Integrated Ocean Drilling Program
Expedition 310 Scientific Prospectus

Tahiti Sea Level Expedition

The last deglacial sea level rise in the South Pacific

Gilbert F. Camoin
UMR 6635 du CNRS
CEREGE
BP 80
13545 Aix-en-Provence
Cedex 04
France

Yasufumi Iryu
Institute of Geology and Paleontology
Graduate School of Science
Tohoku University
Aobayama
Sendai 980-8578
Japan

David McInroy
ESO Staff Scientist
British Geological Survey
Murchison House
West Mains Road
Edinburgh EH9 3LA
United Kingdom

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ABSTRACT

The history of sea level and sea-surface temperature (SST) variation associated with the last deglaciation is of prime interest to understanding dynamics of large ice sheets and their effects on Earth's isostasy. So far, the only sea level record that encompasses the whole deglaciation is based on offshore drilling of Barbados coral reefs that overlie an active subduction zone, implying that the apparent sea level record may be biased by tectonic movements. This proposal seeks to establish the course and effects of the last deglaciation in a reef setting that developed in a tectonically inactive area at sites located far away from glaciated regions in Tahiti (French Polynesia). At each site, we propose to sample a transect of several offshore drill holes using a dynamically positioned drilling vessel. The study will have three major objectives. The first objective will be to reconstruct the deglaciation curve for the period 20.00–10.00 ka in order to establish the minimum sea level during the Last Glacial Maximum (LGM) and to assess the validity, timing, and amplitude of meltwater pulses (so-called meltwater pulse 1A and 1B [MWP-1A and MWP-1B] events; ~13.80 and 11.30 ka, respectively) that are thought to have disturbed the general thermohaline oceanic circulation and, hence, global climate. Second, we will establish the SST variation accompanying the transgression at each transect. These data will allow us to examine the impact of sea level changes on reef growth, geometry, and biological makeup, especially during reef drowning events, and will help improve the modeling of reef development. The third major objective will be to identify and establish patterns of short-term paleoclimatic changes that are thought to have punctuated the transitional period between present-day climatic conditions following the LGM. We propose to quantify the variations of SSTs based on high-resolution isotopic and trace element analyses on massive coral colonies. When possible, we will try to identify specific climatic phenomena such as the El Niño–Southern Oscillation (ENSO) in the time frame prior to 10.00 ka.

INTRODUCTION

The timing and course of the last deglaciation is generally considered to be an essential component for understanding the dynamics of large ice sheets (Lindstrom and MacAyeal, 1993) and their effects on Earth's isostasy (Lambeck, 1993; Peltier, 1994). Moreover, the disappearance of glacial ice sheets was responsible for dramatic changes in the freshwater fluxes to the oceans, which disturbed the general thermohaline circulation and, hence, global climate (e.g., Stocker and Wright, 1991). Coral reefs are excellent sea level indicators, and their accurate dating by mass spectrometry is of prime importance for determination of the timing of deglaciation events and thus for understanding of the mechanisms driving glacial–interglacial cycles. Furthermore, scleractinian coral colonies can monitor sea-surface temperatures (SSTs) and record past SSTs.

Sea Level Changes as a Global Climate Indicator

Only three deglaciation curves based on coral reef records have been accurately dated for times reaching the Pleistocene/Holocene boundary: in Barbados (Fairbanks, 1989; Bard et al., 1990a, 1990b) between 19.00 and 8.00 ka, in New Guinea between 13.00 and 6.00 ka (Chappell and Polach, 1991; Edwards et al., 1993), and in Tahiti between 13.75 ka and 2380 ^{14}C y before present (BP) (Bard et al., 1996) (Fig. F1). So far, the Barbados curve is the only one to encompass the whole deglaciation because it is based on offshore drilling. However, this site, like New Guinea, is located in an active subduction zone where tectonic movements can be large and discontinuous, so that the apparent sea level records may be biased by variations in the rates of tectonic uplift. Hence, there is a clear need to study past sea level changes in tectonically stable regions or in areas where the vertical movements are slow and/or regular.

The Barbados record suggested that the last deglaciation was characterized by two brief periods of accelerated melting superimposed on a smooth and continuous rise of sea level with no reversals (Fig. F1). These so-called meltwater pulse (MWP)-1A and MWP-1B events (~13.80 and 11.30 ka, respectively) are thought to correspond to massive inputs of continental ice (i.e., ~50–40 mm/y, roughly equivalent to annual discharge rates of 16,000 km^3 for MWP-1A). MWP-1A corresponds to a short and intense cooling period between 14.10 and 13.90 ka in the Greenland records (Johnsen et al., 1992; Grootes et al., 1993) and therefore postdates the initiation of the Bölling-Alleröd warm period at ~14.90–14.70 ka (Broecker, 1992). The sea level jump evidenced in New Guinea at 11.00 ka (Edwards et al., 1993) is delayed by a few centuries when compared to that observed at Barbados. These two meltwater pulses are thought to have induced reef-drowning events (Blanchon and Shaw, 1995). Two "give-up" reef levels have been reported at 90–100 and 55–65 m water depth on the Mayotte fore-slopes (Comoro Islands) and have been related to the Bölling and the post-Younger Dryas meltwater pulses (Dullo et al., 1998); similar features are recorded in the southern Great Barrier Reef (GBR) (Troedson and Davies, 2001) and in the Caribbean (MacIntyre et al., 1991; Grammer and Ginsburg, 1992). A third *Acropora* reef-drowning event at ~7.60 ka has been assumed by Blanchon and Shaw (1995).

However, there are still some doubts concerning the general pattern of sea level rise during the last deglaciation events, including the amplitude of the maximum low-stand during the Last Glacial Maximum (LGM) and the occurrence of increased glacial meltwater with resultant accelerated sea level rise (Broecker, 1990). Furthermore, sawtooth sea level fluctuations between 19.00 and 15.28 ka (Locker et al., 1996) and a sea level fall coeval with climatic changes at ~11 ka are still controversial topics.

Worldwide sea level compilations indicate that local sea level histories varied considerably around the world in relation to both postglacial redistribution of water masses and a combination of local processes (Lambeck, 1993; Peltier, 1994), although significant deviations between model predictions and field data have been noted in several regions (Camoin et al., 1997). The post–last glacial sea level changes at sites located far away from glaciated regions ("far field") provide basic information regarding the melting history of continental ice sheets and the rheological structure of the Earth. The effect of hydroisostasy depends on the size of the islands: for very small islands, the addition of meltwater produces a small differential response between the island and the seafloor, whereas the meltwater load produces significant differential vertical movement between larger islands or continental margins and the seafloor (Lambeck, 1993). There is therefore a need to establish the validity of such effects at two ideal sites located at a considerable distance from the major former ice sheets: (1) on a small oceanic island and (2) on a continental margin. In both cases, it is essential for the sites chosen that the tectonic signal is small or regular within the short time period proposed for investigation so that rigorous tests of proposed northern and southern hemisphere deglaciation curves from Barbados and New Guinea can be made. Two such places are proposed: Tahiti and the GBR. This mission-specific platform (MSP) expedition will conduct investigations at the Tahiti sites only.

Climatic and Oceanographic Changes during Last Deglaciation Events

During latest Pleistocene and early Holocene, climatic variability was primarily related to the effects of seasonality and solar radiation. The results of the Long-Range Investigation, Mapping, and Prediction (CLIMAP) program suggested that LGM tropical SSTs were similar to modern ones. However, this interpretation is not consistent with snowline reconstructions and paleobotanic data (Rind and Peteet, 1985; Anderson and Web, 1994).

The available Sr/Ca and U/Ca data from coral reef areas report SSTs 5°C colder than today during the LGM and 2°C lower at ~10–9 ka at Barbados (Guilderson et al., 1994), whereas studies in the west Pacific indicate that the full amplitude of the glacial Holocene temperature change may have ranged between 3° and 6°C (McCulloch et al., 1996; Beck et al., 1997; Gagan et al., 1998) (Fig. **F1**). Troedson and Davies (2001) define SSTs immediately south of the GBR some 4.5°C colder during the LGM and 1°C colder at 10 ka. This casts doubt upon the phase shift of 3000 y for climate changes between the two hemispheres that was assumed by Beck et al. (1997), in clear distinction to the apparent synchronism of the last deglaciation, inferred from various sources (i.e., coral records, ice cores, snowline reconstructions, vegetation records, and alkenone palaeothermometry) (Bard et al., 1997).

Recent studies have documented Holocene climatic variations. SSTs warmer by 1°C, monsoonal rainfall, and possibly weaker El Niño–Southern Oscillation (ENSO) at ~5.80 ka in Eastern Australia have been deduced from isotopic and Sr/Ca high-resolution measurements on corals from the central GBR (Gagan et al., 1998). An ENSO-like cyclic climatic variation with a return period of 3–5 y has been evidenced in a 4150 y old coral from the Seychelles, although the intensity of the annual decrease in SST caused by monsoonal cooling was lower than that of today (Zinke et al., 2005).

Additional information is required for better knowledge of climatic conditions in tropical regions during the last deglaciation. In these areas, the most debated points are twofold: (1) the quantification of SSTs and the identification of related climatic variations during the last deglaciation events and (2) the timing of the relevant postglacial warming in the two hemispheres.

SCIENTIFIC OBJECTIVES

This proposal succeeds a preliminary proposal submitted to the Joint Oceanographic Institutions for Deep Earth Sampling (JOIDES) in September 1997 to drill drowned reefs and reef terraces at Tahiti. The present submission is a revised version of Proposal 519, which was assessed in Fall 1998 by the Environment Science Steering and Evaluation Panel (ESSEP). It includes some revised sections that address a few comments raised in the panel discussion and concerning the scientific objectives and technical/operational issues. As noted by ESSEP during its fall 1998 review, "the goals are well-aligned with the high-priority objectives of the Long Range Plan (1996) and cover the two subthemes 'Earth's Changing Climate' and 'Causes and Effects of Sea Level Change'." These aims are related to other international scientific programs such as International Geosphere-Biosphere Program (IGBP), Past Global Changes (PAGES) and PAGES/Climate Variability and Predictability (CLIVAR) interface.

1. To establish the course of postglacial sea level rise at Tahiti (i.e., to define the exact shape of the deglaciation curve for the period 20.00–10.00 ka.

The expected results are the following:

- To assess the validity, timing, and amplitude of the MWP-1A event;,
- To assess the maximum sea level drop during the LGM,
- To prove or disprove the sawtooth pattern of sea level rise during the last deglaciation (Locker et al., 1996), and
- To test predictions based on different ice and rheological models.

Reconstruction of sea level curves relies on absolute dating of in situ corals by radiometric methods (^{230}Th/^{234}U by thermal ionization mass spectrometry [TIMS], ^{14}C by accelerator mass spectrometry [AMS]), and paleobathymetric information deduced from biological communities (corals, algae, and mollusks) that live in a sufficiently narrow or specific depth range to be useful as absolute sea level indicators.

2. To define SST variations for the region over the period 20.00–10.00 ka in order gain better knowledge of

- Regional variation of SSTs in the South Pacific,
- Climatic variability and the identification of specific phenomena such as ENSO, and
- Global variation and relative timing of postglacial climate change in the southern and northern hemispheres.

Methods include stable isotope ($\delta^{18}O$) and trace element (Sr/Ca ratios by TIMS) analyses on high-resolution (i.e., at the monthly scale) sampling of massive coral colonies. Coupled analyses of $\delta^{18}O$ and Sr/Ca on the same sample may yield estimates of both temperature and salinity (McCulloch et al., 1996). Stable isotope $\delta^{18}O$ measurements, systematically coupled with those of $\delta^{18}O$ in coral skeletons, will provide information on other parameters (e.g., solar variations or metabolism processes). Geochemical methods will be coupled with measurements and analyses of the bandwidths and microstructural variations in the coral skeletons.

3. To analyze the impact of sea level changes on reef growth and geometry and, especially

- The impact of glacial meltwater phases (identification of reef drowning events),
- The morphological and sedimentological evolution of the foreslopes (highstand versus lowstand processes),
- Modeling of reef building, and
- Environmental changes during reef development.

A numerical model simulating reef building will be used to study the effect of a sea level jump on reef geometry and to qualitatively assess the effect of sea level fluctuations on the reef shape and age-depth relationships.

The present proposal may provide the opportunity to better constrain the deglacial history (see Peltier, 1994; Fleming et al., 1998; Okuno and Nakada, 1999) by documenting, for the first time, the LGM lowstand in well-studied cores in the far field and by comparing the MWP-1A event in the Pacific and Atlantic Oceans. Furthermore, the study of very early deglacial coral material should provide the first Sr/Ca SSTs for the LGM in the Pacific, which could then supplement Barbados sample data (Guilderson et al., 1994) and the recent study of Stage 6 corals (McCulloch et al., 1999).

