecules will take place immediately after retrieval of core barrels, except if and when critical intervals may be destroyed or rendered useless to other studies as a consequence of biological sampling. The overall number of 100 samples should be taken as a sampling rule. Exceptions (e.g., in the case of very small samples) must be cleared with the SAC.

Redundancy of Studies

Some redundancy of measurement is unavoidable, but minimizing this redundancy among the shipboard party and identified shore-based collaborators will be a factor in evaluating sample requests. Requests for independent shore-based studies that substantially replicate the intent and measurements of shipboard participants will require the approval of both those shipboard investigators and the SAC.

Shipboard Samples and Data

Following core labeling, measurement of nondestructive properties, and splitting, samples will be selected from core working halves by members of the shipboard party for routine measurement of physical and magnetic properties, bulk chemical analyses by inductively coupled plasma-atomic emission spectrophotometer (ICP-AES), carbon-hydrogen-nitrogen-sulphur (CHNS) analyzer, and X-ray diffraction as necessary. Polished thin sections will be prepared for identification of minerals, determination of mineral modes by point counting, and studies of texture and fabric.

We shall identify a suite of samples for full measurement characterization. At ~9.5-m intervals (once per full core), slabs measuring 10 cm x 6 cm x 1.5 cm, with a previously sampled central minicore, will be cut for all shipboard measurements then subdivided and split appropriately for further shore-based geochemical, mineralogical, and petrographic studies. Where necessary to avoid or include features like veins and alteration, full half-round slices or quarter slices may be taken instead of slabs.

Data from all shipboard studies, regardless of method or observer, including all core descriptions and measurements and the nondestructive measurements of physical and magnetic properties, are the property of the entire shipboard party and may be used exclusively by them in publication and preparation of manuscripts with proper citation to the *Initial Reports* volume until the publication of the *Initial Reports* volume or 12 months postcruise, whichever is later.

Shipboard Thin Sections

Shipboard thin sections will be selected from representative sections of the core and at some critical intervals. These sections will remain the property of ODP. The thin-section chips from which the sections are made will be retained by ODP and should normally be thick enough to allow for the production of additional sections unless the sampling plan for a critical interval precludes this. Members of the shipboard party can request the production of a thin section from these chips for their personal use as part of their nominal 100 sample limit, but must arrange for the prepaid manufacture of these thin sections with a third-party commercial service at their own expense unless otherwise approved by the ODP Curator. The thin-section chip will then be sent directly to the commercial service and returned directly to ODP by the service.

Sampling for Shore-Based Studies and Sampling Parties

To minimize the time and physical effort required for additional sampling for shore-based studies, we shall organize sampling consortia among the principal scientific teams (igneous, metamorphic, structural, physical, and magnetic properties) that will identify locations for similarly large (10 cm x 6 cm x 1.5 cm—a minicore) or even larger samples, averaging approximately once per 9.5 m of core. The actual size will depend on the number of investigators in the group, and it will be subdivided among them, to count against the nominal 100-sample limit of each consortium investigator. Follow-up sampling will be organized as short sample parties during reentries or logging runs, for individuals using the second-look lab, or at the ODP Gulf Coast Repository, as necessary.

Storage and Shipping Needs

The usual labeling, orientation, core placement, and storage procedures should be sufficient for safe transportation to the ODP Gulf Coast Repository. Core handlers should wear back supports while lifting and handling individual archive or working halves and especially when maneuvering core storage boxes. Additionally, sulfide-bearing cores may require storage in special sealed bags in an inert atmosphere.

Formation Water Sampling

Sampling and analysis of deep-seated hydrothermal fluids that enter the two outflow-zone boreholes (Sites PCM-2A and PCM-3A) at permeable aquifers will greatly enhance our ability to assess subsurface fluid-rock interactions and the chemical controls at the depth of sulfide mineral deposition. Such fluids will also provide key information for modeling hydrothermal processes deeper than the extent of coring, including additional pathways to assessing the sources of fluids and metals, as well as the first comparisons with vent fluids previously collected at active chimneys. Technologies used to collect high-temperature hydrothermal fluids from boreholes on previous cruises have not been particularly successful, and an effort will be made prior to Leg 193 to design new sampling instruments. Our intention is to deploy these into the open hole at staged intervals of drilling, or after completion of wireline logging, at depths where temperature anomalies have been detected. With simpler forms of instrumentation, we do not expect the samples to be pure end-member fluids from narrow formation intervals; rather, they will typically be variably mixed within the borehole from several aquifers and will have been diluted by seawater and drilling fluid. Procedures exist to resolve these effects of contamination. If suitable high-temperature packers can be developed, sampling of more concentrated hydrothermal fluids with more specific sources will become an option. The exact strategies for collection of hydrothermal fluids will depend on the nature and time requirements of the instrumentation adopted. At a minimum, we will attempt one sample near the bottom of holes at Sites PCM-2A and PCM-3A, and one near the collar of these or the adjacent logging-while-drilling holes.

LOGGING PLAN

Logging and downhole measurements will be critically important to the scientific objectives of Leg 193, particularly because previous coring experiences in Middle Valley and TAG have been characterized by poor core recovery. The main objectives of the logging program will be to assess the changes in physical properties resulting from hydrothermal alteration and to determine how these variations relate to existing hydrological models. In addition to defining structural and lithologic boundaries as a function of depth, the downhole program will also attempt to establish hole-to-hole correlations to determine lateral stratigraphic variations in active hydrothermal systems and produce direct correlations with discrete laboratory data. Altogether, downhole measurements will be used to assess compositional variations throughout massive sulfide deposits and the underlying altered volcanic flows and to determine fracture densities that may serve as conduits for vigorous focused fluid flow. Finally, downhole measurements will complement core measurements by filling gaps in downhole stratigraphy and determining the thickness of lithological units in intervals where poor core recovery is prevalent.

Hole stability and temperature conditions will dictate the amount of wireline logging completed during Leg 193. If hole stability is not an issue and temperature conditions are moderate ($T \leq 175°C$) to high ($T > 175°C$), the measurement of borehole temperatures with either wireline or memory tools should precede any other logging operation. This step is required to determine the temperature of the borehole fluids, estimate the geothermal gradient, and approximate the time of postdrilling temperature rebound. Schlumberger tools rated to 175°C will be deployed when adequate hole cooling is achieved by circulating cold fluids for ~2-3 hr prior to tool deployment. If temperatures rebound quickly, these tools will be at risk and logs may be recorded onlyin cases where the side-entry sub (SES) is used. After circulating for several hours, a Schlumberger tool string could be lowered into the borehole as quickly as possible and temperature measurements at the cable head will be monitored closely to assess the in situ conditions during the entire deployment. If temperatures can be lowered only to a range of 200° to 230°C, deployment of a modified Schlumberger string consisting of a hostile environment gamma-ray sonde (HNGS) and a hostile environment lithodensity sonde (HLDS) can be attempted for the characterization of the different lithologic units.

Overall, if temperature and borehole conditions are favorable (T < 175°C), wireline logging operations will consist of two to three tool strings plus a fluid sampling probe. The strings will consist of the triple combo with the HNGS, the accelerator porosity sonde (APS), the HLDS, the dual induction tool (DIT), a caliper tool, and cable head temperature measurements. If electrical resistivities in the volcanic section exceed the upper limit (~200 ohm-m) of the DIT, the use of a dual laterolog (DLL) may be necessary, pending final approval from the Lamont-Doherty Earth Observatory Borehole Research Group (LDEO/BRG). Following the deployment of the triple combo, the Formation MicroScanner (FMS)/dipole sonic imager (DSI) combination will be lowered into the borehole. Temperature probes will be used to determine the presence of active fluid-flow conduits that will be potential targets for subsequent deployment of a fluid sampling tool. The temperature probes that will be available are the LDEO/BRG wireline Hi-T probe and the University of Miami GRC Ultra Hi-T Memory Tool. The LDEO/BRG Hi-T tool will deployed in cases where temperatures do not exceed an upper limit of 235°C, whereas the GRC tool will be used in cases where the temperatures exceed the upper limit of the wireline capabilities.

The triple combo with caliper measurements and cable head temperature sensors will be used to determine concentrations of K, U, and Th, obtain formation density, electrical resistivity and porosity values, and assess borehole conditions. These measurements will be utilized for characterization of stratigraphic sequences and determination of possible variations in alteration. Mapping the potassium distribution will help to delineate acid-sulfate (K depletion) and higher temperature phyllic (K addition) styles of alteration, particularly if core recovery is poor. The FMS will provide high-resolution borehole images of stratigraphic sequences and boundaries, oriented fracture patterns, and information regarding hole stability. The DSI will produce a full set of compressional and shear waveforms, cross-dipole shear wave velocities and amplitudes measured at different azimuths, and Stoneley waveforms. These types of measurements may be used to determine preferred mineral and/or fracture orientations and densities, paleostress directions, and permeability estimates, all required to accurately model the hydrological characteristics of the hydrothermal system.

Projected Wireline Logging Plan

The breakdown of wireline logging operations for each hole are as follows

Site/Hole	*Measurements*	*Hole depth (mbsf)*	*Time* with no SES (with SES)*
Hole PCM-1A	Triple Combo, FMS/DSI Temperature**, Fluid Sampler	700	1.6 (2.1)
Hole PCM-2A	Triple Combo, FMS/DSI, Temperature, Fluid Sampler	500	1.4 (1.8)
Hole PCM-3A	Triple Combo, FMS/DSI, Temperature, Fluid Sampler	300	1.2 (1.6)
Hole PCM-4A	Triple Combo, FMS/DSI, Temperature, Fluid Sampler	350	1.3 (1.7)
Total			**5.5 (7.2)**

Logging While Drilling (LWD)

There are two potential plans for LWD operations during Leg 193. At the present time, the Compensated Dual Resistivity (CDR) tool is scheduled to be on board for the duration of the cruise for augmenting cruise results, especially if unstable hole conditions and poor core recovery restrict the scientific results of the leg. Our intent will be to drill three holes throughout the leg to an approximate depth of 100 mbsf. These holes will be drilled to characterize the upper intervals that are commonly not recovered and not logged with conventional wireline tools. The CDR will provide gamma-ray and borehole compensated deep and shallow resistivity measurements that will allow direct correlation with core and wireline results in nearby holes and will permit bed boundary definition.

If logistics can be arranged, a resistivity-at-the-bit (RAB) tool will be used in lieu of the CDR. The RAB tool will be brought on board at the end of the cruise and three 100-m holes will be drilled near existent conventional holes during a 6-day period. There are several scientific advantages to replacing the CDR with the RAB. The RAB is a laterolog tool that has a larger range of resistivity measurements (0.2-2000 ohm-m) than the CDR (0.2-200 ohm-m). This capability could become

* Time is recorded in days
* *Might be required if excessively high temperatures are encountered.

crucial in identifying volcanic flows that may have resistivity values much greater than 200 ohm-m. The RAB also provides complete azimuthal coverage of the borehole, providing high-resistivity images comparable to those obtained with the FMS. These data will provide visual identification of massive sulfide and volcanic layers as well as identification of fracture patterns, structural orientations, and formation thickness. The availability of resistivity images will also allow better characterization of shallow deposits that are usually not accounted for because of drilling operations and lack of wireline logs. Finally, performing the RAB measurements at the end of the leg will provide the flexibility to plan hole locations in places where stable hole conditions, favorable temperatures, and penetration depths were established by previous conventional drilling.

REFERENCES

Auzende, J.-M., Urabe, T., and Scientific Party of ManusFlux Cruise, 1996. Submersible observation of tectonic, magmatic and hydrothermal activity in the Manus Basin (Papua New Guinea). *Eos*, WPGM Supplement, 77:W115.

Binns, R.A., and Scott, S.D., 1993. Actively forming polymetallic sulfide deposits associated with felsic volcanic rocks in the eastern Manus backarc basin, Papua New Guinea. *Econ. Geol.*, 88: 2226-2236.