PROPOSED DRILL SITES

Site Location

Tahiti (17°50′ S, 149°20′ W; S = 142 km^2) is the largest of the Society Islands and is composed of twin shield volcanoes that were active at 1.367 ± 0.016 to 0.187 ± 0.003 Ma. Subsidence rates of 0.25 mm/y have been deduced from dating of aerial lava underlying the Pleistocene reef sequence. This island is surrounded by discontinuous fringing reefs that grade locally into a chain of barrier reefs, commonly interrupted and locally enclosing a narrow lagoon. The barrier reef complex includes, from land seaward: a back-reef zone that corresponds to a 1 km wide bay, reaching a maximum depth of 20 m, a relatively narrow reef-flat zone (130 m in maximum width), and an outer-reef slope that consists of coral-built spurs and grooves. In the northwest, the reef foreslope gently deepens seaward to a depth of 15 m and then steepens sharply to 50 m and forms an almost vertical wall between 50 and 100 m (Table **T1;** Fig. **F2**). Before our site survey data (October 2002), the occurrence of two prominent terraces at 50 m and 90–100 m, dipping seaward and exhibiting living coral reef was demonstrated through a survey by the submersible *Cyana* (Salvat et al., 1985) and bathymetric data from Port Autonome Papeete, Service Hydrographique et Océanographique de la Marine (SHOM), and Institut Français de Recherche pour l'Exploitation de la Mer (IFREMER).

Scientific Achievements on Existing Holes

The first drilling operations on Tahiti reefs were carried out in Papeete Harbor, where a 40 m long core penetrated the detrital talus close to the reef edge (Core ETM) and 20 m long cores penetrated large patch reefs (Cores PAD3 and PPTD5) (Montaggioni, 1988; Camoin and Montaggioni, 1994) (Fig. **F2**).

Subsequently, the barrier reef edge facing Papeete has been cored at several points by a Sedidrill drilling machine and coring system in 1992 and 1995 (Institut de Recherche pour le Développement [IRD, formerly ORSTOM] and Programme National Récifs Coralliens [PNRCO] programs). Cores with diameters ranging from 48 to 64 mm were recovered from two vertical (Holes P6 and P7) and three inclined (Holes P8, P9, and P10; 30°–33° from vertical) drill holes (Fig. **F3**). Holes P6, P7, and P8 are located on the outer barrier reef-flat, whereas Holes P9 and P10 were drilled on the edge of Papeete Pass (see Camoin et al., 1999; Cabioch et al., 1999). Recovery in these P-series cores was dependent upon framework type and on the size of internal cavities but ranged from 50% to 95%; sections with poor or no recovery generally correspond to unconsolidated sands. During drilling, the tube barrel was advanced in 1.5 m increments; core depths were estimated with ±0.3 m accuracy.

Except for the Core P6, the P-series cores penetrated the entire postglacial carbonate sequence beneath the reef edge and reached the antecedent substrate. The volcanic bedrock that lies beneath the reef has a general southwest–northeast slope of 6° and dips gently seaward (average = 10°). Below the barrier reef, the depth of the basaltic or terrigenous substrate ranges from 85.4 m (Core P9) to 114.0 m (Core P7), deepening toward the northeast. In Cores P9 and P10, the basalt is overlain by brownish clay including pebbles of volcanic rocks that may correspond to the weathering profile of the basalts. Correlations between the drill holes on the barrier reef and those in Papeete Harbor (Cores ETM, PAD3, and PPTD5) indicate that the terrigenous deposits form a 18–45 m thick wedge below the modern back reef zone, thinning both seaward and landward (Camoin et al., 1999).

The overlying sequence may be subdivided into two units separated by a clear unconformity with evidence of subaerial exposure:

1. The lower unit, up to 30 m thick, is probably late Pleistocene in age and occurs in Cores P7 and P8 at 87.0 and 92.0 m deep, respectively, and is interpreted as having been deposited in a reef-flat environment and capped by a karst surface. It is absent in the area of Holes P9 and P10, where the volcanic substrate is much shallower.
2. The upper unit encompasses the last 13.85 k.y. and exhibits stratigraphically consistent ages with no reversals (Bard et al., 1996). It ranges in thickness from 85.5 to 92.5 m in Cores P9 and P8, respectively, and is primarily composed of in situ 0.1–6 m thick coral frameworks alternating locally with unconsolidated coral rubble and skeletal sands, terrigenous sands, and silts (Camoin et al., 1999; Cabioch et al., 1999). It corresponds to the longest continuous postglacial reef sequence described so far (Montaggioni et al., 1997). The reconstructed sea level curve for the past 13.70 k.y. is based on more than 100 U-Th dates confirming that the samples used for this study are of high quality and remained closed geochemical systems in the past, thus implying that the measured ages are accurate.

Available Site Survey Data at Tahiti

Before the SISMITA cruise (October 2002), bathymetric seafloor mapping and seismic lines at depths >250 m were carried out on the northern side of the island by the *Washington* in 1982, whereas SeaBeam data were collected during the ETM 19 cruise in 1983–1987 (*Jean Charcot*) (Voisset, 1990). Available data at depths >500 m around Tahiti include bathymetric and acoustic data collected during the Zone Economique de Polynésie Française (ZEPOLYF) (Sichoix and Bonneville, 1996) and POLYDRAG1 (1997) oceanographic cruises (*Atalante* and *Alis*, respectively), whereas available data at depths <250 m were restricted to bathymetric data around Papeete (IFREMER and SHOM) (i.e., in the vicinity of the proposed drilling Site TAH-01A).

The SISMITA cruise was carried out in October 2002 (18–24 October), using the *Alis*, owned by IRD. Shipboard participants included G. Camoin (Centre National de la Recherche Scientifique–Centre de Recherche en Gestion [CNRS-CEREGE]), G. Cabioch (IRD), F. Gallois (IRD), B. Hamelin (CEREGE), and G. Lericolais (IFREMER). During this cruise we planned to acquire very high resolution seismic and multibeam bathymetric data at depths ranging from 50 to 250 m around Tahiti, especially in the three proposed drilling areas: offshore Papeete-Faaa (proposed Site TAH-01A), Tiarei (proposed Site TAH-02A), and Maraa (proposed Site TAH-03A) (Camoin et al., 2003). The major objectives were the following:

- To determine the thickness and geometry of the postglacial (late Pleistocene–Holocene) reef sequence and, if possible, of the underlying carbonate units;
- To identify unconformities in the carbonate units overlying the volcanic basement;
- To evaluate the transitional patterns between the outer-reef slope and the downslope environments; and
- To determine the morphology of the volcanic substrate.

Navigation Data

Accurate navigation information has been obtained from a Global Positioning System (GPS). Other information regarding water currents has also been acquired.

Multibeam Data

Simrad EM 1002, 100 kHz data have been acquired around Tahiti and Moorea at depths ranging from 30–40 to 500–700 m. The three target zones in Tahiti have been mapped in great detail.

Very High Resolution Seismic Data

IFREMER/SIG seismic equipment: asynchronic THR seismic, sediment sounder, and sparker data have been collected in the three target zones in water depths ranging from 40 to 500 m (see maps of the seismic grids and profiles):

- Along lines longitudinal and perpendicular to the axis of the barrier reef and
- within grids of 6 km × 1 km (Tiarei area), 8.5 km × 1 km (offshore Papeete-Faaa), and 9 km × 1 km (Maraa area). The seismic lines are located at a minimal distance of 250 m from the barrier reef, and the distance between the lines forming the grid were fixed to 200–400 m in order to crosscut the proposed drilling sites. All potential drilling target zones have crossing seismic lines.

A total of 120 seismic lines have been carried out in the three target zones. In several lines, the hard bottom over most of the outer shelf inhibited subbottom penetration, rendering interpretation of the recorded data problematic, although some internal structure is revealed. This illustrates the difficulty of imaging drilling targets in reef environments.

The morphology of the fore-reef slope as obtained from echo and seismic profiling exhibits consistent features around Tahiti, especially in the three drilling target zones. The most significant morphological features were imaged, mapped, and ground-truthed by a series of 38 dredgings at depths ranging from 50 to 500 m. The maps and the seismic lines provided illustrate these features (see bathymetric maps and seismic lines in Figs. **F4, F5, F6, F7, F8, F9, F10, F11, F12,** and **F13**):

- An extensive terrace recorded at 50–60 m water depth is characterized by build-ups corresponding to relict reefs. The terrace is gently inclined seaward down to 90 m. The reef sequence deposited on top of this terrace forms a sedimentary wedge that pinches out at 90 m deep in the Tiarei area.
- A narrower terrace typically characterizes depths ranging from 75 to 90–100 m. It displays abundant build-ups that are interpreted as drowned reefs. In the Tiarei area (proposed Site TAH-02A), the height of these build-ups ranges from 30 m (base = 100 m, top = 70 m below sea level) to 45 m (base = 90 m, top = 45 m below sea level). There is a clear break in slope at 90–100 m, where the slope steepens sharply to form a cliff.
- The transition zone between 90–100 and 200–250 m may correspond either to an almost vertical wall or to a steep slope. A significant break in slope is observed at 120–130 m. This zone is generally composed of laterally discontinuous ledges and gives the appearance of being highly stratified down to a depth of 200 m. Build-ups as high as 45 m (base = 135 m, top = 90 m below sea level) on the slope are interpreted as relict reef ridges.
- A major reflector, possibly corresponding to the top of the volcanic basement, has been imaged from 120–150 m water depth close to the cliff, up to 80 m below the 60 m terrace.

Dredging

Dredging carried out on the successive reef terraces and slopes at depths ranging from 50 to 500 m yielded reef material including coral colonies and fragments, coralline algal encrustations, and microbial crusts (Camoin et al., in press). Datable material has been obtained at all depths within the bathymetric range of the development of the postglacial reef sequence (i.e., to 150 m below the present sea surface). It has served to establish a preliminary chronological frame based on the radiometric dating

(U/Th and ^{14}C) of recovered corals and other datable organisms (Camoin et al., in press).

Coring Strategy

Drilling offshore Barbados (Fairbanks, 1989) demonstrated that the reef sequence corresponding to the last deglaciation developed only on slopes and therefore forms discontinuous successive terraces of various lateral extent.

Recovery of the whole postglacial reef sequence requires the drilling of successive reef terraces that occur seaward of the living barrier reef.

Studies and surveys around Tahiti have demonstrated the occurrence of successive reef terraces at various depths, 100, 90, 60, and 40–50 m (see above), which therefore correspond to drilling targets. Thus, at each site, we propose to sample a transect of several offshore drill holes in order to recover the entire postglacial reef sequence.

The numerical model simulating reef building used to study the effect of sea level jumps on the reef geometry in Tahiti has demonstrated that only offshore drilling can recover the corals that were living during the period between the LGM and the MWP-1A event (Fairbanks, 1989) at 13.80 ka (see Bard et al., 1996, and subsequent unpublished tests with the same model). This reconstruction is supported by dating of reef deposits related to the LGM and early deglacial stages in continuous drill holes with seaward deviations of 30°–45°, 300 m in length, carried out on the northeast rim of the Moruroa atoll (French Polynesia; ages ranging from 15.55 ± 0.08 ka to 23.51 ± 0.07 ka) (Camoin et al., 2001), which then demonstrate the feasibility of our investigations on the Tahiti slopes.

Based on the results of previous scientific drilling and bathymetric and seismic data acquired during the SISMITA cruise, we propose to drill a transect of holes in three areas around Tahiti: offshore Papeete-Faaa (proposed Site TAH-01A), Tiarei (proposed Site TAH-02A), and Maraa (proposed Site TAH-03A). The involved water depths range from 40 to 310 m with one exception concerning the drilling of a keep-up reef in the Tiarei area (water depth = 25 m). The detailed drilling plan is described below. Based on the results of drilling carried out on the Papeete Reef and on the results of dredging carried out during the SISMITA cruise, the expected lithologies for the postglacial reef sequence and the underlying Pleistocene carbonate units include reef frameworks (corals, algal crusts, etc.), lithified limestones, and carbonate sands. The depth of penetration below seafloor to reach the volcanic basement should be <100 m at all sites. Furthermore, the volcanic basement will be penetrated at all sites.

Bathymetric and seismic data obtained for the three potential drilling sites, coupled with the results of previous scientific drilling and dredging, demonstrate the feasibility of our project and that the proposed drilling plan is the best to recover the entire postglacial reef sequence. The location of the proposed drill holes and the expected thickness of the carbonate sequence have been determined on the basis of the available site survey data (seismics, bathymetry, and dredging) and the data acquired on the drill holes carried out on the Papeete Reef.

The exact location of the drill holes will be determined during the cruise by checking the nature and morphology of the seafloor with a remotely operated vehicle (ROV) and/or video. Ideally, a circle of ~100 m around the spots indicated below would give enough flexibility to reach the best targets. A 150 m circle around the spots indicated has been accepted by the Environmental Pollution and Safety Panel (EPSP).

OPERATIONAL STRATEGY

Drilling Platform

The water depths for the proposed drilling sites in Tahiti range from 25 to 310 m and require the use of a mission-specific platform. The *Hunter*, a dynamically positioned (DP) vessel with a large moonpool, has been contracted as the drilling vessel. The drilling contractor is Seacore of Gweek, Cornwall, who will install a drilling rig on the *Hunter* over the moonpool and onto part of the aft deck. The *Hunter* is a class 2 DP vessel, and as such has a minimum dual redundancy in propulsion and navigation systems which meets the Integrated Ocean Drilling Program (IODP) and international environmental requirements for the Tahiti coring operation.

Coring System

An HQ mining-type wireline coring system with a conductor to the seabed will be used for coring. This is commonly termed “piggy back” coring because the mining coring rig is installed on top of the conventional API rig, which will deploy the conductor pipe. This allows minimum cuttings due to the small kerf on the bit, a smooth hole profile due to bit type, and the best chance of obtaining high quality and high recovery of core. This type of equipment has been used extensively in other coral reef situations world-wide and has a good track record. For offshore use the drill string is protected by the conductor pipe to seabed. This serves both to avoid excessive string bending and provide a conduit to the vessel for any cuttings that come to the surface. Experience shows that the majority of cuttings are dissipated subsurface while coring.

The coring system for the project is outlined below.

Conductor Pipe

The conductor pipe is a heavyweight drill pipe or casing with an internal diameter (ID) of ~100 mm and a casing shoe to set it ~1 m into the seabed. A seabed template of ~1.5 m diameter and weighing 10–12 T will be deployed at the end of the conductor pipe, which will sit on the seabed with the conductor pipe projecting through. This pipe will be deployed with the main drilling power swivel attached to the main heave-compensation system of the drilling rig. The coring system will be installed above this in piggy-back fashion so that all coring is carried out in compensated mode.

Wireline Coring System

A mining-type assembly of triple tube configuration in the HQ range (core = 61 mm) will allow the core bits to pass through the conductor pipe and core ahead. There will be a range of core bits available, including surface set diamond or tailored impregnated bits, which are most likely to be used. As the base of each hole is intended to terminate in basement, a surface set diamond bit would allow the best opportunity to complete the borehole without a change of bit. However, reentry is possible, as there will be a conductor pipe installed between the vessel and seabed.

Coring Run Lengths

Typically with mining tools, the maximum coring run to obtain optimum recovery is 3 m. Shorter coring runs can be made to ensure that this high recovery is maintained in a reef environment, but additional time would be required for the additional wireline trips. The excellent core recovery obtained on the Tahiti land-based coring used 1.5 m runs and the same core diameter to be used in this expedition.

Wireline Overshot and Retrieval System

All inner barrels are wireline retrievable using a well-proven mining core barrel retrieval system. This allows continuous coring operations without having to pull the drill string to recover each core run and the flexibility to drill/spot-core or take measurements in any borehole without recourse to pulling the drill pipe.

Seawater will normally be used for drilling.

Core on Deck

Once the drilling operation commences and cores begin to come on deck, the coring operations team will be responsible for delivering that core to the laboratory for examination and curation. The operation will proceed using a changeover of inner core barrels to ensure continuity of the coring operation in as timely a fashion as possible. The deck operators will deploy an empty core barrel immediately after the full one has been retrieved, then address the core removal and readying of that core barrel for reuse. The cores will be collected in a plastic liner and IODP curation procedures will be followed.

Gas detection equipment will be carried as part of the total coring operation.

Downhole Logging

This service is contracted as part of the services for the Tahiti expedition and will be managed by the European Petrophysics Consortium (EPC). The logging equipment and team will be interfaced for a seamless operation on board the drill ship, ready to undertake any requirements as the project progresses.

To facilitate downhole measurements and core petrophysics for MSPs, the EPC has been developing protocols for use both offshore and as part of the shore-based party.

In all expeditions the downhole logging program will be integrated with the scientific objectives to ensure maximum scientific output. This may include the use of specialty third-party tools.

Unlike the *Chikyu* and nonriser vessels where the pipe size is constant and allows a standard set of logging tools to be deployed, MSPs have variable pipe sizes and drill in a variety of water depths, each of which provides constraints on the anatomy of logging operations. Pipe diameter is the controlling factor, and for this expedition slim-hole mining-type logging tools will be utilized. Nuclear sources will not be deployed.

Camera and/or ROV

The water depths involved in the general drilling plan related to this proposal range from 40 to 310 m with two exceptions concerning the drilling of keep-up reefs and build-ups on the reefs in the Tiarei and Maraa areas (water depths, respectively = 25 and 30 m). Seventeen of the 19 drill sites are deeper than 40 m, which corresponds to the limit where the abundance of the living cover (especially the coral cover) decreases sharply and becomes limited (40–50 m water depth) to almost zero (below 50 m). For the two drill sites shallower than 40 m above (keep-up reefs), an ROV and/or video camera will be used to accurately determine the location of the drill sites, on sand or bare rocks, and help avoid damage to living coral heads.

Each site drilled within the active reef (and preferably at all drilling sites) will be monitored using a through-pipe video system to ensure that the landing area is free from living coral heads. Additionally, the same camera system will be utilized on completion of the borehole to take photographs to show the effects of the coring in the immediate vicinity of the borehole. These before and after photographs will be stored with the drilling data.

SCIENCE OPERATIONS

A sampling and measurements plan for Expedition 310 (see the "Appendix") was prepared to meet the scientific objectives of IODP Proposal 519-Add2 following the recommendations of the Science Advisory Structure.

Offshore Science Operations at Tahiti

It should be possible to carry out all necessary scientific work on board the ship. After due consideration, it has been decided that the cores will not be split at sea, as it will be more efficient to carry out most of the scientific analysis during an onshore party at Bremen. Therefore, there will be only limited scientific analysis carried out on board and only a limited number of scientists will be required to sail. It is currently planned that core will be cut (unless there is a continuous section of a massive coral colony) on board into 1.5 m lengths and curated. The core catcher sample will be split and a visual description recorded. Samples for microbiology will be taken and suitably stored for analysis. Some preliminary microbiology measurements will be conducted offshore (see "Microbiology" in the "Appendix").

Staffing

Scientific staffing has been decided on the basis of task requirements and nominations from the ECORD Science Support Advisory Committee (ESSAC), U.S. Science Advisory Committee (USSAC), Japan Drilling Earth Science Consortium (JDESC), and Ministry of Science and Technology (MOST) of the People's Republic of China. ESO staffing is based on the need to carry out the drilling and scientific operations efficiently and safely.

The following ESO and science staffing amounts to 23 participants:

ESO

- 1 Operations Superintendent
- 1 Staff Scientist
- 1 Trainee Staff Scientist
- 1 Petrophysics Staff Scientists
- 2 Curators
- 2 Drilling Coordinators
- 1 Database Operator
- 1 Electronics Engineer
- 1 ESO Petrophysicist
- 1 ESO Geochemist
- 2 Logging Contractors
- 1 Microbiology Technician

Offshore Science Team

- 2 Co-Chief Scientists
- 2 Carbonate Sedimentologists
- 2 Coral Specialists
- 1 Microbiologist
- 1 Core Petrophysicist

Drillship Science Activities

Science activities on the drillship are likely to be confined to those essential for early sampling and logging, as well as for safety and curation (see the **"Appendix"** for more details):

- Basic curation and labeling of core,

- Core catcher lithological and macropaleontological analysis,
- Core storage,
- Petrophysics (see **"Offshore Petrophysics Measurements"** and **"Appendix"**),
- Pore water sampling for chemistry/circulation studies (if Scientific Party requests),
- Collection/storage of microbiology samples under appropriate conditions, and
- Associated data management of all activities (see below).

The coral reefs require rotary coring, and the hard rock cores collected will be collected in ordinary liners. The cores will be split during the onshore party in Bremen.

In order to carry out the science requirements on the drillship with a small crew, a staffing plan has been devised. The plan requires flexibility of approach from all participants, with priority to safety, core recovery, curation, and procedures for the measurement of ephemeral properties.

Cruise report preparation and compilation will take place on board. A detailed cruise report will be broken down into the following sections:

- Coring operations
- Operations cost (which will be monitored daily)
- Preliminary scientific results
- Databasing

Regular reports will be sent to IODP-MI in requested formats and at the required frequency.

Offshore Petrophysical Measurements

It is planned to run all cores on the multisensor core logger (MSCL) (density, resistivity, velocity, and susceptibility) on board the drillship (see the **"Appendix"** for more details).

Tahiti Logging Operations

Considering the anticipated shallow depth of many holes, short tool strings are highly recommended. Because of environmental concerns (shallow-water reef environment) the use of chemical sources is prohibited; as such, density and porosity logging tools that require these sources cannot be used.

Three depth transects are planned, and the logging plan will be optimized through further discussions with the Co-Chief Scientists. It is envisioned that two holes per transect will be fully logged, with a reduced logging plan in some of the other holes (subject to hole conditions).

Given the anticipated small diameter of the boreholes (HQ core bit outer diameter = 96 mm), only slimline-type logging tools can be utilized. The following is a generic list of minimum and additional tools, based on formation properties discussed with proponents, and not on operator-based trademark names:

Minimum Measurements

- Optical images: millimeter-scale geological description
- Acoustic images: centimeter-scale impedance and mesoscale porosity
- Spectral gamma logging: U, Th, K, and red algae
- Acoustic velocity logging: V_P and V_S at 10–20 kHz)
- Induction resistivity logging: pore fluid salinity and porosity
- Hydrochemical borehole fluid logging: pressure, temperature, pH, Eh, SP, and fluid electrical conductivity to identify fluid circulation

Onshore Science Activities

The onshore sampling party is expected to take place during February 2006 under the supervision of Dr. Ursula Röhl, manager of the IODP Bremen Core Repository (BCR).

The following facilities will be available for the expedition scientists at BCR (see the **"Appendix: Measurements Plan"** for more details):

- Core splitting
- Core description
- Core photography
- Core sampling
- Thin section and smear slide preparation
- Micropaleontology
- Inorganic geochemistry
- X-ray diffraction analysis
- Petrophysical measurements

Staffing

ESO

- 1 Superintendent (Curation and Laboratory Manager)
- 1 Staff Scientist
- 1 Assistant Superintendent (Assistant Curation and Laboratory Manager)
- 1 Petrophysics Staff Scientist
- 1 ESO Petrophysicist
- 2 Curators
- 2 Database Operators
- 1 Trainee Staff Scientist
- 1 Yeoperson
- Laboratory Team (provided by University of Bremen)

Expedition Scientists

- 2 Co-Chief Scientists (2 sailing)
- 4 Carbonate Sedimentologists (2 sailing)
- 2 Coral Specialists (2 sailing)
- 1 Microbiologist (1 sailing)
- 2 Core Petrophysicists (1 sailing)
- 1 Foraminifer Paleontologist
- 10 Inorganic Geochemists (SST variation and dating)
- 1 Paleomagnetist
- 1 Igneous Petrologist
- 1 Observer

Data Management

A detailed specification and configuration of data management systems for the Tahiti Expedition will be developed from the finalized science/operational data requirements and operational logistics. The plan outline is as follows:

- A modified version of the International Continental Scientific Drilling Program (ICDP) Drilling Information System (DIS) (OffshoreDIS) will be used to capture drilling and core-related data during the operation and postoperation shore party phases.

- Data will be transferred to Janus and the World Data Center for Marine Environmental Sciences (WDC-MARE)/Publishing Network for Geoscientific and Environmental Data (PANGAEA), the MSP data repository.
- The data management plan and the petrophysics plan (developed by EPC) will be integrated.
- The longer-term plan for data management will take into account IODP Information Services requirements once these are known.

OffshoreDIS will be configured to match the science/operational requirements of the expedition. The timing of transfer of metadata/data from OffshoreDIS to WDC-MARE/PANGAEA will depend on the data type and operational requirements; transfer formats, procedures, and data security policy/implementation have still to be finalized.

DEFINITION OF TAHITI SEA LEVEL EXPEDITION RESULTS DATA

Expedition Report data for Tahiti Sea Level include the following:

- All data collected on the drilling vessel during the expedition (Table **T2**).
- All data derived from samples taken on the drilling vessel that are defined as minimum measurements by the Scientific Measurements Panel (SciMP).
- All data collected onshore during the science party (Table **T2**).