Binns, R.A., Parr, J.M., Scott, S.D., Gemmell, J.B., and Herzig, P.M., 1995. PACMANUS: An active seafloor hydrothermal field on siliceous volcanic rocks in the eastern Manus Basin, Papua New Guinea. *In* Proceedings of the 1995 PACRIM Congress, Mauk, J.L., and St. George, J.D. (Eds.), Australasian Institute of Mining and Metallurgy, Melbourne, 49-54.

Binns, R.A., Waters, J.C., Carr, G.R., and Whitford, D.J., 1996a. A submarine andesite-rhyodacite lineage of arc affinity, Pual Ridge, eastern Manus backarc basin, Papua New Guinea. *Eos*, WPGM Supplement, 77:W119-120

Binns, R.A., Parr, J.M., Waters, J.S., Gemmell, J.B., Moss, R., Scott, S.D., Naka., J., Charlou, J.-L., Gena, K., and Herzig, P.M., 1996b. Actively-forming sulfide deposits at the PACMANUS hydrothermal field, eastern Manus Basin, Papua New Guinea. *Eos*, WPGM Supplement, 77:W115-116.

Binns, R.A., Scott, S.D., and Gemmell, J.B., 1997a. Modern analogue of a mineral field: Sea-floor hydrothermal activity hosted by felsic volcanic rocks in the eastern Manus Basin, Papua New Guinea. *Soc. Econ. Geol.*, Neves Corvo Field Conference, Abstracts and Program, 33.

Binns, R.A., Scott, S.D., Gemmell, J.B., and Crook, K.A.W.C., and Shipboard Party, 1997b. The SuSu Knolls hydrothermal field, eastern Manus Basin, Papua New Guinea. *Eos*, 78: F772.

Both, R., Crook, K., Taylor, B., Brogan, S., Chappell, B., Frankel, E., Liu, L., Sinton, J., and Tiffin, D., 1986. Hydrothermal chimneys and associated fauna in the Manus backarc basin, Papua New Guinea. *Eos*, 67:489-490.

Bischoff, J.L, and Rosenbauer, R.J., 1985. An empirical equation of state for hydrothermal seawater (3.2% NaCl). *Am. J. Sci.* 285:725-763.

Charlou, J.L., Donval, J.P., Fouquet, Y., Henry, K., Jean-Baptiste, P., Auzende, J.-M., Gamo, T., Ishibashi, J., and shipboard party, 1996. Variability in the chemistry of hydrothermal fluids from the Manus backarc basin, Papua New Guinea. *Eos*, WPGM Supplement, 77:W116

Dickson, B., Parr, J., and Binns, R., 1995. Rapid growth of seafloor sulfides. *CSIRO Exploration and Mining Research News*, 3:12-13.

Douville, E., Bienvenu, P., Charlou, J.-L., Donval, J.-P., Fouquet, Y., Appriou, P., and Gamo, T., 1999. Yttrium and rare earth elements in fluids from various deep-sea hydrothermal systems. *Geochim. Cosmochim. Acta,* 63:627-643.

Eguchi, T., Fujinawa, Y., and Ukawa, M., 1989. Earthquakes associated with the backarc opening in the eastern Bismarck Sea: activity, mechanisms, and tectonics*. Phys. Earth Planet. Int.*, 56:189-209.

Exon, N.F., and Marlow, M.S., 1988. Geology and offshore resources potential of the New Ireland - Manus region - a synthesis. *In* Marlow, M.S., Dafisman, S.V., and Exon, N.F. (Eds.), *Circum-Pacific Council for Energy and Mineral Resources*, Earth Science Series, 9:241-262.

Falvey, D.A., and Pritchard, T, 1985. Preliminary paleomagnetic results from northern Papua New Guinea: Evidence for large microplate rotations*. Trans. Circum-Pacific Council Energy Mineral & Resources*, 3:593-600.

Gamo, T., Okmura, K., Kodama, Y, Urabe, T., Auzende, J.-M., Shipboard party, and Ishibashi, J., 1996. Chemical characteristics of hydrothermal fluids from the Manus backarc basin, Papua New Guinea, 1. Major chemical components. *Eos*, WPGM Supplement, 77:W116

Gemmell, J.B., 1995. Comparison of volcanic-hosted massive sulphide deposits in modern and ancient backarc basins; examples from the southwest Pacific and Australia. *In* Mauk, J.L., and St. George, J.D. (Eds.), *Proceedings of the 1995 PACRIM Congress*, Australasian Institute of Mining and Metallurgy, Melbourne, 227-231.

Gemmell, J.B., Binns, R.A., and Parr, J.M., 1996. Comparison of sulfur isotope values between modern backarc and midocean ridge seafloor hydrothermal systems. *Eos*, WPGM Supplement, 77:W117.

Hashimoto, J., Ohta, S., Fiala-Médioni, A., Auzende, J.-M., Kojima, S., Segonzac, M., Fujiwara, Y., Hunt, J.C., Gena, K., Miura, T., Kikuchi, T., Yamaguchi, T., Toda, T., Chiba, H., Tsuchida, S., Ishibashi, J., Henry, K., Zbinden, M., Pruski, A., Inoue, A., Kobayashi, H., Birrien, J.-L., Naka, J., Yamanaka, T., Laporte, C., Nishimura, K., Yeats, C., Malagun, S., Kia, P., Oyaizu, M., and Katayama, T., 1999. Hydrothermal vent communities in the Manus Basin, Papua New Guinea: Results of the BIOACCESS cruises in ’96 and ’98. *InterRidge News*, 8:12-18.

Hohnen, P.D., 1978. Geology of New Ireland, Papua New Guinea. Bureau of Mineral Resources, Geology and Geophysics, Australia, Bulletin 194.

Ishibashi, J., Wakita, H., Okamura, K., Gamo, T., Shitashima, K., Charlou, J.L., Jean-Baptiste, P., and Shipboard Party, 1996. Chemical characteristics of hydrothermal fluids from the Manus backarc basin, Papua New Guinea,. II. Gas components. *Eos*, WPGM Supplement, 77:W116.

Johnson, R.W., 1976. Late Cainozoic volcanism and plate tectonics at the southern margin of the Bismarck Sea, Papua New Guinea. *In*, R.W. Johnson (Ed), *Volcanism in Australasia*, Elsevier, 101-116.

Martinez, F., and Taylor, B., 1996. Fast backarc spreading, rifting and microplate rotation between transform faults in the Manus Basin, Bismarck Sea. *In* Auzende, J.-M., and Collot, J.-Y.C (Eds.), *Seafloor Mapping in the West, Southwest and South Pacific.* Mar. Geophys. Res., 18:203-224.

Parr, J.M., Binns, R.A., and Gemmell, J.B., 1996. Sulfide chimneys from the Satanic Mills site in the PACMANUS hydrothermal field, eastern Manus Basin, Papua New Guinea. *Eos*, WPGM Supplement, 77:W120.

Scott, S.D., and Binns, R.A., 1995. Hydrothermal processes and contrasting styles of mineralization in the western Woodlark and eastern Manus basins of the western Pacific. *In* Parson, L.M., Walker, C.L., and Dixon, D.R. (Eds.), *Hydrothermal Vents and Processes*, Geol. Soc. Spec. Pub., 87:191-205.

Shitashima, K., Gamo, T., Okamura, K., and Ishibashi, J., 1997. Trace elements at the Manus Basin, Papua New Guinea. *JAMSTEC Jour. Deep Sea Res.*, 13:249-255.

Stewart, W.D., and Sandy, M.J., 1988. Geology of New Ireland and Djaul Islands, northeastern Papua New Guinea. *In* Geology and Offshore Resources of Pacific Island Arcs, - New Ireland and Manus region, Papua New Guinea. *In* Marlow, M.S., Dafisman, S.V., and Exon, N.F. (Eds.), *Circum-Pacific Council for Energy and Mineral Resources, Earth Science Series*, 9:13-30.

Taylor, B., 1979. Bismarck Sea: evolution of a backarc basin. *Geology*, 7:171-174.

Taylor, B.J., Crook, K.A.W., Sinton, J.L., and Petersen, L., 1991. Manus Basin, Papua New Guinea. Hawaii Institute of Geophysics, Pacific Sea Floor Atlas, Sheets 1-7.

Taylor, B., Goodliffe, A., Martinez, F., and Hey, R., 1995. Continental rifting and initial sea-floor spreading in the Woodlark basin. *Nature*, 374:534-537.

Tregoning, P., Lambeck, K., Stolz, A., Morgan, P., McClusky, S., van der Beek, P., McQueen, H., Jackson, R., Little, R., Laing, A., and Murphy, B., 1998. Estimation of current plate motions in Papua New Guinea from Global Positioning System observations. *J. Geophys. Res.*, 103:12,181-12,203.

Waters, J.C., Binns, R.A., and Naka, J., 1996. Morphology of submarine felsic volcanic rocks on Pual Ridge, eastern Manus Basin, Papua New Guinea. *Eos*, WPGM Supplement, 77:W120.

Woodhead, J.D., Eggins, S.M., and Johnson, R.W., 1998. Magma genesis in the New Britain island arc: Further insights into melting and mass transfer processes. *J. Petr.*, 39:1641-1668.

Woodhead, J.D., and Johnson, R.W., 1993. Isotopic and trace-element profiles across the New Britain island arc, Papua New Guinea. *Cont. Min. Pet.*, 113:479-491.

Yang, K., and Scott, S.D., 1996. Possible contribution of a metal-rich magmatic fluid to a sea-floor hydrothermal system. *Nature*, 383:420-423.

FIGURE CAPTIONS

Figure 1. Major active hydrothermal sites (stars) at convergent margins of the western Pacific Ocean. Large arrows indicate general plate motion directions.

Figure 2. Regional tectonic setting of the PACMANUS area to be drilled during Leg 193. The Manus Basin occupies a backarc position relative to present-day subduction on the New Britain Trench to its south. Creation of new oceanic crust occurs at the Manus spreading center and at smaller segments to its west. Major transform faults are somewhat oblique to the spreading segments. The eastern Manus rift zone is a pull-apart structure between two of the major transform faults. It is underlain by thinned lower Tertiary arc crust, equivalent to exposures on New Ireland to the north and New Britain to the south. This older crust was generated during subduction on the now inactive Manus Trench. Active volcanoes of the Bismarck arc, above the New Britain subduction-Benioff zone are indicated by serrated-edged circles. Submarine volcanism in the eastern Manus rift lies well off the trend of this chain. Known hydrothermal sites include Conical Seamount, SuSu, Franklin Seamount, Vienna Woods, and Williaumez Rise. Plate motions are denoted by large arrowheads on thin lines annotated with rates. Curved thin arrows denote the sense of rotation on microplates as defined by GPS geodesy (Tregoning et al., 1998) or by opening and westward propagation of the Woodlark Basin (Taylor et al., 1995).

Figure 3. Tectonic model for the Manus Basin, following Martinez and Taylor (1996). About 80 km of extension by low-angle normal faulting and crustal thinning has occurred in the eastern Manus Basin between the Weitin and Djaul transform faults. The same amount of movement occurred on the Willaumez transform fault, where a slight obliquity between extension direction and fault strike allowed volcanism in the Extensional transform zone. Between the Willaumez and Djaul transforms, equivalent movement was accommodated by wedge-shaped opening of the Manus spreading center and compensating counter-clockwise rotation of the Manus microplate. MORB-type basaltic volcanism dominates the Manus spreading center, the Extensional transform zone, the east Sherburne volcanic zone, which overlies a sediment basin, and limited activity in the Southern rifts. By contrast, the eastern Manus Basin is dominated by arc-type volcanism.

Figure 4. Bathymetry of the eastern Manus Basin, from multibeam data compiled by Institut francàis de rescherche pour l'exploitation de la mer (IFREMER). The southeast-trending Djaul

transform is conspicuous. The northeast trending deep on the western side is a failed spreading segment. PACMANUS lies at the crest of a northeast trending ridge of dacite (Pual Ridge).