SAMPLE ALLOCATION COMMITTEE AND SAMPLE REQUESTS

The IODP Sample, Data, and Obligations policy is scheduled to be published by 1 October 2005 on the Program Policies page of the IODP Web site (**www.iodp.org/**), and will apply to Expedition 310.

Access to data and core samples during Expedition 310 or within the 1 y moratorium following the onshore part of the expedition must be approved by the Sample Allocation Committee (SAC).

The SAC (composed of Co-Chief scientists, Staff Scientist, and ESO Curation Manager/IODP Curator onshore or the shipboard curatorial representative) will work with the Expedition Scientists to formulate a formal expedition-specific sampling plan for postcruise sampling.

The SAC has agreed that the review of sample requests will be deferred until after the offshore operation, so that sample requests can be reviewed in the context of the known core recovery and lithology.

All sample frequencies and sizes must be justified on a scientific basis and will depend on core recovery, the full spectrum of other requests, and the expedition objectives. Some redundancy of measurement may be unavoidable, but minimizing the duplication of measurements among the Expedition Scientists Party (may include approved shore-based collaborators) will be a factor in evaluating sample requests.

The minimum permanent archive will consist of one-half of each core taken from the deepest hole drilled at a site (depending on the growth direction of the coral colony, if any). As such, the archive halves of cores from additional holes drilled to equal or shallower depths that contain replicate copies of stratigraphic intervals constituting the minimum permanent archive need not be designated as permanent archive, but can be, if so desired by the SAC. This may be required, for example, to fill gaps in recovery in the deepest hole. If not designated as permanent archive, they are "temporary archive." If a composite splice section is constructed and the sampling demand exceeds the working half, an alternative scenario may be required to make sure that all samples can be taken from the spliced section. In this case, the permanent archive will be defined from cores that are not part of the splice (e.g., from cores from different holes). It should be stressed that the availability of archive halves for sampling depends on the presence of comparable sedimentary sequences in adjacent holes that can be directly correlated and thereby identified as duplicate material. In the drilling of corals, similar to the situation in hard rock environments, the paucity of replicate material may severely limit the availability of nonpermanent archive-half material.

The Sample Allocation Committee comprises the following members:

- Gilbert Camoin: Co-Chief Scientist
- Yasufumi Iryu: Co-Chief Scientist
- Ursula Röhl: ESO Curation Manager/IODP Curator (or shipboard representative)
- David McInroy: ESO Staff Scientist

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Table T1. Proposed site transects.

Hole	Water depth (m)	Sediment penetration (m)	Substrate penetration (m)	Longitude	Latitude	Target
Proposed Site TAH-01A (Faaa area)						
A	40–45	80	5	149°36.2299′ W	17°32.1298′ S	Terrace
B	50–55	70	5	149°36.0869′ W	17°32.0989′ S	Build-up on terrace
C	65	50–55	5	149°35.9187′ W	17°32.0632′ S	Build-up at edge of terrace
D	100	30–40	5	149°35.7727′ W	17°32.0339′ S	Drowned reefs(?)
E	110–115	40	5	149°35.5772′ W	17°31.9917′ S	Slope
F	150	50	5	149°35.4506′ W	17°31.9661′ S	Slope
Total penetration:		335	30			
Proposed Site TAH-02A (Tiarei area)						
A	40	80	5	149°24.6986′ W	17°29.9625′ S	Terrace
B	25	95	5	149°24.5788′ W	17°29.8142′ S	Keep-up reef
C	70	70	5	149°24.4315′ W	17°29.6200′ S	Terrace
D	70	70	5	149°24.2418′ W	17°29.3631′ S	Drowned reef
E	85–90	60	5	149°24.1822′ W	17°29.2799′ S	Drowned reef
F	120	50	5	149°24.1488′ W	17°29.2347′ S	Slope
G	310	100	5	149°24.0589′ W	17°29.1047′ S	Slope
Total penetration:		525	35			
Proposed Site TAH-03A (Maraa area)						
A	45	70–75	5	149°32.8766′ W	17°45.9808′ S	Terrace
B	30	80–85	5	149°32.9645′ W	17°45.9621′ S	Build-up on terrace
C	60	60–65	5	149°33.0407′ W	17°45.9553′ S	Edge of terrace (reefs?)
D	75	70	5	149°33.0529′ W	17°45.9888′ S	Slope
E	115	50	5	149°33.0614′ W	17°46.0196′ S	Slope
G	150	50	5	149°33.0712′ W	17°46.0471′ S	Toe of slope
Total penetration:		395	30			

Table T2. Offshore and onshore measurements to be included in the Expedition Report.

Offshore measurements	Onshore measurements
Core catcher description (lithology, macropaleontology, photographs)	Visual core description (thin section and smear slide descriptions)
MSCL (density, velocity, resistivity)	Core photographs
Microbiology	Micropaleontology
Physical properties	Inorganic geochemistry
Downhole logging	X-ray diffraction analysis
	Repeat whole-core petrophysical measurements
	Split-core MSCL measurements + NGR logging
	Discrete sample MAD
	Color reflectance/digital line-scan image

Note: MSCL = multisensor core logger, NGR = natural gamma radiation, MAD = moisture and density.

Figure F1. A. Sea level history reconstructed for long drill cores from Tahiti (squares), Barbados (dots), and New Guinea (triangles) (from Bard et al., 1996). **B.** Reconstructed SSTs for various time windows on corals from Vanuatu (Beck et al., 1997).

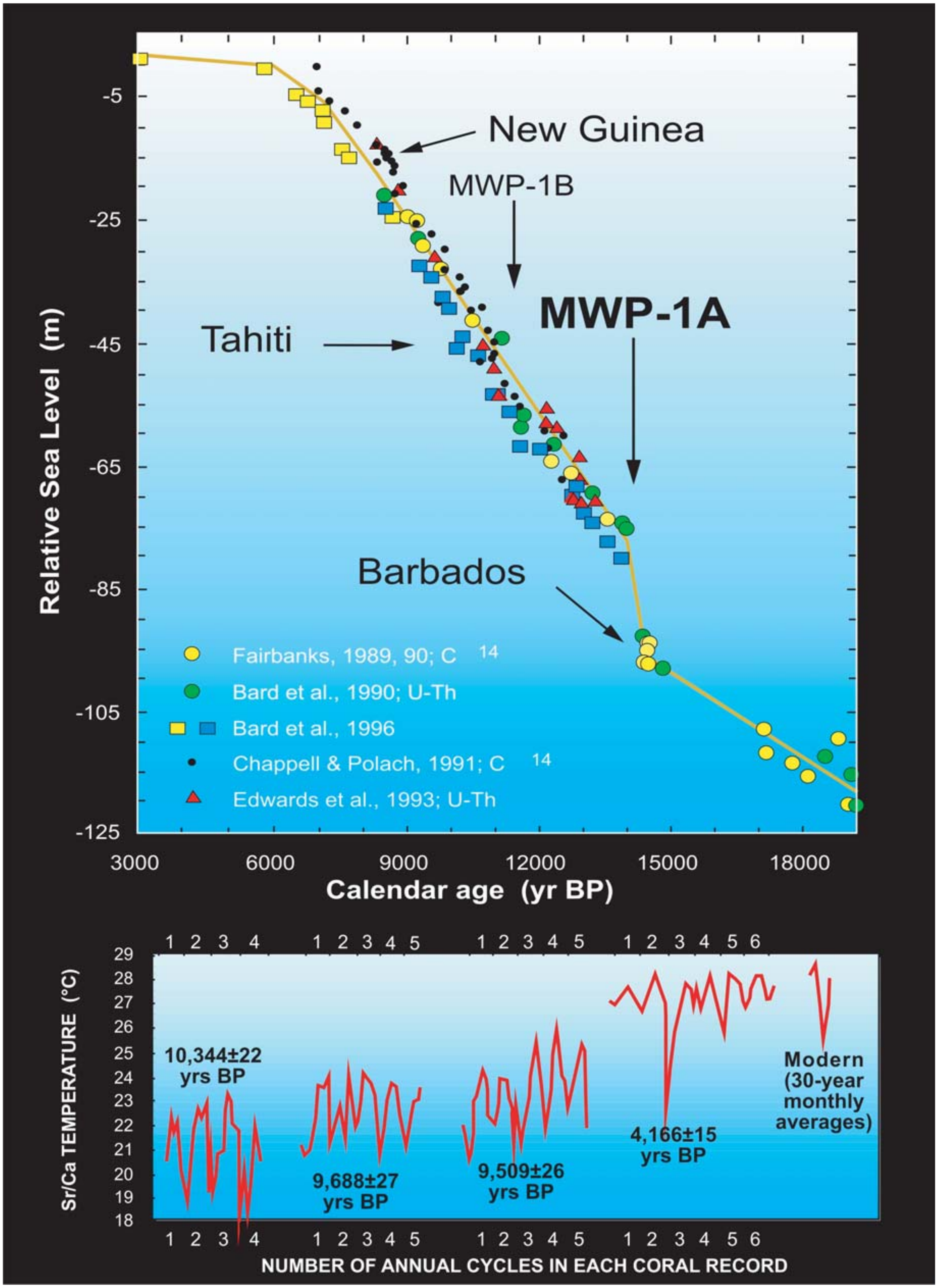


Figure F2. Location of existing holes and proposed drill sites on Tahiti. Location map of (**A**) existing drill holes and proposed drill sites (**B**) and cross section in the area of Site TAH-01A.

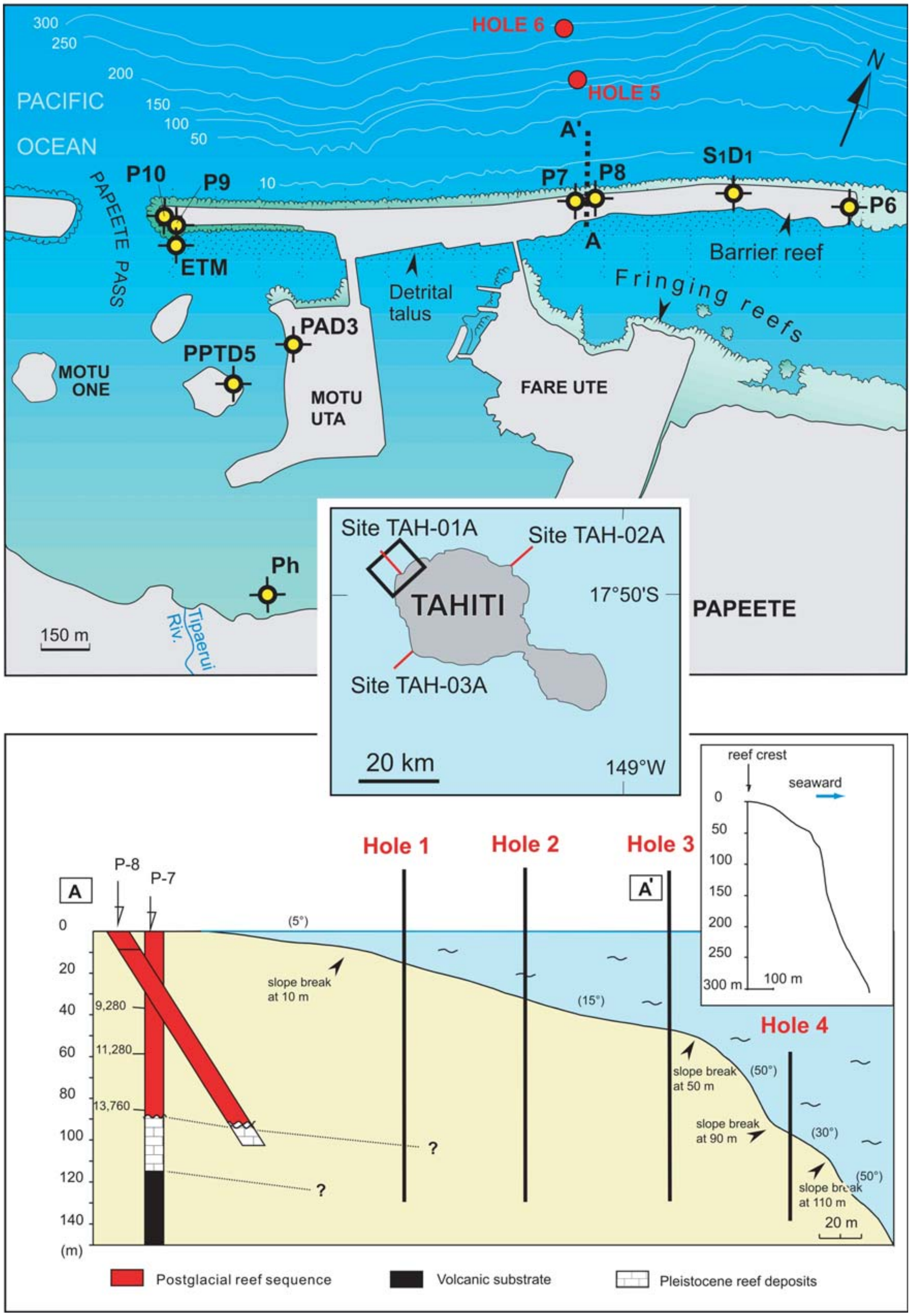


Figure F3. Lithologic data and radiometric ages on existing drill cores from Tahiti (see Fig. F1 for location of drill holes) (data from Bard et al., 1996; Montaggioni et al., 1997; Camoin et al., 1999; Cabioch et al., 1999).

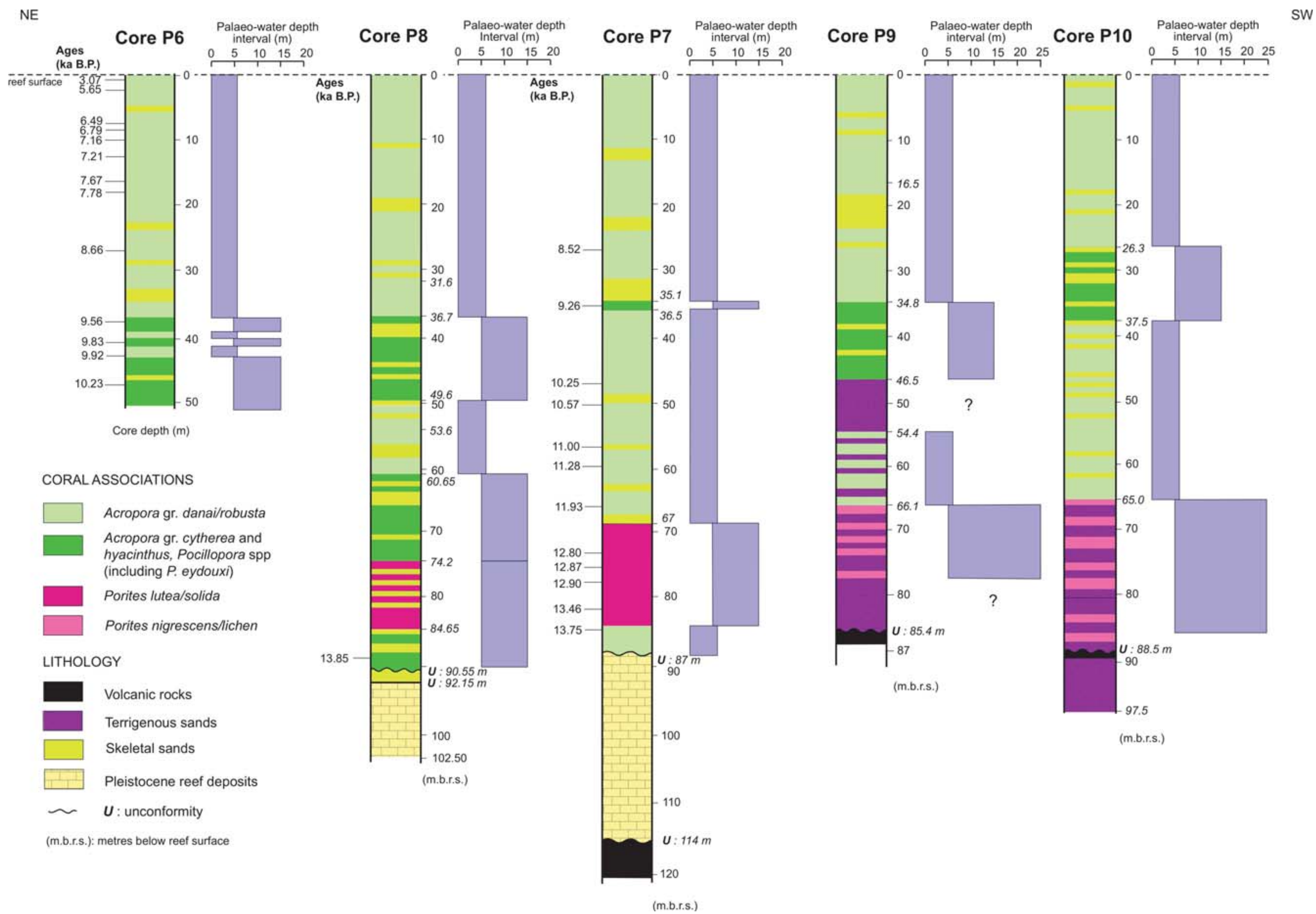


Figure F4. Map showing the location of the three proposed study areas: Faaa (proposed Site TAH-01A), Tiarei (proposed Site TAH-02A), and Maraa (proposed Site TAH-03A). Detailed maps are shown in Figures **F5, F6, F8, F9, F11,** and **F12.**

Figure F5. Swath bathymetry and seismic lines in Faaa area (proposed Site TAH-01A Holes A–F).

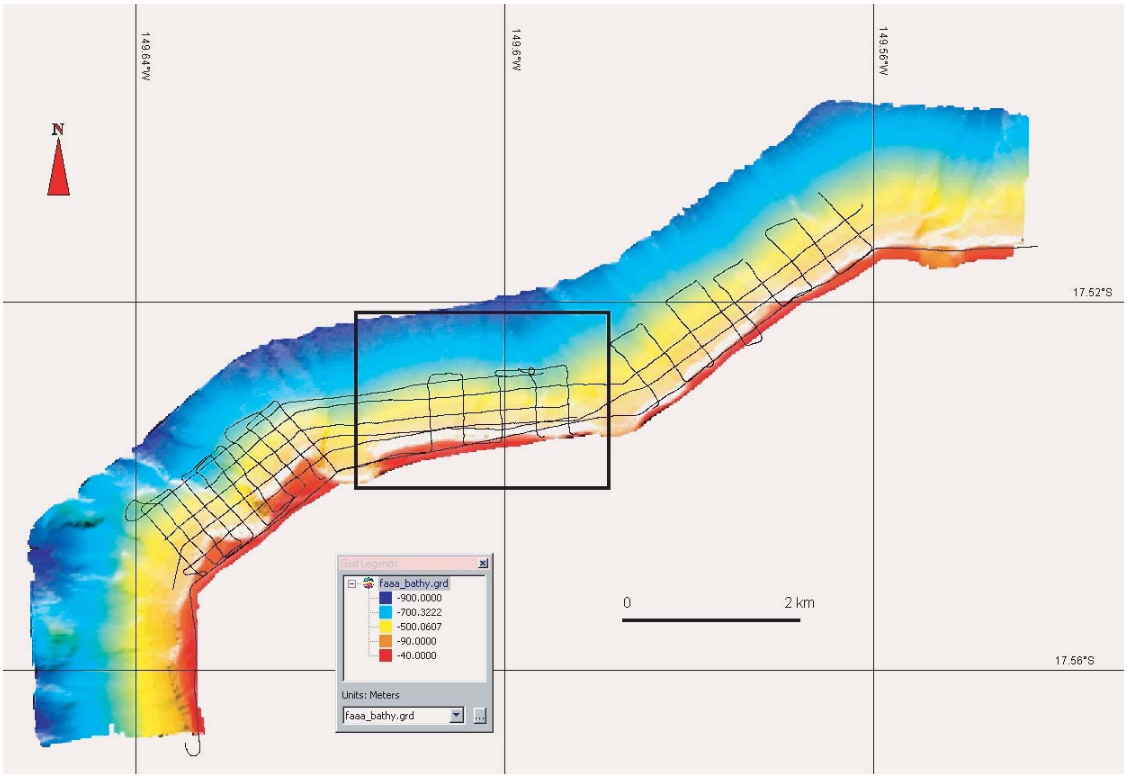


Figure F6. Swath bathymetry and seismic lines around proposed Site TAH-01A, Holes A–F. Time annotations on seismic Line SISM088 (Fig. F7).

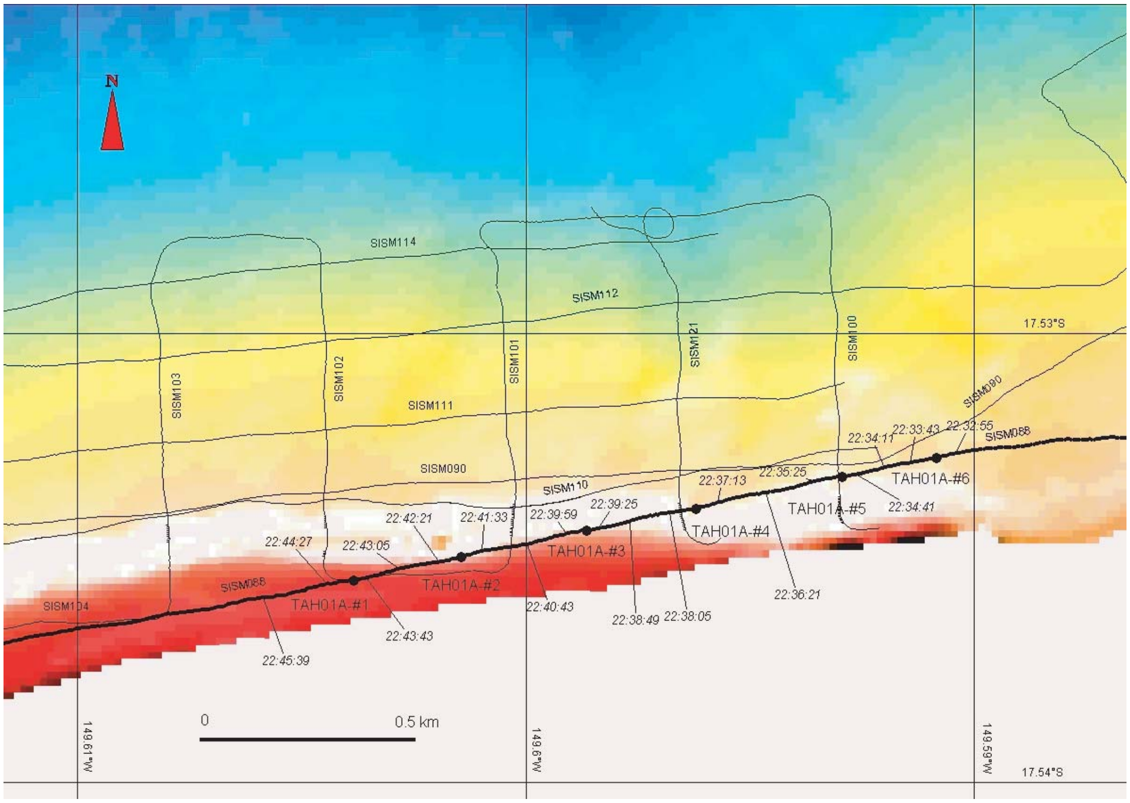


Figure F7. Location of proposed Site TAH-01A Holes A–F. Location is shown in Figure F6.