Figure 5. Seafloor geology of the eastern Manus Basin. Edifices of the Eastern Manus volcanic zone, which extends between the active ends of the Djaul and Weitin transform faults, range from picritic basalt to rhyodacite in composition. Filled circles denote known hydrothermal sites, including the three main active sites of PACMANUS, DESMOS, and Susu Knolls. Gray lines indicate extensional fault scarps.

Figure 6. Geology of the PACMANUS hydrothermal field as derived from bottom-tow photography and manned submersible dives. Tracks shown are from the PACMANUS cruises (*Frankin*, 1991, 1993, 1996, and 1997), EDISON-I cruise (*Sonne*, 1994), ManusFlux cruise (*Yokosuka*, 1995), BIOACCESS cruises (*Natsushima*, 1996, 1998), and KODOS'99 cruise (*Onnuri*, 1999).

Figure 7. Primary and alternate drill sites (PCM-xA) along the crest of Pual Ridge. Active hydrothermal areas containing sulfide chimneys are identified. Proposed Site PCM-4A lies at the foot of the southeastern flank of Pual Ridge. Alternate Site PCM-5A is ~600 m northeast of primary Site PCM-1A, in a flat area farther from hydrothermal discharge.

Figure 8. A True-scale cross section and (**B**) longitudinal section of Pual Ridge (see transect lines on Fig. 7), showing inferred subsurface geology and presumed mixing between magmatic fluids and circulating seawater—models to be tested during Leg 193. Zones of progressively higher temperature alteration are expected to be telescoped under the focused vent site with massive sulfide chimneys relative to the situation under the diffuse venting zone at Snowcap. Leg 193 is not expected to intersect the main intrusive body but might cut some smaller apophyses. mbsl = meters below sea level. T = temperature.

Figure 9. A High-resolution single channel seismic profile across Pual Ridge at the position of the PACMANUS hydrothermal field and (**B**) interpretation. Proposed Sites PCM-2A and PCM-4A lie on the section, whereas proposed Sites PCM-1A and PCM-3A have been projected along the crest of Pual Ridge, which is seismically opaque. A fault is interpreted under Site PCM-4A, where 150 m of basaltic andesite is interpreted to overlie earlier Tertiary basement in the hanging wall.

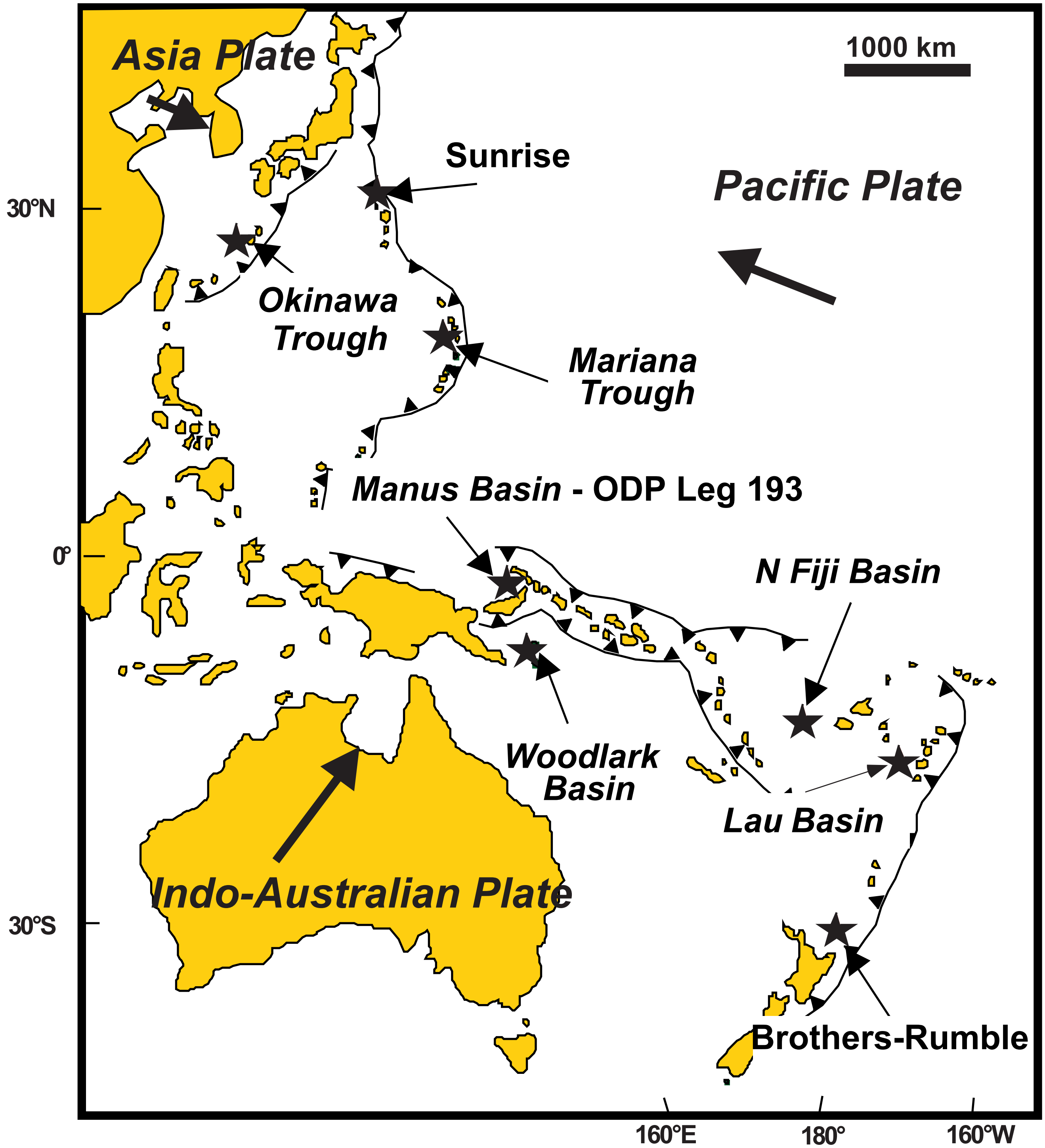
Asia Plate
1000 km
Sunrise
Pacific Plate
30°N
Okinawa
Trough
Mariana
Trough
Manus Basin - ODP Leg 193
N Fiji Basin
0°
Woodlark
Basin
Lau Basin
Indo-Australian Plate
30°S
Brothers-Rumble
160°E
180°
160°W

Figure 1

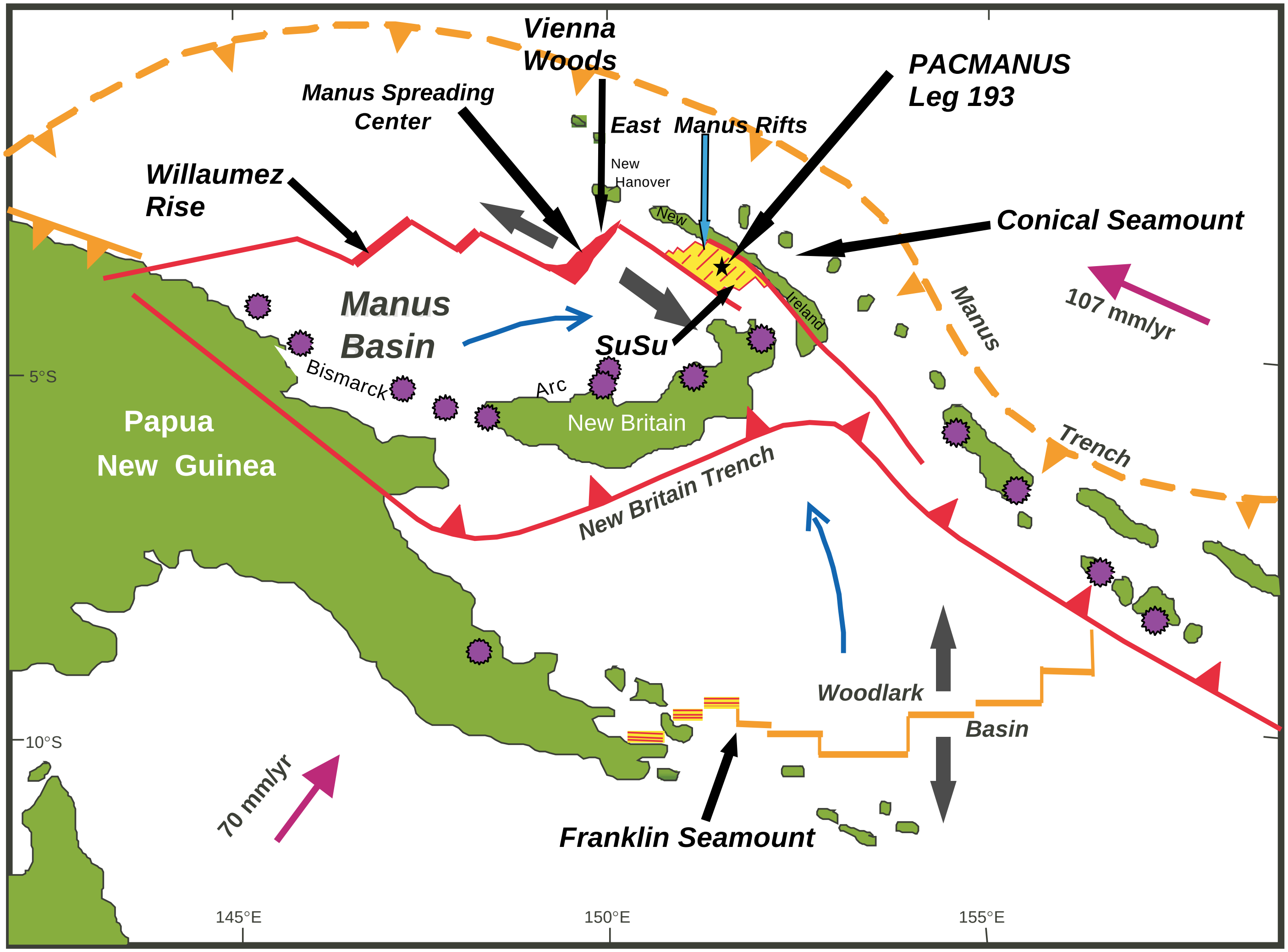
Vienna
Woods
PACMANUS
Leg 193
Manus Spreading
Center
East Manus Rifts
Willaumez
Rise
New
Hanover
New
Ireland
Conical Seamount
Manus
Basin
SuSu
Manus
Trench
107 mm/yr
5°S
Bismarck
Arc
New Britain
Papua
New Guinea
New Britain Trench
Woodlark
Basin
10°S
70 mm/yr
Franklin Seamount
145°E
150°E
155°E