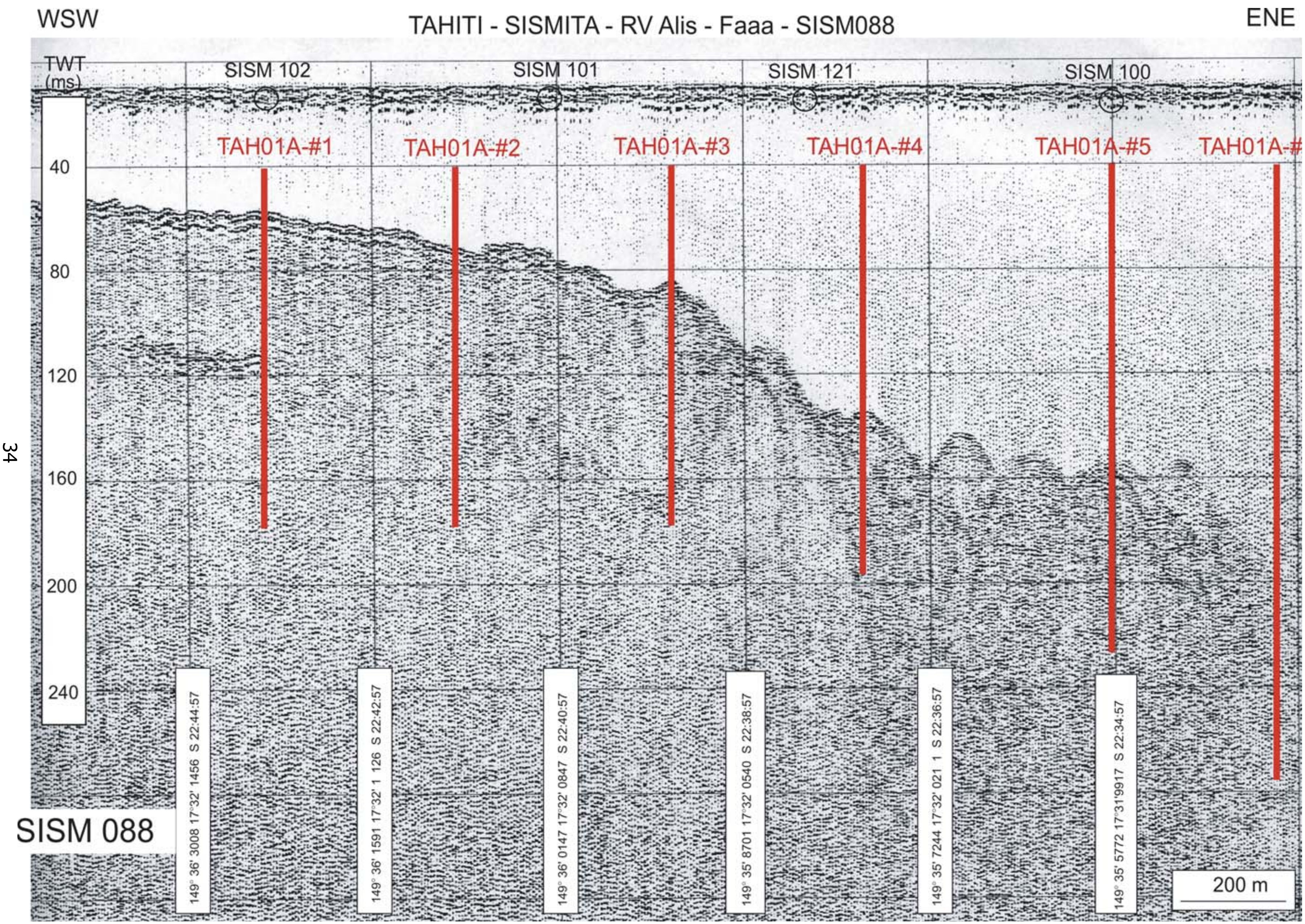


Figure F8. Swath bathymetry and seismic lines in Tiarei area (proposed sites TAH-02A Holes A–G).

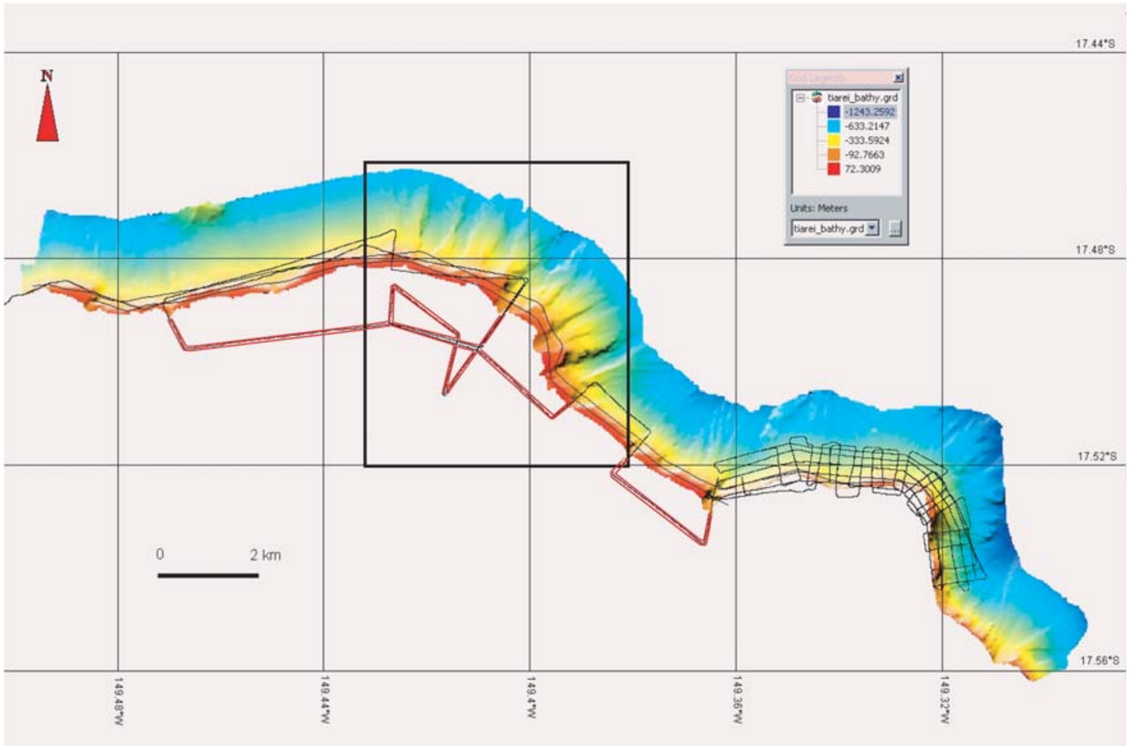


Figure F9. Swath bathymetry and seismic lines around proposed Site TAH-02A Holes A–G. Time annotations on seismic Line SISM079 (Fig. **F10**).

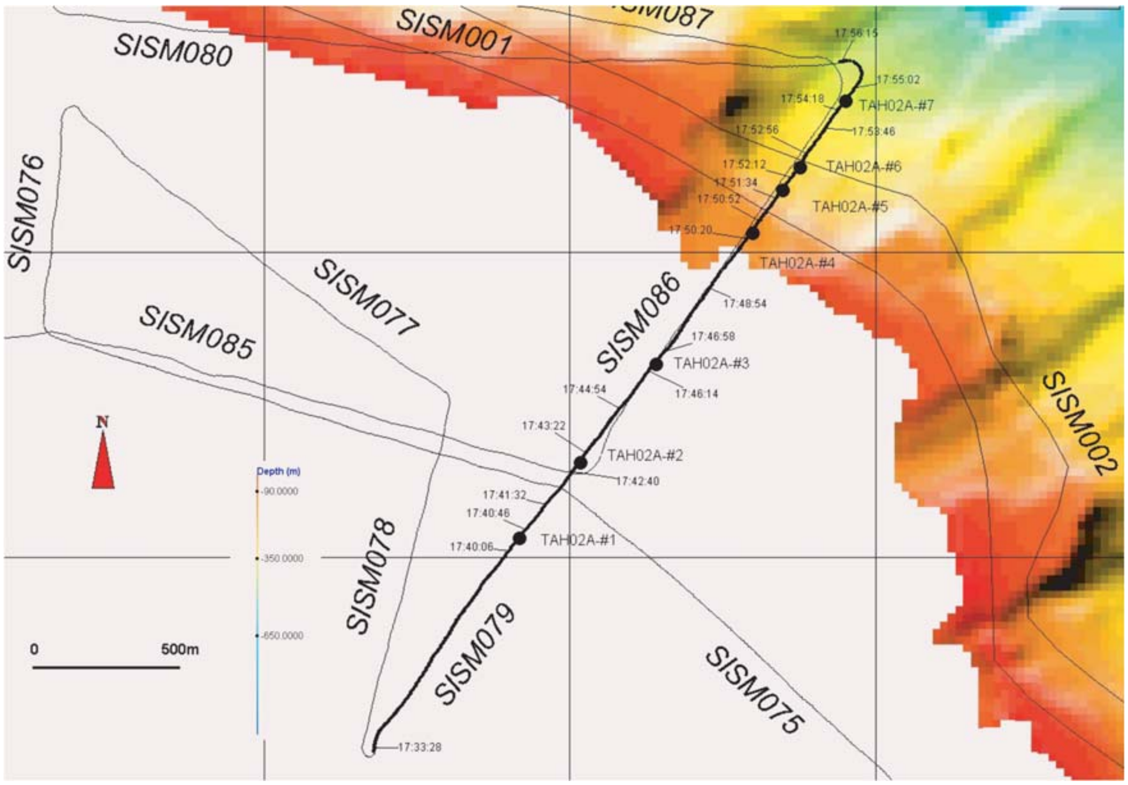


Figure F10. Location of proposed Site TAH-02A Holes A–G. Location shown in Figure F9.

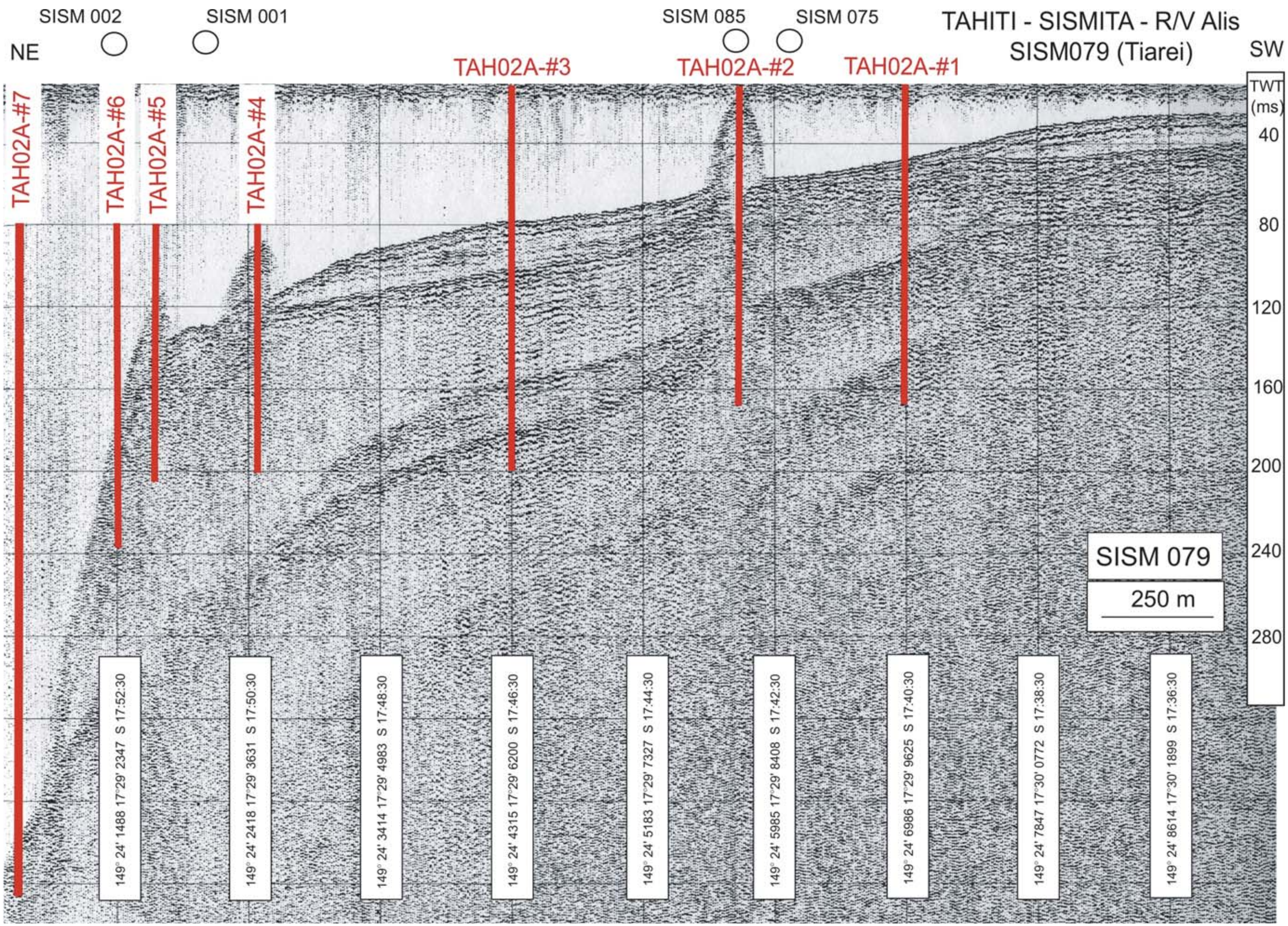


Figure F11. Swath bathymetry and seismic lines in Maraa area (proposed Site TAH-03A Holes A–F).