Figure 2

Tectonic elements of the Central and Eastern Manus Basin

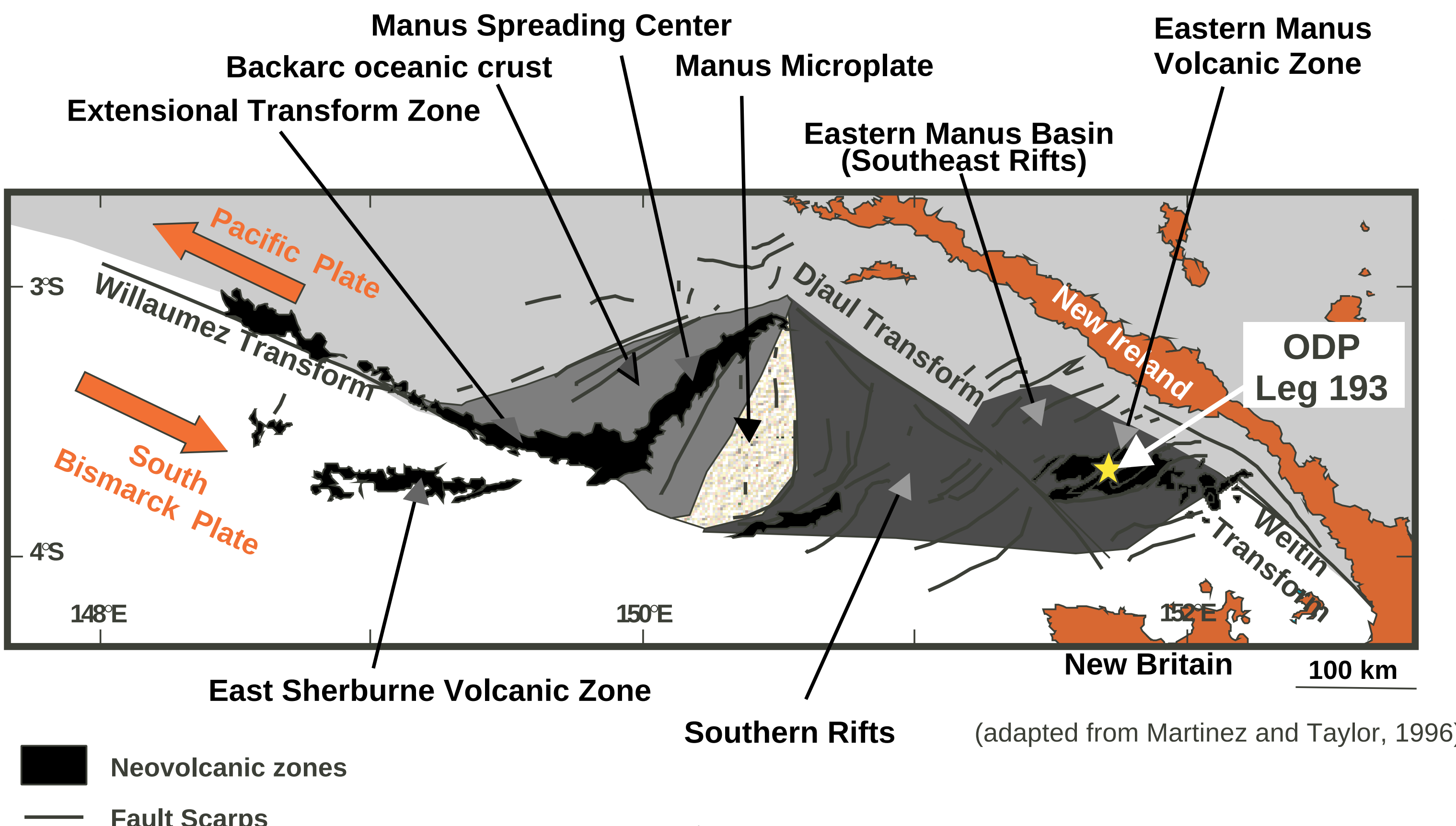

Figure 3

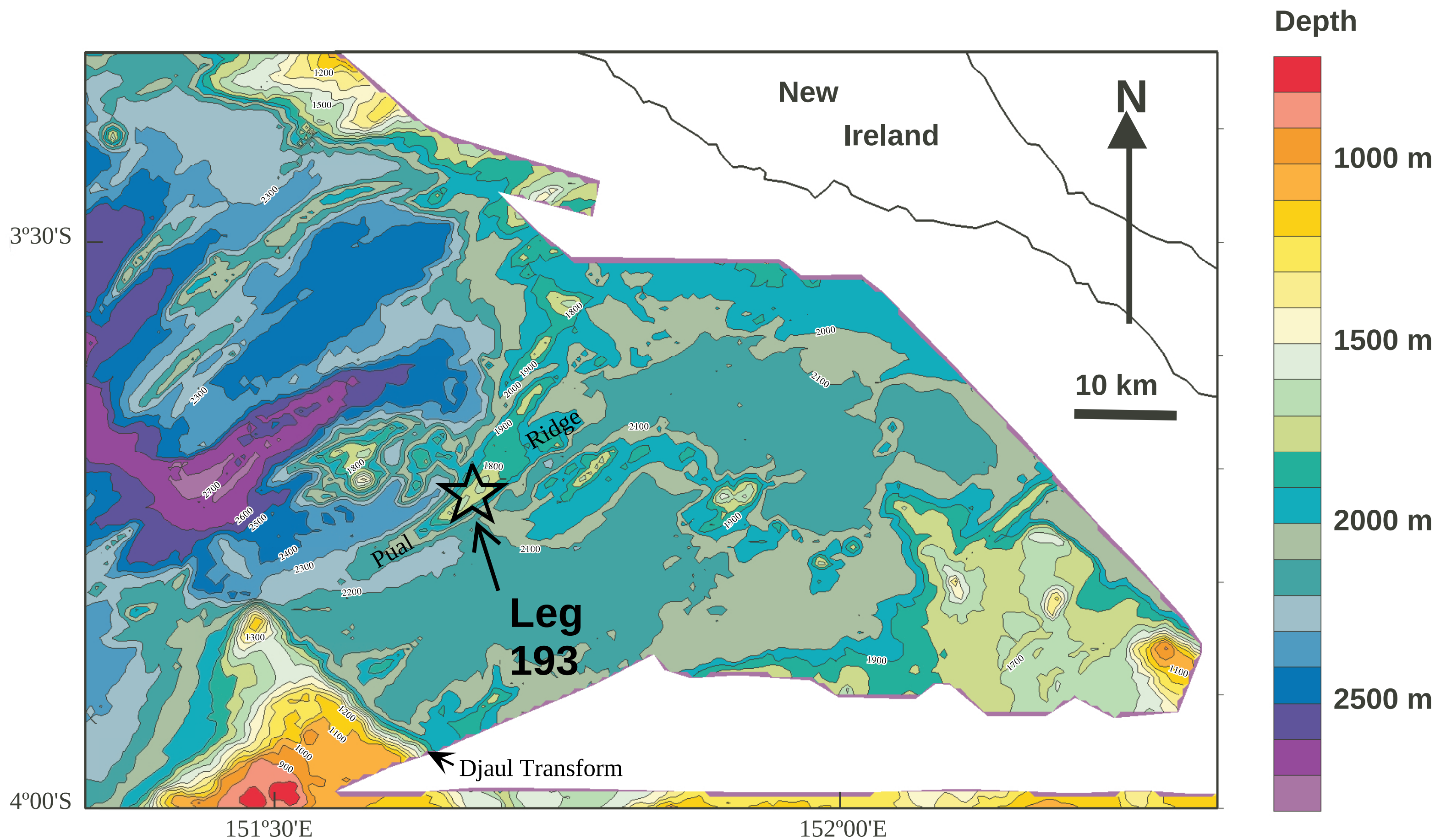
Depth
1000 m
1500 m
2000 m
2500 m
New
Ireland
N
10 km
3°30'S
4°00'S
151°30'E
152°00'E
Pual
Ridge
Leg
193
Djaul Transform

Figure 4

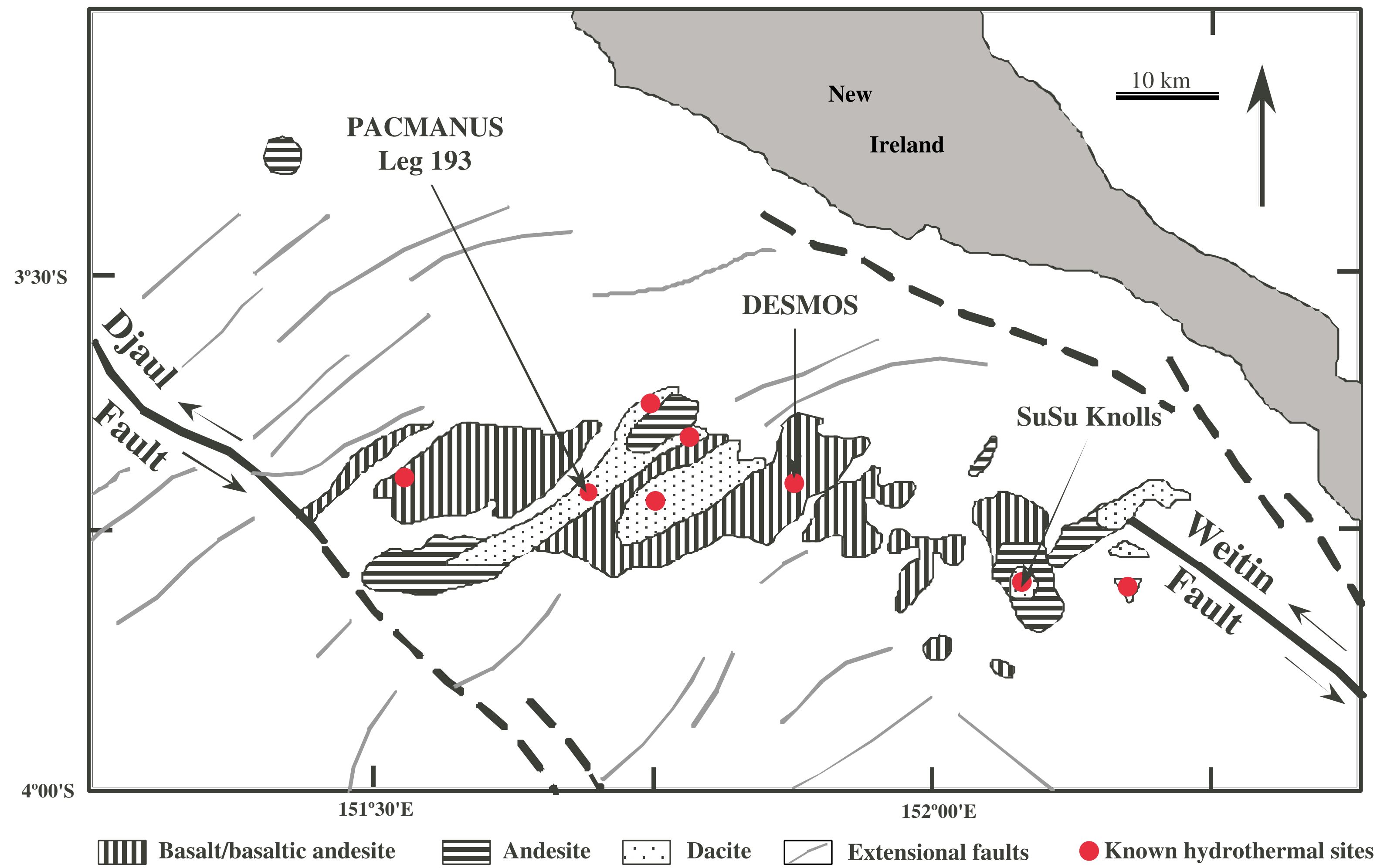
New
Ireland
10 km
PACMANUS
Leg 193
DESMOS
SuSu Knolls
Djaul
Fault
Weitin
Fault
3°30'S
4°00'S
151°30'E
152°00'E
Basalt/basaltic andesite
Andesite
Dacite
Extensional faults
Known hydrothermal sites

Figure 5

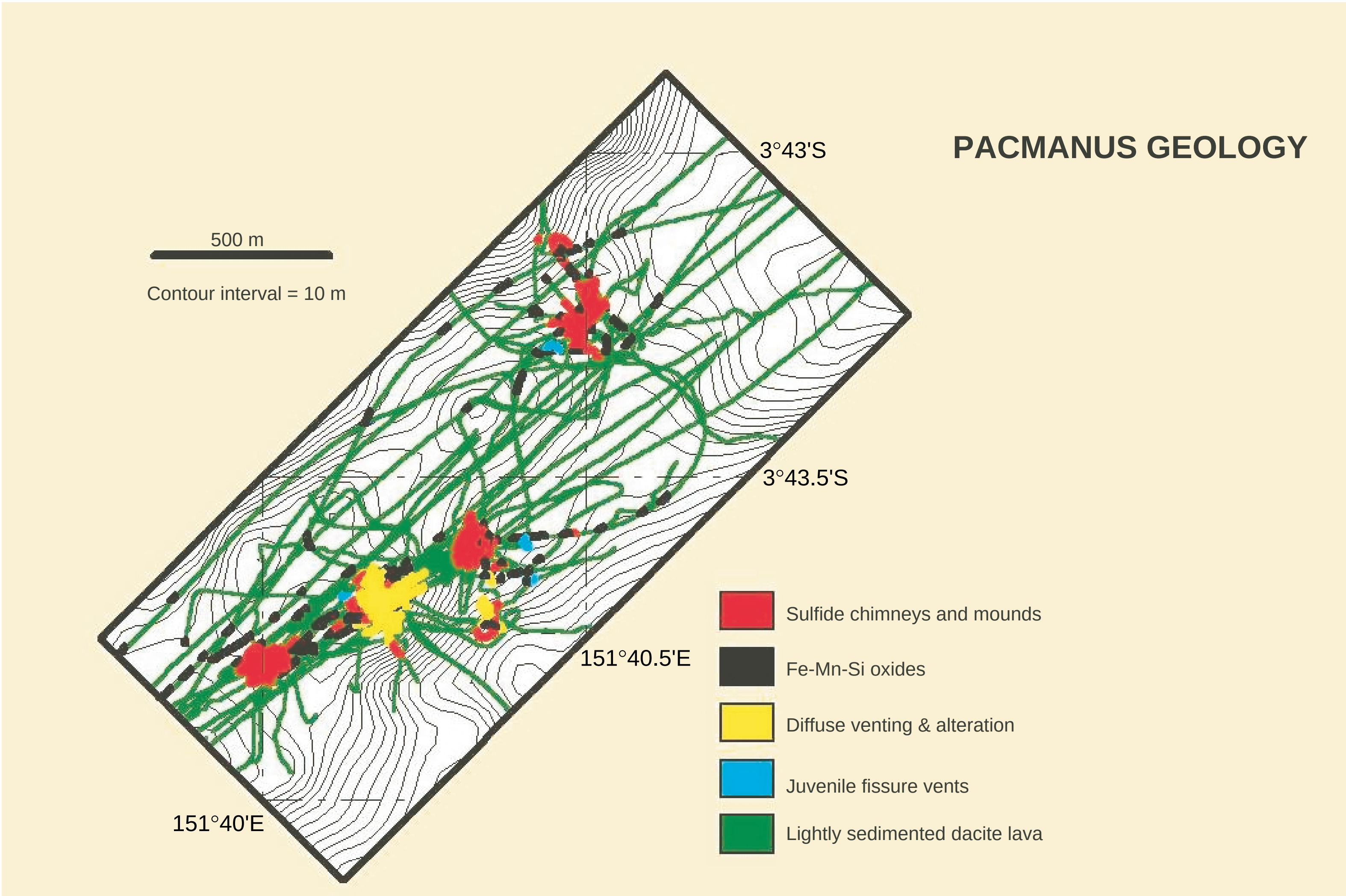
PACMANUS GEOLOGY
500 m
Contour interval = 10 m
3°43'S
3°43.5'S
151°40.5'E
151°40'E
Sulfide chimneys and mounds
Fe-Mn-Si oxides
Diffuse venting & alteration
Juvenile fissure vents
Lightly sedimented dacite lava

Figure 6

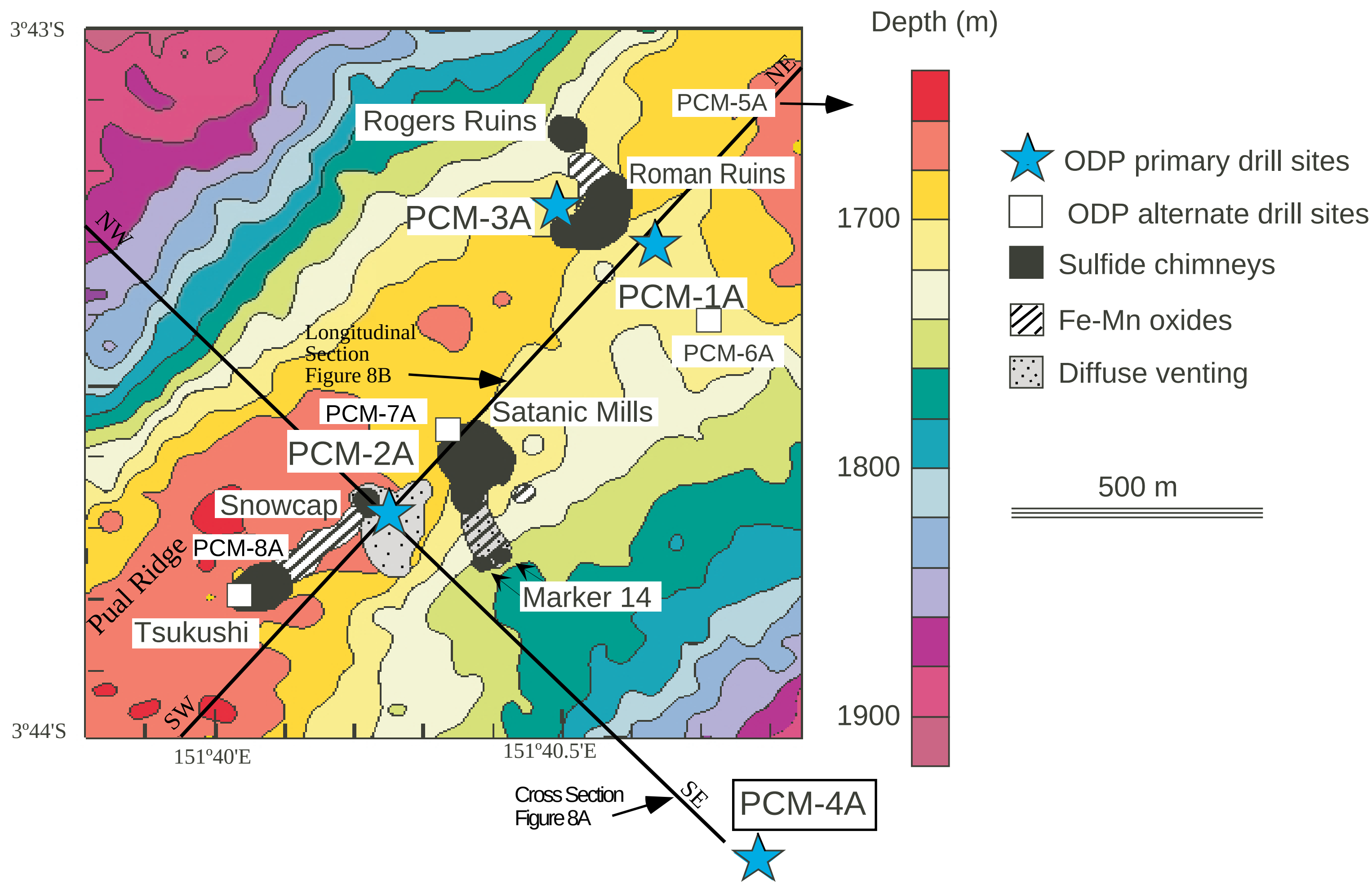
3°43'S
3°44'S
151°40'E
151°40.5'E
Depth (m)
1700
1800
1900
Rogers Ruins
Roman Ruins
PCM-5A
NE
PCM-3A
PCM-1A
PCM-6A
NW
Longitudinal Section Figure 8B
PCM-7A
Satanic Mills
PCM-2A
Snowcap
PCM-8A
Marker 14
Pual Ridge
Tsukushi
SW
SE
Cross Section Figure 8A
PCM-4A
ODP primary drill sites
ODP alternate drill sites
Sulfide chimneys
Fe-Mn oxides
Diffuse venting
500 m

Figure 7

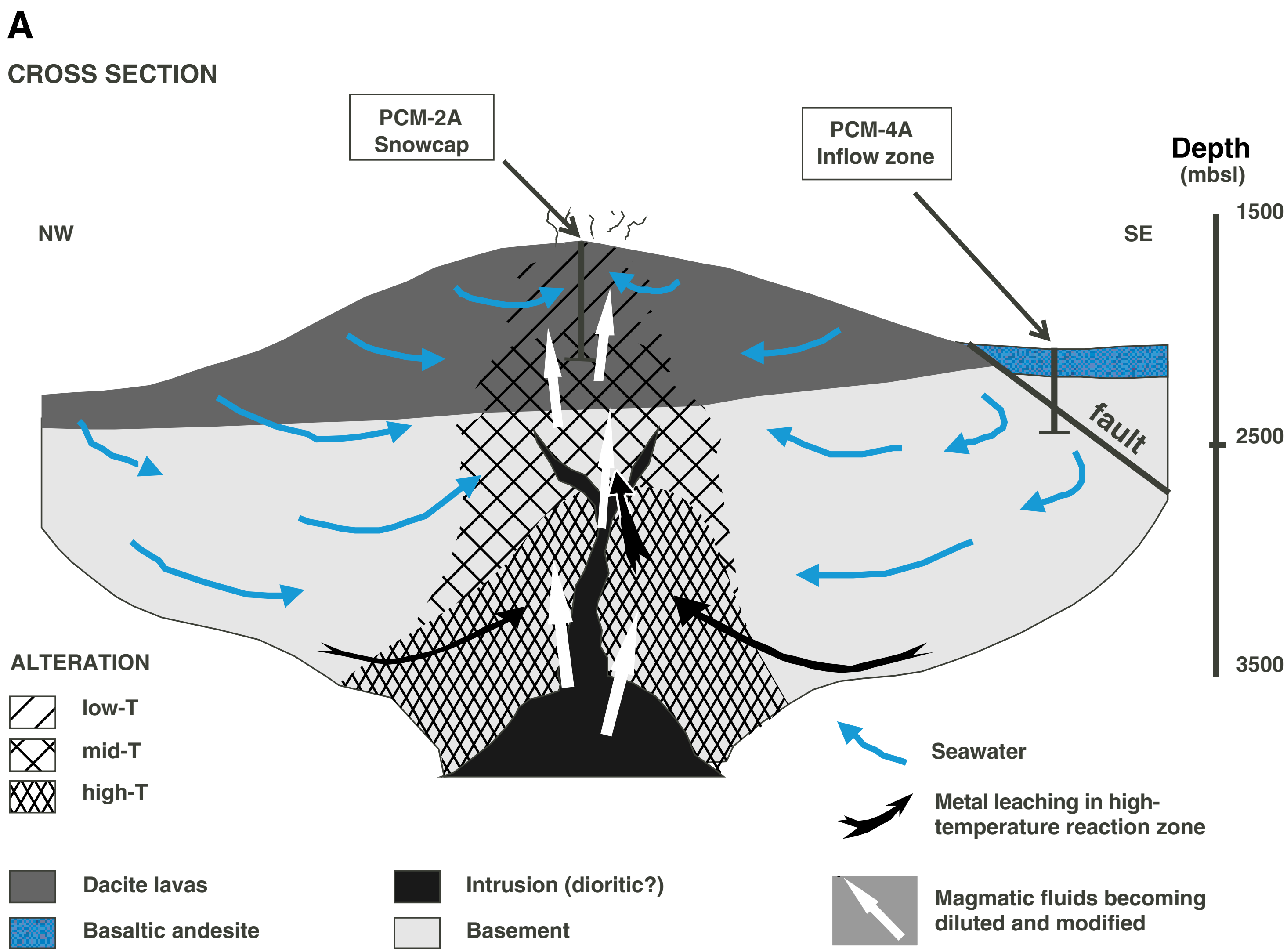
A
CROSS SECTION
PCM-2A
Snowcap
PCM-4A
Inflow zone
Depth
(mbsl)
1500
2500
3500
NW
SE
fault
ALTERATION
low-T
mid-T
high-T
Dacite lavas
Basaltic andesite
Intrusion (dioritic?)
Basement
Seawater
Metal leaching in high-temperature reaction zone
Magmatic fluids becoming diluted and modified