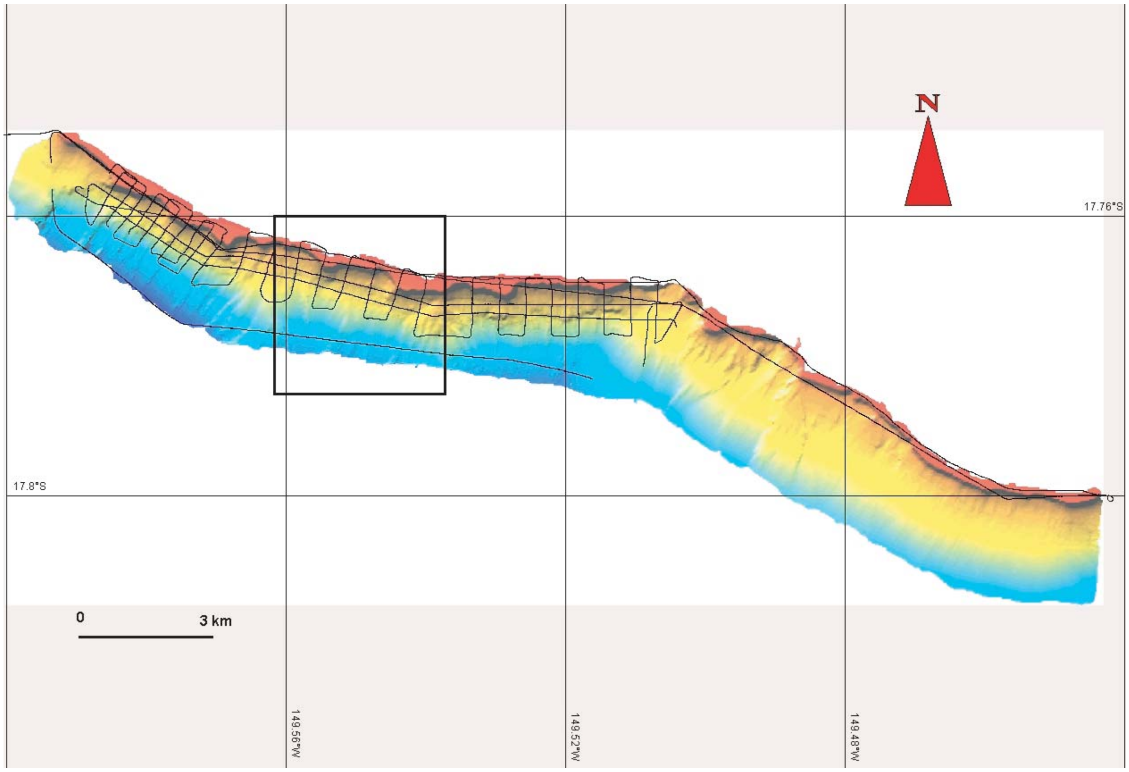


Figure F12. Swath bathymetry and seismic lines around proposed Site TAH-03A Holes A–F. Time annotations on seismic Line SISM046 (Fig. **F13**).

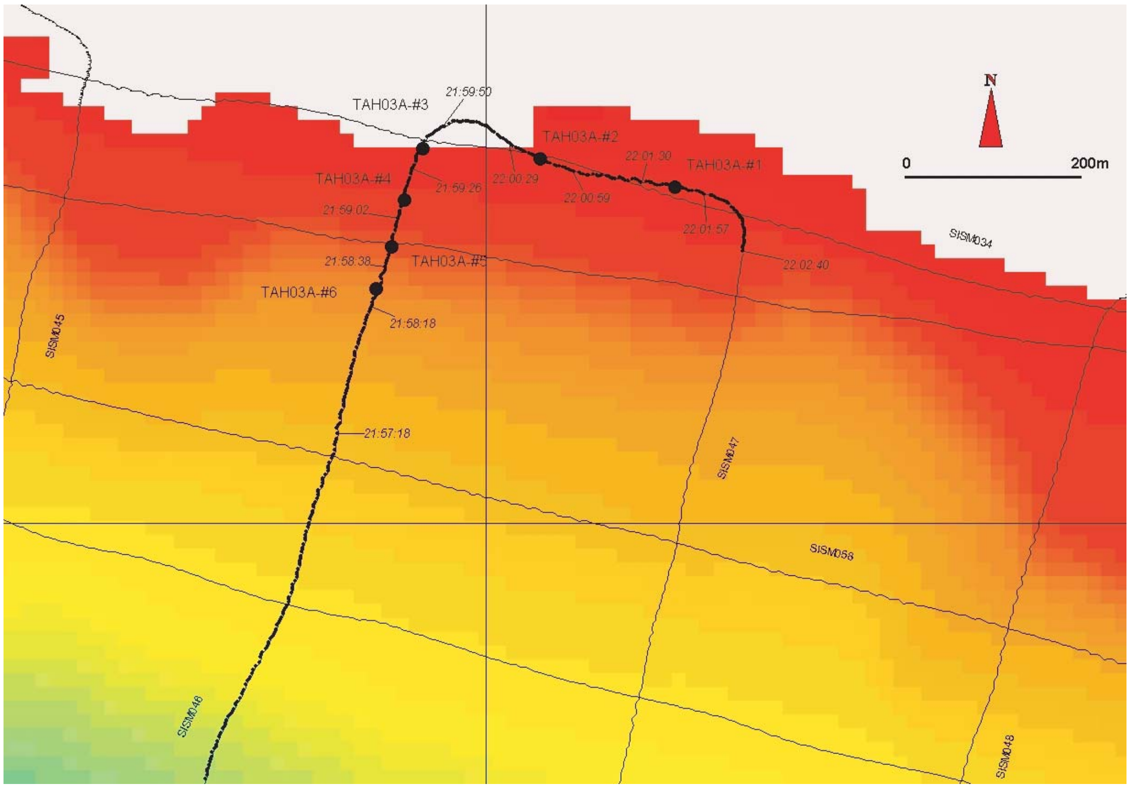
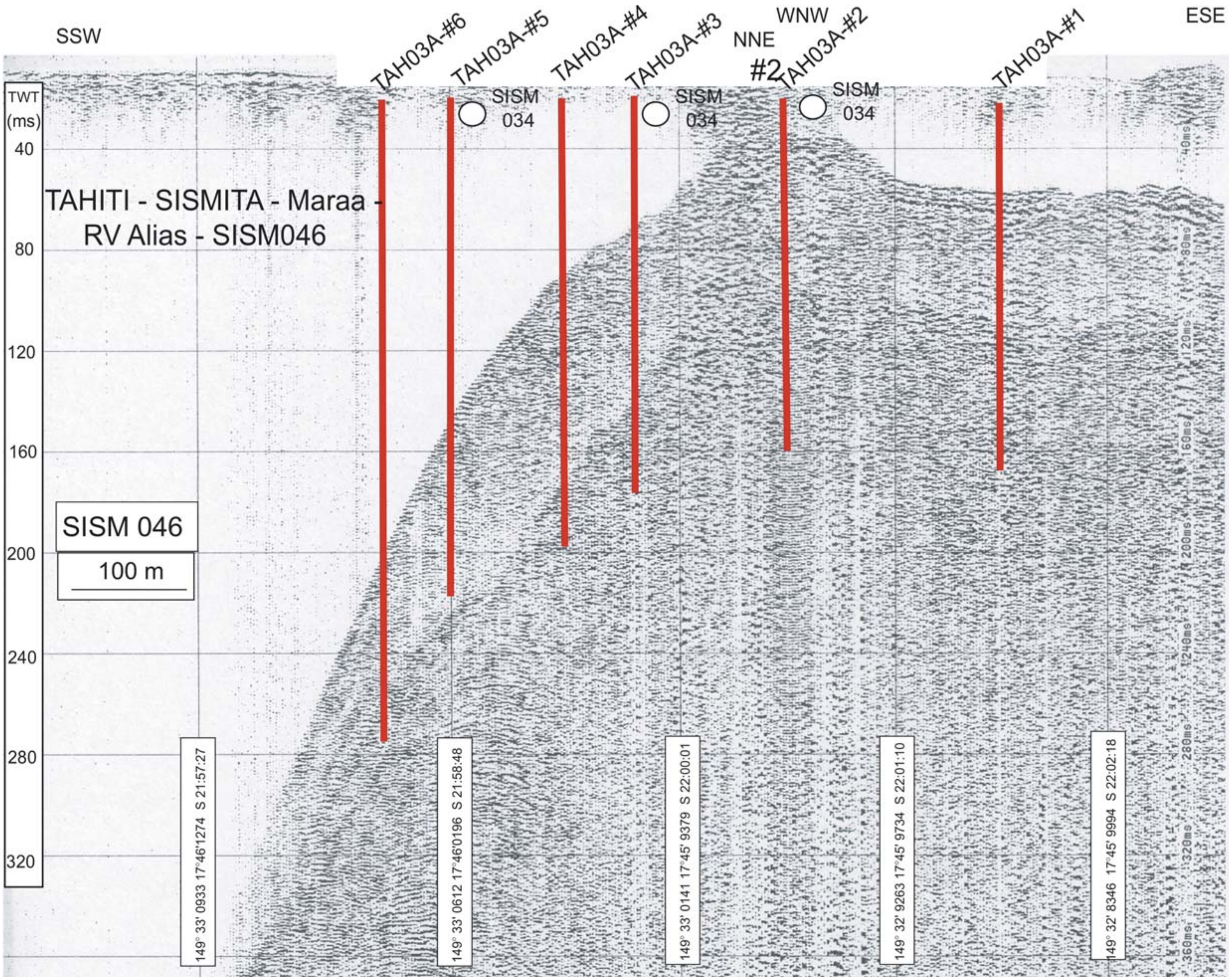


Figure F13. Location of proposed Sites TAH-03A Holes A–F. Location shown in Figure F12.



SITE SUMMARIES

Proposed Site: TAH-01A (transect)

Priority:	2 (Alternate site)
Position:	149°36′ W, 17°32′ S
Water depth (m):	40–150
Target drilling depth (mbsf):	30–80
Survey coverage:	Seismic: SISMITA cruise (October 2002) • High-resolution seismic reflection • Seismic grid • Swath bathymetry Imagery • Photography and video available Sediment sampling: ORSTOM • Holes P6, P7: 1991 and 1992 • Holes P8–P10: 1995 Rock sampling: SISMITA (October 2002) • Dredging Other • Water current and navigation data available See Figures **F5, F6, F7;** Table **T1**
Objective:	• Establish the course of postglacial sea level rise at Tahiti (i.e., to define the exact shape of the deglaciation curve) for the period 20–10 ka. • Define short-term paleoclimatic changes, especially SST variations, for the region over the last 20 k.y. • Analyze the impact of sea level changes on reef growth, geometry, and biological makeup.
Logging program:	• Litho-density • Natural gamma radiation • Resistivity: induction • Acoustic velocity • Borehole televiewer • Borehole pressure and temperature
Nature of rock anticipated:	Sediments: reef frameworks, limestones, and unconsolidated sands Basement: volcanic

Proposed Site: TAH-02A (transect)

Priority:	1
Position:	149°24′ W, 17°29′ S
Water depth (m):	25–310
Target drilling depth (mbsf):	50–100
Survey coverage:	Seismic: SISMITA cruise (October 2002) • High-resolution seismic reflection • Seismic grid • Swath bathymetry Imagery (*Cyana* submersible) • Photography and video available Sediment sampling: ORSTOM • Holes P6, P7: 1991 and 1992 • Holes P8–P10: 1995 Rock sampling: SISMITA (October 2002) • Dredging Other • Water current and navigation data available See Figures **F8, F9, F10;** Table **T1**
Objective:	• Establish the course of postglacial sea level rise at Tahiti (i.e., to define the exact shape of the deglaciation curve) for the period 20–10 ka. • Define short-term paleoclimatic changes, especially SST variations, for the region over the last 20 k.y. • Analyze the impact of sea level changes on reef growth, geometry, and biological makeup.
Logging program:	• Litho-density • Natural gamma radiation • Resistivity: induction • Acoustic velocity • Borehole televiewer • Borehole pressure and temperature
Nature of rock anticipated:	Sediments: reef frameworks, limestones, and unconsolidated sands Basement: volcanic

Proposed Site: TAH-03A (transect)

Priority:	3 (Alternate site)
Position:	149°33′ W, 17°45′ S
Water depth (m):	30–150
Target drilling depth (mbsf):	50–85
Survey coverage:	Seismic: SISMITA cruise (October 2002) • High-resolution seismic reflection • Seismic grid • Swath bathymetry Imagery (*Cyana* submersible) • Photography and video available Sediment sampling: ORSTOM • Holes P6, P7: 1991 and 1992 • Holes P8–P10: 1995 Rock sampling: SISMITA (October 2002) • Dredging Other • Water current and navigation data available See Figures **F11, F12, F13;** Table **T1**
Objective:	• Establish the course of postglacial sea level rise at Tahiti (i.e., to define the exact shape of the deglaciation curve) for the period 20–10 ka. • Define short-term paleoclimatic changes, especially SST variations, for the region over the last 20 k.y. • Analyze the impact of sea level changes on reef growth, geometry, and biological makeup.
Logging program:	• Litho-density • Natural gamma radiation • Resistivity: induction • Acoustic velocity • Borehole televiewer • Borehole pressure and temperature
Nature of rock anticipated:	Sediments: reef frameworks, limestones, and unconsolidated sands Basement: volcanic

Expedition 310 Scientists and Scientific Participants

Co-Chief Scientist
Gilbert Camoin*
Europôle Méditerranéen de l'Arbois
CEREGE, UMR CNRS 6635
BP 80
13545 Aix-en-Provence Cedex 4
France
gcamoin@cerege.fr