Figure 8

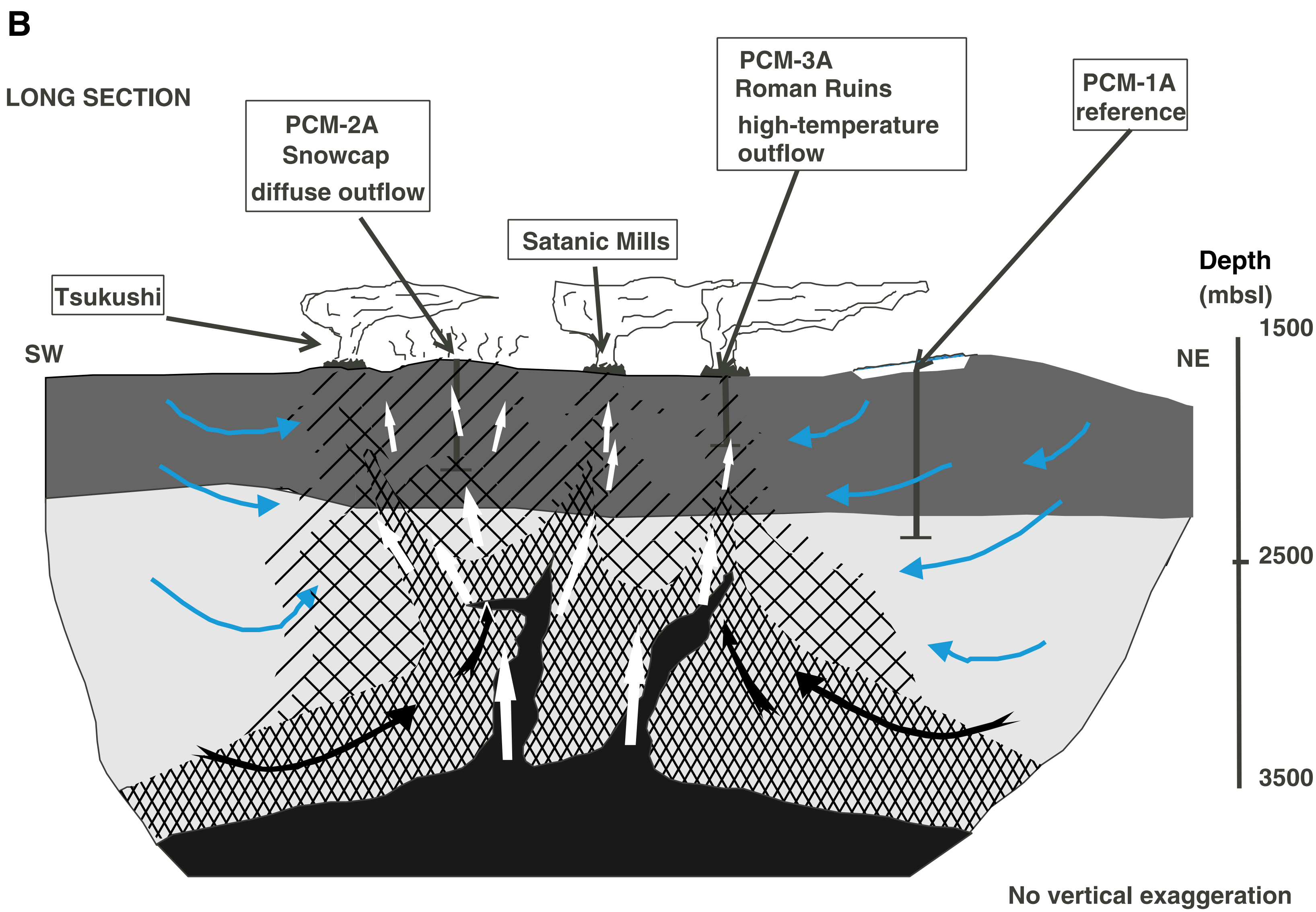

Figure 8

See legend on Figure 8A

A

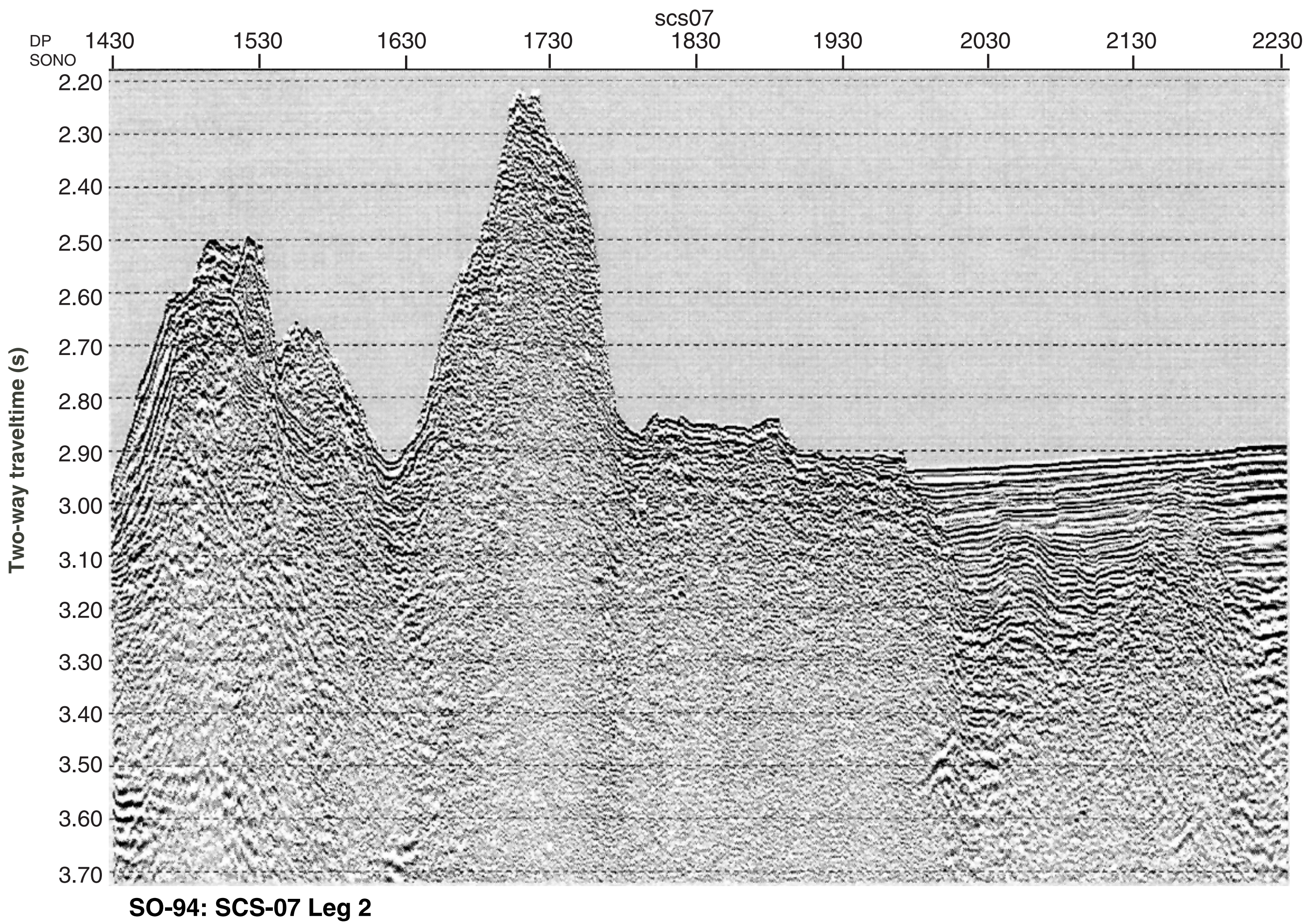
scs07
DP
SONO
1430
1530
1630
1730
1830
1930
2030
2130
2230
Two-way traveltime (s)
2.20
2.30
2.40
2.50
2.60
2.70
2.80
2.90
3.00
3.10
3.20
3.30
3.40
3.50
3.60
3.70
SO-94: SCS-07 Leg 2

Figure 9

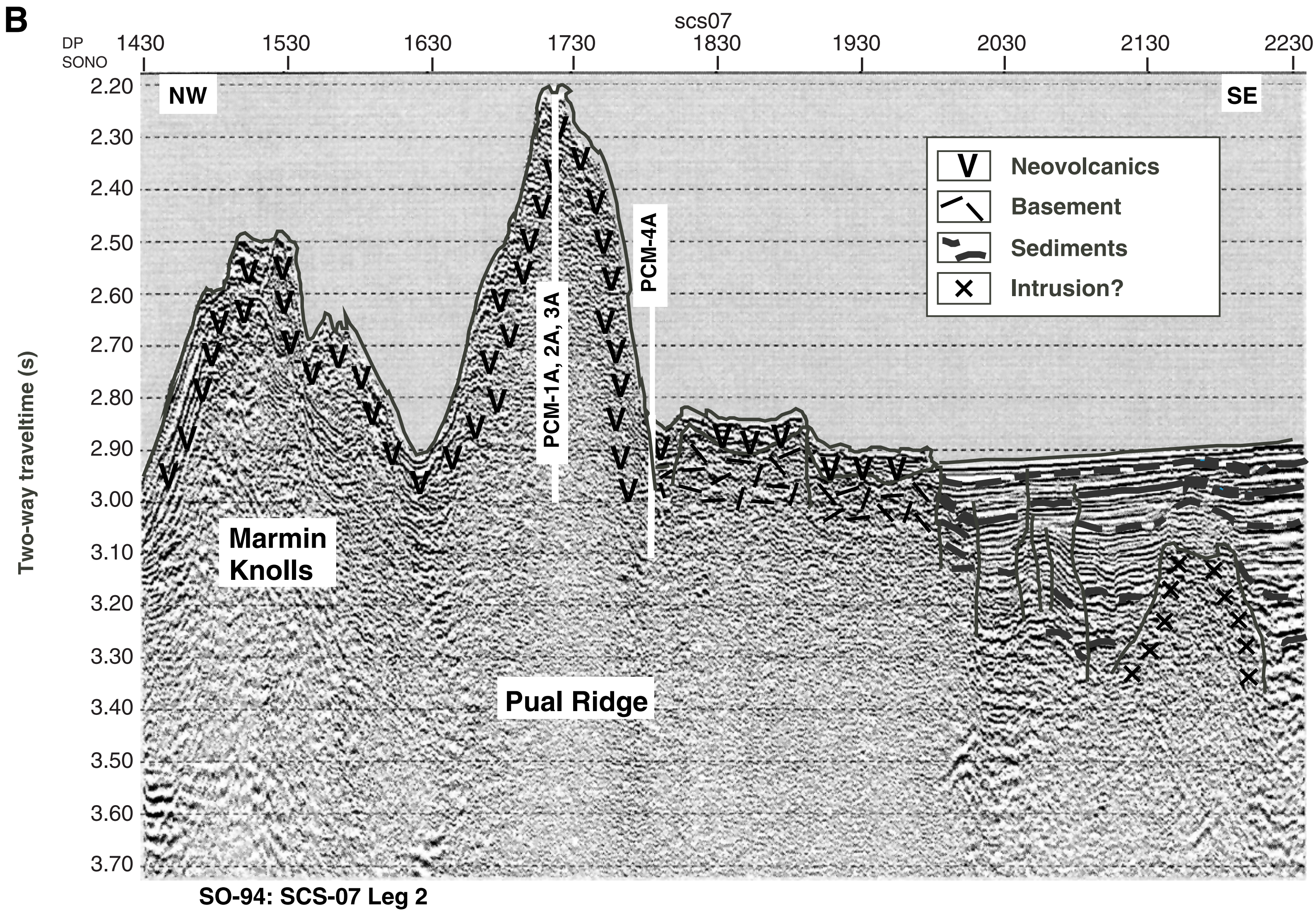
B
scs07
DP
SONO
1430
1530
1630
1730
1830
1930
2030
2130
2230
NW
SE
Two-way traveltime (s)
2.20
2.30
2.40
2.50
2.60
2.70
2.80
2.90
3.00
3.10
3.20
3.30
3.40
3.50
3.60
3.70
Neovolcanics
Basement
Sediments
Intrusion?
PCM-1A, 2A, 3A
PCM-4A
Marmin Knolls
Pual Ridge
SO-94: SCS-07 Leg 2

Figure 9

Leg 193 - Eastern Manus Back Arc Basin (P479-Rev2)

Operations Plan and Time Estimate for Primary Sites

Site No.	Location Lat/Long	Water Depth	Projected Operations Plan (depths in mbsf)	Transit (days)	Drilling (days)	Logging (days)	Total On-site
Guam	013°20.0'N		Port call activities - Guam				
	159°57.789'E						
			Transit 1147 nmi from Guam to PCM-2A @ 10.5 kt	4.6			
PCM-2A	3°43.690'S	1655m	Hole A: RCB/ADCB core to ~500 mbsf,		14.4	1.4	15.8
	151°40.200'E		1st/2nd bits RCB, then 3rd/4th bits ADCB				
			Log w/triple combo, FMS-DSI, temp tool, and 2 ea fluid samples				
			DP move 0.6 nmi from PCM-2A to PCM-3A @ 1.5 kt	0.1			
PCM-3A	3°43.230'S	1696m	Hole A: RCB/ADCB core to ~300 mbsf,		8.6	1.2	9.8
	151°40.521'E		1st bit RCB and 2nd bit ADCB				
			Log w/triple combo, FMS-DSI, temp tool, and 2 ea fluid samples				
			DP move from PCM-3A to PCM-1A @ 1.5 kt	0.1			
PCM-1A	3°43.293'S	1720m	Hole A: RCB/ADCB core to ~300 mbsf,		8.6	1.2	9.8
	151°40.583'E		1st bit RCB and 2nd bit ADCB				
			Log w/triple combo, FMS-DSI, temp tool, and 2 ea fluid samples				
			DP move from PCM-1A to PCM-3A @ 1.5 kt	0.1			
PCM-3A	3°43.230'S	1696m	Hole B: LWD/RAB hole to ~100 mbsf			2.6	2.6
(return to)	151°40.521'E						
			DP move from PCM-3A to PCM-2A @ 1.5 kt	0.1			
PCM-2A	3°43.690'S	1655m	Hole B: LWD/RAB hole to ~100 mbsf			2.6	2.6
(return to)	151°40.200'E						
			DP move from PCM-2A to PCM-1A @ 1.5 kt	0.1			
PCM-1A	3°43.293'S	1720m	Hole B: LWD/RAB hole to ~100 mbsf			2.9	2.9
(return to)	151°40.583'E						
Townsville	019°07.8' S		Transit 1075 nmi from PCM-1A to Townsville @ 10.5 kt	4.4			
	146°28.8' E						
				9.5	**31.6**	**11.9**	**43.5**

Note: Total includes 5.0 day port call. **TOTAL DAYS: 58.0**

DATE: 25 April 2000 **FILE: I:\ DATA \ DSD_INFO \ Leg193\193ProjB.xls** **BY: M. A. Storms**

Leg 193 - Eastern Manus Back Arc Basin (P479-Rev2)

Alternate Sites

Site No.	Location Lat/Long	Water Depth	Projected Operations Plan (depths in mbsf)	Transit (days)	Drilling (days)	Logging (days)	Total On-site
PCM-4A	3°44.445'S	2139m	Hole A: RCB to 300 mbsf	n/a	9.0	1.4	10.4
(4th priority	151°40.755'E		Log w/triple combo, FMS-DSI, and temp tool/fluid sampling				
site)							
PCM-5A	3°43.115'S	1647m	Hole A: RCB to 700 mbsf. Drilling plan TBD based upon results	n/a	20.4	1.6	22.0
(alternate to	151°41.084'E		at PCM-2A. Possible bare hole reentry or FFF or reentry cone				
PCM-1A)			Log w/triple combo, FMS-DSI, and temp tool/fluid sampling				
PCM-6A	3°43.433'S	1725m	Hole A: RCB to 700 mbsf. Drilling plan TBD based upon results	n/a	20.4	1.6	22.0
(alternate to	151°41.727'E		at PCM-2A. Possible bare hole reentry or FFF or reentry cone				
PCM-1A)			Log w/triple combo, FMS-DSI, and temp tool/fluid sampling				
PCM-7A	3°43.600'S	1700m	Hole A: RCB to TBD mbsf. Drilling plan TBD based upon result	n/a	8.6	1.2	9.8
(alternate to	151°40.325'E		at PCM-2A. Possible bare hole reentry or FFF or reentry cone				
PCM-3A)			Log w/triple combo, FMS-DSI, and temp tool/fluid sampling				
PCM-8A	3°43.790'S	1690m	Hole A: RCB to 300 mbsf. Drilling plan TBD based upon results	n/a	8.6	1.2	9.8
(alternate to	151°40.015'E		at PCM-2A. Possible bare hole reentry or FFF or reentry cone				
PCM-3A)			Log w/triple combo, FMS-DSI, and temp tool/fluid sampling				

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SITE SUMMARIES

Site: PCM-1A

Priority: 2 (or 3 if PCM-2A yields volcanic architecture)
Position: 3°43.293'S, 151°40.583'E
Water Depth: 1720 m
Sediment Thickness: 0 m
Target Drilling Depth: 700 m
Approved Maximum Penetration: 700 mbsf
Seismic Coverage: SO-94/SCS-07 Leg 2, 600 m abeam common depth point (CDP) 1709 (profile shows no substructure)

Objectives: The objectives of PCM-1A are to determine the

1. Volcanic architecture of Pual Ridge;

2. Possible fringes of subsurface alteration system; and

3. Possible evidence for shallow-level seawater input to system.

Drilling Program: To be determined (TBD) after evaluating the results of drilling at Site PCM-2A. Options include bare-hole reentry (BHR), free-fall funnel (FFF) deployment and/or a reentry cone. Requires multiple reentry to achieve depth target.

Logging and Downhole: Fluid and temperature sampling as required. Triple combo, FMS/sonic, logging while drilling.

Nature Of Rock Anticipated: Dacite lavas, some dikes and sills, possible andesite at depth, possible metavolcanic basement. Local altered dacite and mineralized veins.

Site: PCM-2A

Priority: 1
Position: 3°43.690'S, 151°40.200'E
Water Depth: 1655 m
Sediment Thickness: 0 m
Target Drilling Depth: up to 700 m
Approved Maximum Penetration: 500 mbsf
Seismic Coverage: Sonne SO-94/SCS Leg 2, CDP 1720

Objectives: The objectives of PCM-2A are to determine the

1. Subsurface alteration and mineralization patterns, and their variation with depth, beneath an area of diffuse, low-temperature venting and acid sulfate alteration;

2. Hydrothermal fluid pathways;

3. Possible existence of subhalative massive sulfide bodies; and

4. Volcanic architecture if detectible through alteration.

Drilling Program: Bare rock spud with 9-7/8-in RCB. Drill until ±50 rotating hours or depth in excess of 250 mbsf. Bare-hole reentry with ADCB and core to target depth (TD). Alternate strategy if BHR fails is to drill large diameter pilot hole, insert free-fall funnel, core to TD. If hole stability is problematic, we may decide to deploy a reentry cone with casing.

Logging and Downhole: Fluid and temperature sampling as required. Triple combo, FMS/sonic, logging while drilling.

Nature Of Rock Anticipated: Altered and fresh dacite lava and hyaloclastite, mineralized veins.

Site: PCM-3A

Priority: 3 (or 2 if PCM-2A yields volcanic architecture)
Position: 3°43.230'S, 151°40.521'E
Water Depth: 1696 m
Sediment Thickness: 0 m
Target Drilling Depth: up to 650 m
Approved Maximum Penetration: 300 mbsf
Seismic Coverage: Sonne SO-94/SCS Leg 2, 150 m abeam CDP 1705

Objectives: The objectives of PCM-3A are to determine the

1. Subsurface alteration and mineralization patterns, and their variation with depth, adjacent to an area of focused, high-temperature venting; and

2. Hydrothermal fluid pathways.

Drilling Program: Bare-rock spud; reentry may be required to meet depth objectives. Alternate drilling strategy may be employed based on the results of operations at Site PCM-2A. Options include bare-hole reentry, free-fall funnel deployment and/or a reentry cone.

Logging and Downhole: Fluid and temperature sampling as required. Triple combo, FMS/sonic, logging while drilling.

Nature Of Rock Anticipated: Fresh and altered dacite lava, mineralized veins, possible massive sulfide intervals.

Site: PCM-4A

Priority: 4 (or 3 if PCM-2A yields volcanic architecture)
Position: 3°44.445'S, 151°40.755'E
Water Depth: 2139 m
Sediment Thickness: 10-20 cm ooze
Target Drilling Depth: 350 m
Approved Maximum Penetration: 350 mbsf
Seismic Coverage: Sonne SO-94/SCS-07 Leg 2; 150 m abeam CDP1785

Objectives: The objectives of PCM-4A are to determine the

1. Heat flow and alteration at a potential seawater influx zone;

2. Intersect and characterize a presumed low angle extensional fault controlling Pual Ridge eruption (at ca 250 m); and

3. Test arc crust basement beneath 150 m basaltic andesite flow sequence.

Drilling Program: TBD after evaluating the results of drilling at Site PCM-2A. Options include bare-hole reentry, free-fall funnel deployment and/or a reentry cone. Requires multiple reentry to achieve depth target.

Logging and Downhole: Fluid and temperature sampling as required. Triple combo, FMS/sonic, logging while drilling.

Nature Of Rock Anticipated: Basaltic andesite lavas, metavolcanics (basement), fault gouge.

Site: PCM-5A

Priority: Alternate for PCM-1A
Position: 3°43.115'S, 151°41.084'E
Water Depth: 1647 m
Sediment Thickness: 0 m
Target Drilling Depth: 700 m
Approved Maximum Penetration: (Not yet approved by Site Survey Panel [SSP], Marker A at start of tow MCV-24)
Seismic Coverage: Sonne SO-94/SCS Leg 2

Objectives: The objectives of PCM-5A are to determine the

1. Volcanic architecture of Pual Ridge;

2. Possible fringes of subsurface alteration system; and

3. Possible evidence for shallow-level seawater input to system.

Drilling Program: TBD after evaluating the results of drilling at Site PCM-2A. Options include bare-hole reentry, free-fall funnel deployment and/or a reentry cone. Requires multiple reentry to achieve depth target.

Logging and Downhole: Fluid and temperature sampling as required. Triple combo, FMS/sonic, logging while drilling.

Nature of Rock Anticipated: Dacite lavas, some dikes and sills, possible andesite at depth, possible metavolcanic basement. Local altered dacite and mineralized veins.

Site: PCM-6A

Priority: Alternate for PCM-1A
Position: 3°43.433'S, 151°40.727'E
Water Depth: 1725 m
Sediment Thickness: 0 m
Target Drilling Depth: 700 m
Approved Maximum Penetration: (Not yet approved by SSP, 1348h on Dive 1063, lightly sedimented sheetflow surface)
Seismic Coverage: Sonne SO-94/SCS Leg 2

Objectives: The objectives of PCM-6A are to determine the

1. Volcanic architecture of Pual Ridge;

2. Possible fringes of subsurface alteration system; and

3. Possible evidence for shallow-level seawater input to system.

Drilling Program: TBD after evaluating the results of drilling at Site PCM-2A. Options include bare-hole reentry, free-fall funnel deployment and/or a reentry cone. Requires multiple reentry to achieve depth target.

Logging and Downhole: Fluid and temperature sampling as required. Triple combo, FMS/sonic, logging while drilling.

Nature Of Rock Anticipated: Dacite lavas, some dikes and sills, possible andesite at depth, possible metavolcanic basement. Local altered dacite and mineralized veins.

Site: PCM-7A

Priority: Alternate for, or supplement to, PCM-3A
Position: 3°43.600'S, 151°40.325'E
Water Depth: 1700 m
Sediment Thickness: 0 m
Target Drilling Depth: to bit destruction
Approved Maximum Penetration: Not reviewed by SSP, center of Satanic Mills chimney field
Seismic Coverage: Sonne SO-94/SCS Leg 2, abeam CDP 1715

Objectives: The objectives of PCM-7A are to determine the

1. Subsurface alteration and mineralization patterns, and their variation with depth, beneath an area of focused, high-temperature venting;

2. Hydrothermal fluid pathways; and

3. Thickness of exhalative sulfides, and nature of mound beneath chimneys.

Drilling Program: Bare rock spud, reentry may be required to meet depth objectives. Alternate drilling strategy may be employed based on the results of operations at Site PCM-2A. Options include bare-hole reentry, free-fall funnel deployment and/or a reentry cone.

Logging and Downhole: Fluid and temperature sampling as required. Triple combo, FMS/sonic, logging while drilling.

Nature Of Rock Anticipated: Fresh and altered dacite lava, mineralized veins, possible massive sulfide intervals.

Site: PCM-8A

Priority: Alternate for, or supplement to, PCM-3A
Position: 3°43.790'S, 151°40.015'E
Water Depth: 1690 m
Sediment Thickness: 0 m
Target Drilling Depth: 300 m (continue if conditions allow and results justify)
Approved Maximum Penetration: Not reviewed by SSP, center of Tsukushi chimney field
Seismic Coverage: Sonne SO-94/SCS Leg 2, abeam CDP 1710

Objectives: The objectives of PCM-8A are to determine the

1. Subsurface alteration and mineralization patterns, and their variation with depth, beneath an area of focused, high-temperature venting;

2. Hydrothermal fluid pathways; and

3. Thickness of exhalative sulfides, and nature of mound beneath chimneys.

Drilling Program: Bare rock spud, reentry may be required to meet depth objectives. Alternate drilling strategy may be employed based on the results of operations at Site PCM-2A. Options include bare-hole reentry, free-fall funnel deployment, and/or a reentry cone.

Logging and Downhole: Fluid and temperature sampling as required. Triple combo, FMS/sonic, logging while drilling.

Nature Of Rock Anticipated: Fresh and altered dacite lava, mineralized veins, possible massive sulfide intervals

SCIENTIFIC PARTICIPANTS*

Co-Chief
Fernando Barriga
Departamento de Geologia
Universidade de Lisboa
Edificio C2, Piso 5
Campo Grande, Lisboa 1749-016
Portugal
Internet: f.barriga@fc.ul.pt
Work: (351) 1-750-0066
Fax: (351) 1-759-9380

Co-Chief
Raymond A. Binns
Division of Exploration and Mining
CSIRO
Gate 1, 51 Delhi Road
P.O. Box 136
North Ryde, NSW 2113
Australia
Internet: r.binns@syd.dem.csiro.au
Work: (61) 2-9490-8741
Fax: (61) 2-9490-8921

Staff Scientist
Jay Miller
Ocean Drilling Program
Texas A&M University
1000 Discovery Drive
College Station, TX 77845
USA
Internet: miller@odpemail.tamu.edu
Work: (979) 845-2197
Fax: (979) 845-0876

Geochemist
Liane G. Benning
Department of Earth Sciences
University of Leeds
Leeds LS2 9JT
UK
Email: liane@earth.leeds.ac.uk
Work: (44) 113-233-5220
Fax: (44) 113-233-5259

* Participation will be reviewed to comply with clearance requirements, when such requirements are identified.

Microbiologist
Ryuji Asada
Department of Earth Sciences
Kanazawa University
Kanazawa, Ishikawa Prefecture 920-1192
Japan
Internet: rasada@kenroku.kanazawa-u.ac.jp
Work: 81-76-264-5732
Fax: 81-76-264-5746

Microbiologist
Hiroyuki Kimura
Graduate School of Biosphere Sciences
Hiroshima University
1-4-4 Kagamiyama
Higashi-Hiroshima, Hiroshima 739-8528
Japan
Internet: hirok@ipc.hiroshima-u.ac.jp
Work: (81) 824-24-7986
Fax: (81) 824-22-7059

Paleomagnetist
Sang-Mook Lee
Marine Geology and Geophysics Division
Korea Ocean Research and Development Institute
Anson P.O. Box 29
Seoul 425-600
Korea
Internet: smlee@kordi.re.kr
Work: (82) 345-400-6255
Fax: (82) 345-418-8772

Petrologist
Wolfgang Bach
Department of Geology and Geophysics
Woods Hole Oceanographic Institution
360 Woods Hole Road
MS #8
Woods Hole, MA 02543
USA
Internet: wbach@whoi.edu
Work: (508) 289-2523
Fax: (508) 457-2183

Petrologist
Holger Paulick
Institut für Mineralogie

* Participation will be reviewed to comply with clearance requirements, when such requirements are identified.

Technische Universität Bergakademie Freiberg
Lehrstulh für Lagerstättenlehre
Brennhausgasse 14
Freiberg 09599
Federal Rebublic of Germany
Internet: hpaulick@hotmail.com
Work: (49) 3731-392662
Fax: (49) 3731-392610

Igneous Petrologist
David A. Vanko
Department of Geology
Georgia State Universiy
Atlanta, GA 30303
USA
Internet: dvanko@gsu.edu
Work: (404) 651-2272
Fax: (404) 651-1376

Sulfide Petrologist
Álvaro M. Pinto
Departamento de Geologia
Universidade de Lisboa
Edificio C2, 5 Piso
Campo Grande, Lisboa 1749-016
Portugal
Internet: alvaro.pinto@clix.pt
Work: (351) 1-750-0066
Fax: (351) 1-759-9380

Sulfide Petrologist
Stephen Roberts
Southampton Oceanography Centre
University of Southampton
Empress Dock
Southampton SO14 3ZH
United Kingdom
Internet: sr1@mail.soc.soton.ac.uk
Work: (44) 1703-593246
Fax: (44) 1703-593052

Sulfide Petrologist
Christopher J. Yeats
Division of Exploration and Mining
CSIRO
PO Box 136
North Ryde, NSW 1670

* Participation will be reviewed to comply with clearance requirements, when such requirements are identified.

Australia
Internet: cyeats@syd.dem.csiro.au
Work: (61) 2-9490-8697
Fax: (61) 2-9490-8921

Physical Properties Specialist
Lizet Brokner Christiansen
Department of Earth and Planetary Science
Johns Hopkins University
3400 N. Charles Street
Baltimore, MD 21218
USA
Internet: lizet@jhu.edu
Work: (410) 516-8543
Fax: (410) 516-7933

Sedimentologist
Klas S. Lackschewitz
Fachbereich Geowissenschaften
Universität Bremen
Postfach 330440
Bremen 28334
Federal Republic of Germany
Internet: klacksch@uni-bremen.de
Work: (49) 421-218-7763
Fax: (49) 421-218-9460

LDEO Logging Staff Scientist
Gerardo J. Iturrino
Lamont-Doherty Earth Observatory
Columbia University
Bore Research Group
Palisades, NY 10964
USA
Internet: iturrino@ldeo.columbia.edu
Work: (914) 365-8656
Fax: (914) 365-3182

LDEO Logging Trainee
Anne C. M. Bartetzko
Angewandte Geophysik
Rheinisch-Westfälischen Technischen Hochschule Aachen
RW Technische Hochschule
Lochnerstr. 4-20
Aachen 52064

* Participation will be reviewed to comply with clearance requirements, when such requirements are identified.

Federal Republic of Germany
Internet: anne@sun.geophac.rwth-aachen.de
Work: (49) 241-806773
Fax: (49) 241-8888-132

Schlumberger Engineer
Kerry Swain
Schlumberger Offshore Services
369 Tristar Drive
Webster, TX 77598
USA
internet: swain@webster.wireline.slb.com
Work: (281) 480-2000
Fax: (281) 480-9550

Operations Manager
Michael A. Storms
Ocean Drilling Program
Texas A&M University
1000 Discovery Drive
College Station, TX 77845-9547
USA
Internet: storms@odpemail.tamu.edu
Work: (979) 845-2101
Fax: (979) 845-2308

Laboratory Officer
Burney Hamlin
Ocean Drilling Program
Texas A&M University
1000 Discovery Drive
College Station, TX 77845-9547
USA
Internet: hamlin@odpemail.tamu.edu
Work: (979) 845-2496
Fax: (979) 845-0876

Marine Lab Specialist: Yeoperson
Michiko Hitchcox
Ocean Drilling Program
Texas A&M University
1000 Discovery Drive
College Station, TX 77845-9547
USA
Internet: hitchcox@odpemail.tamu.edu
Work: (979) 845-2483
Fax: (979) 845-0876

* Participation will be reviewed to comply with clearance requirements, when such requirements are identified.

Marine Lab Specialist: Chemistry
Dennis Graham
Ocean Drilling Program
Texas A&M University
1000 Discovery Drive
College Station, TX 77845-9547
USA
Internet: graham@odpemail.tamu.edu
Work: (979) 845-8482
Fax: (979) 845-0876

Marine Lab Specialist: Chemistry
Chieh Peng
Ocean Drilling Program
Texas A&M University
1000 Discovery Drive
College Station, TX 77845-9547
USA
Internet: peng@odpemail.tamu.edu
Work: (979) 845-2480
Fax: (979) 845-0876

Marine Lab Specialist: Core
Maniko Kamei
Ocean Drilling Program
Texas A&M University
1000 Discovery Drive
College Station, TX 77845-9547
USA
Internet: kamei@odpemail.tamu.edu
Work: (979) 458-1865
Fax: (979) 845-0876

Marine Lab Specialist: Curator
Jessica Huckemeyer
Ocean Drilling Program
Texas A&M University
1000 Discovery Drive
College Station, TX 77845
USA
Internet: huckemeyer@odpemail.tamu.edu
Work: (979) 845-4822
Fax: (979) 845-1303

* Participation will be reviewed to comply with clearance requirements, when such requirements are identified.

Marine Lab Specialist: Downhole Tools, Thin Sections
Gus Gustafson
Ocean Drilling Program
Texas A&M University
1000 Discovery Drive
College Station, TX 77845-9547
USA
Internet: gustafson@odpemail.tamu.edu
Work: (979) 845-8482
Fax: (979) 845-0876

Marine Lab Specialist: Paleomagnetics
Charles A. Endris
Ocean Drilling Program
Texas A&M University
1000 Discovery Drive
College Station, TX 77845
USA
Internet: endris@odpemail.tamu.edu
Work: (979) 845-5135
Fax: (979) 845-0876

Marine Lab Specialist: Physical Properties
Anastasia Ledwon
Ocean Drilling Program
Texas A&M University
1000 Discovery Drive
College Station, TX 77845-9547
USA
Internet: ledwon@odpemail.tamu.edu
Work: (979) 845-9186
Fax: (979) 845-0876

Marine Lab Specialist: Underway Geophysics
Don Sims
Ocean Drilling Program
Texas A&M University
1000 Discovery Drive
College Station, TX 77845-9547
USA
Internet: sims@odpemail.tamu.edu
Work: (979) 458-1067
Fax: (979) 845-0876

Marine Lab Specialist: X-Ray
Robert Olivas
Ocean Drilling Program

* Participation will be reviewed to comply with clearance requirements, when such requirements are identified.

Texas A&M University
1000 Discovery Drive
College Station, TX 77845-9547
USA
Internet: olivas@odpemail.tamu.edu
Work: (979) 845-2481
Fax: (979) 845-0876

Marine Electronics Specialist
Randy W. Gjesvold
Ocean Drilling Program
Texas A&M University
1000 Discovery Drive
College Station , TX 77845-9547
USA
Internet: gjesvold@odpemail.tamu.edu
Work: (979) 845-8482
Fax: (979) 845-0876

Marine Computer Specialist
David Kotz
Ocean Drilling Program
Texas A&M University
1000 Discovery Drive
College Station, TX 77845-9547
USA
Internet: kotz@odpemail.tamu.edu
Work: (979) 862-4848
Fax: (979) 458-1617

ODP/TAMU Programmer
Christopher Bodley
Ocean Drilling Program
Texas A&M University
1000 Discovery Drive
College Station, TX 77845-9547
USA
Internet: bodley@odpemail.tamu.edu
Work: (979) 845-1918
Fax: (979) 845-4857

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