Co-chief Scientist
Yasufumi Iryu*
Institute of Geology and Paleontology
Tohoku University
Aobayama
Sendai 980-8578
Japan
iryu@dges.tohoku.ac.jp

Staff Scientist
David McInroy*
British Geological Survey
Murchison House
West Mains Road
Edinburgh EH9 3LA
United Kingdom
dbm@bgs.ac.uk

Petrophysics Staff Scientist
Hendrik Braaksma*
Laboratoire de Tectonophysique
CC49, Université Montpellier 2
Place Eugène Bataillon
34095 Montpellier Cedex 05
France
hendrik.braaksma@dstu.univ-montp2.fr

Inorganic Geochemist
Ryuji Asami
Institute of Geology and Paleontology
Tohoku University
Aobayama, Sendai
Japan
ryuji@dges.tohoku.ac.jp

Coral Specialist
Kaoru Sugihara*
Earth System Science
Faculty of Science, Fukuoka University
8-19-1, Nanakuma
Jonan-ku
Fukuoka 814-0180
Japan
sugihara@fukuoka-u.ac.jp

Coral Specialist
Jody Michael Webster*
School of Earth Sciences
James Cook University
Townsville QLD 4811
Australia
Jody.Webster@jcu.edu.au

Igneous Petrologist
Paterno Castillo
Scripps Institution of Oceanography
University of California, San Diego
9500 Gilman Drive
La Jolla CA
USA
pcastillo@ucsd.edu

Inorganic Geochemist
Anne L. Cohen
Geology and Geophysics
Woods Hole Oceanographic Institution
Clark 118, Mailstop 23
Woods Hole MA
USA
acohen@whoi.edu

Inorganic Geochemist
Julia E. Cole
Geosciences Department
University of Arizona
1040 East 4th Street
Tucson AZ
USA
jcole@geo.arizona.edu

Inorganic Geochemist
Pierre Deschamps
UMR 6635, CNRS
CEREGE
Europôle Méditerranéen de l'Arbois
BP80
Aix-en-Provence
France
deschamps@cerege.fr

Inorganic Geochemist
Richard G. Fairbanks
Earth and Environmental Sciences
Lamont-Doherty Earth Observatory
Columbia University
210 Isotope Laboratory
Palisades NY
USA
fairbanks@LDEO.columbia.edu

Inorganic Geochemist
Thomas Felis
DFG-Research Center Ocean Margins
University of Bremen
POB 330440
Bremen
Germany
tfelis@allgeo.uni-bremen.de

Inorganic Geochemist
Terrence Michael Quinn
College of Marine Science
University of South Florida
140 7th Avenue, South, MSL 119
St. Petersburg FL
USA
quinn@marine.usf.edu

Inorganic Geochemist
Alexander Thomas
Department of Earth Science
University of Oxford
Parks Road
Oxford
United Kingdom
alext@earth.ox.ac.uk

Inorganic Geochemist
Alexander Tudhope
School of Geosciences, Grant Institute
Edinburgh University
West Mains Road
Edinburgh
United Kingdom
sandy.tudhope@ed.ac.uk

Inorganic Geochemist
Yusuke Yokoyama
Department of Earth and Planetary Sciences
University of Tokyo
7-3-1 Hongo, Bldg 1
Tokyo
Japan
yokoyama@eps.s.u-tokyo.ac.jp

Microbiologist
Crisogono de Olivera Vasconcelos*
Department of Earth Sciences
Swiss Federal Institute of Technology
Geological Institute
Sonneggstrasse 5
8092 Zürich
Switzerland
Cris.Vasconcelos@erdw.ethz.ch

Micropaleontologist (foraminifers)
Kazuhiko Fujita
Department of Physics and Earth Sciences
University of the Ryukyus
Senbaru 1
Nishihara, Okinawa
Japan
fujitaka@sci.u-ryukyu.ac.jp

Paleomagnetist
Kenneth Lee Verosub
Department of Geology
University of California, Davis
One Shields Avenue
Davis CA
USA
verosub@geology.ucdavis.edu

Physical Properties/Logging Specialist
Hideaki Machiyama
Institute for Research on Earth Evolution (IFREE)
Japan Agency for Marine-Earth Science and Technology (JAMSTEC)
2-15 Natsushima-cho
Yokosuka
Japan
bucci@jamstec.go.jp

Physical Properties/Logging Specialist
Klaas Verwer*
Faculty of Earth and Life Sciences
Vrije Universiteit
Sedimentology and Marine Geology
De Boelelaan 1085
Amsterdam
The Netherlands
klaas.verwer@falw.vu.nl

Sedimentologist
Hiroki Matsuda*
Department of Earth Sciences, Faculty of Science
Kumamoto University
2-39-1, Kurokami
Kumamoto 860-8555
Japan
hmat@sci.kumamoto-u.ac.jp

Sedimentologist
Hildegard Westphal
Institut für Paläontologie
Universität Erlangen-Nürnberg
Loewenichstrasse 28
91054 Erlangen
Germany
westphal@pal.uni-erlangen.de

Sedimentologist
Guy Cabioch
Unité de Recherche Palétropique
Institut de Recherche pour le Développement (IRD)
BP A5
98848 Nouméa CEDEX
New Caledonia
France
cabioch@noumea.ird.nc

Sedimentologist, observer
Kyung Sik Woo
Division of Earth Sciences
Kangwon National University
192-1, Hyoja2-Dong
Chunchon
Kangwon-Do
200-701
Korea
wooks@kangwon.ac.kr

Sedimentologist
Tsutomu Yamada*
Institute of Geology and Paleontology
Graduate School of Science
Tohoku University
Aobayama
Sendai
Japan
yamada@dges.tohoku.ac.jp

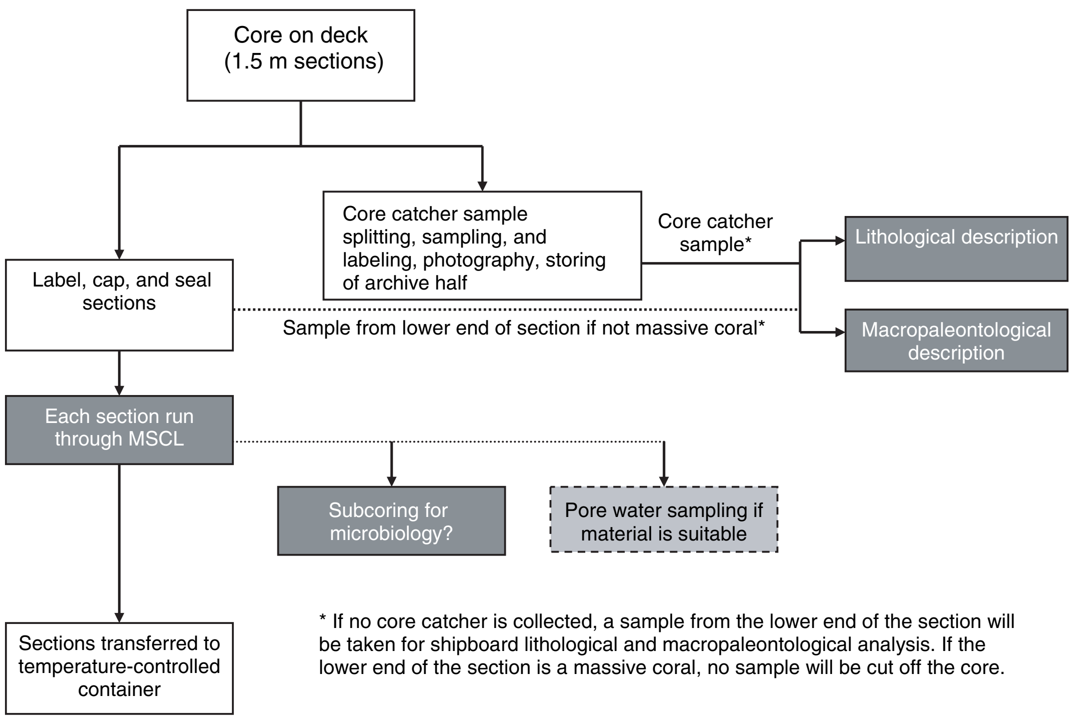
*Denotes Expedition Scientists who will participate in the offshore phase of the expedition.

APPENDIX

ESO Sampling and Measurement Plan

This plan was discussed and agreed on during various meetings and subsequent communications with the chief scientists. Nevertheless, this plan is subject to amendment according to the scientific needs and interests of the Expedition Scientists or operational constraints.

Offshore Sampling and Analysis



Core Curation

There will be a mobile core curation laboratory container onboard the drilling vessel, supervised by the Chief Curator. A second curator will cover the opposite shift. A sufficient number of core storage containers will be on the drilling vessel. There will be no splitting of the cores at sea, as it will be more efficient to carry out most of the following scientific analysis during an onshore party at Bremen.

As the cores will be collected in a plastic liner, the usual IODP curation procedures will be followed: the core will be cut on board into 1.5 m lengths and curated. It has been noted that it is important to store corals in dry conditions to avoid fungi and bacteria that may develop in coral skeletons, with the strong possibility of alteration of the initial geochemical signals.

Lithological and Macropaleontological Description

Core catcher samples will be collected, split, and labeled, and the working half handed over for lithological and macropaleontological description. If no core catcher is collected, a sample from the lower end of the section will be taken for shipboard lithological and macropaleontological analysis. If the lower end of the core is a massive coral, no sample will be cut off the core.

Inorganic Geochemistry

No major mud sequences are expected to be encountered at the proposed drill sites. However, if suitable material is recovered and there are requests from Expedition Scientists, pore water sampling (e.g., by centrifuge) may be conducted for fluid chemistry/circulation studies. In this case, pore water should be extracted immediately from a core sample, and ephemeral properties (e.g., salinity, alkalinity, and ammonia) will be analyzed right away. Depending on the parameter, the interstitial water sample might be specially treated in order to conserve it for later analyses.

Microbiology

Sampling

It is proposed that samples should be taken immediately in the field under the most sterile possible conditions. It will be important to know if microbes from the drilling fluids have entered the cavities during drilling. Ideally, fluorescent microspheres should be used during drilling, but these will not be used during Expedition 310 for environmental reasons. Results should be interpreted with care, as contamination may occur during drilling and any microbial material found may not be in situ. To limit the effects of contamination, samples will be washed with sterile seawater and only the attached microbes will be considered for further activity measurements (which includes typically >99% of the total biomass).

Fixing for Scanning Electron Microscopy/Energy Dispersive X-Ray Analysis/Light Microscopy Studies

It will be important to look for the biofilms in the field using a binocular microscope and a fluorescence microscope (i.e., to look for living microbes revealed by 4′ ,6-diamindino-2-phenylindole [DAPI] staining). Also, counting should be done in the field (but no routine counting is required because we expect that the DAPI and acridine orange staining methods are probably difficult to apply in the coral reef environment because of unspecific binding of the dyes to carbonate minerals). The microbial community should be chemically fixed together with the mineral substrate using glutaraldehyde to preserve the primary structure, and the samples should be frozen at –80°C to be transported back to the laboratory, where the microbial abundance (shipboard) and diversity (shore based) will be studied microscopically using staining techniques. Scanning electron microscopy (SEM) and energy dispersive X-ray analysis (EDAX) studies of microbial related carbonates (microbialites) will be made postcruise using the fixed samples.

Growth Studies

Appropriate growth media should be inoculated with selected core samples in the field. These will be returned to the laboratory, where the growth of microbes from samples will be studied postcruise. This living material can also be used for deoxyribonucleic acid (DNA) analysis.

Activity Measurements

One of the most sensitive tests to detect surface attached microbes (i.e., living cells) is the adenosine triphosphate (ATP) test with a luminometer and the firefly-based enzyme assay. The surfaces can be sampled with a specific type of swab, and the numerical results are available within seconds. This method is ideal for routine analysis, in comparison to the several hours required for the staining/counting methods (furthermore, we expect that the DAPI or acridine orange staining methods will probably be difficult to apply in this environment, see above).

Another sensitive test (qualitative and quantitative) for microbial activity is the measurement of microbial exoenzymes. We propose to measure alkaline phosphatase, glucosidase, and aminopeptidase exoenzymes as detected by fluorometry and compare the data with other subseafloor sites described in the literature. This test requires that defined amounts of sediment be incubated together with fluorescent dye-labeled substrates in stirred vials for 6–12 h and the released dye measured in a spectrofluorometer.

Offshore Petrophysics Measurements

Core Logging

Cores will be logged on the drilling vessel in a modified 20 ft container, housing a single MSCL track comprising one magnetic susceptibility loop and density, velocity, and resistivity sensors. The single core-logger system will include a full spares kit.

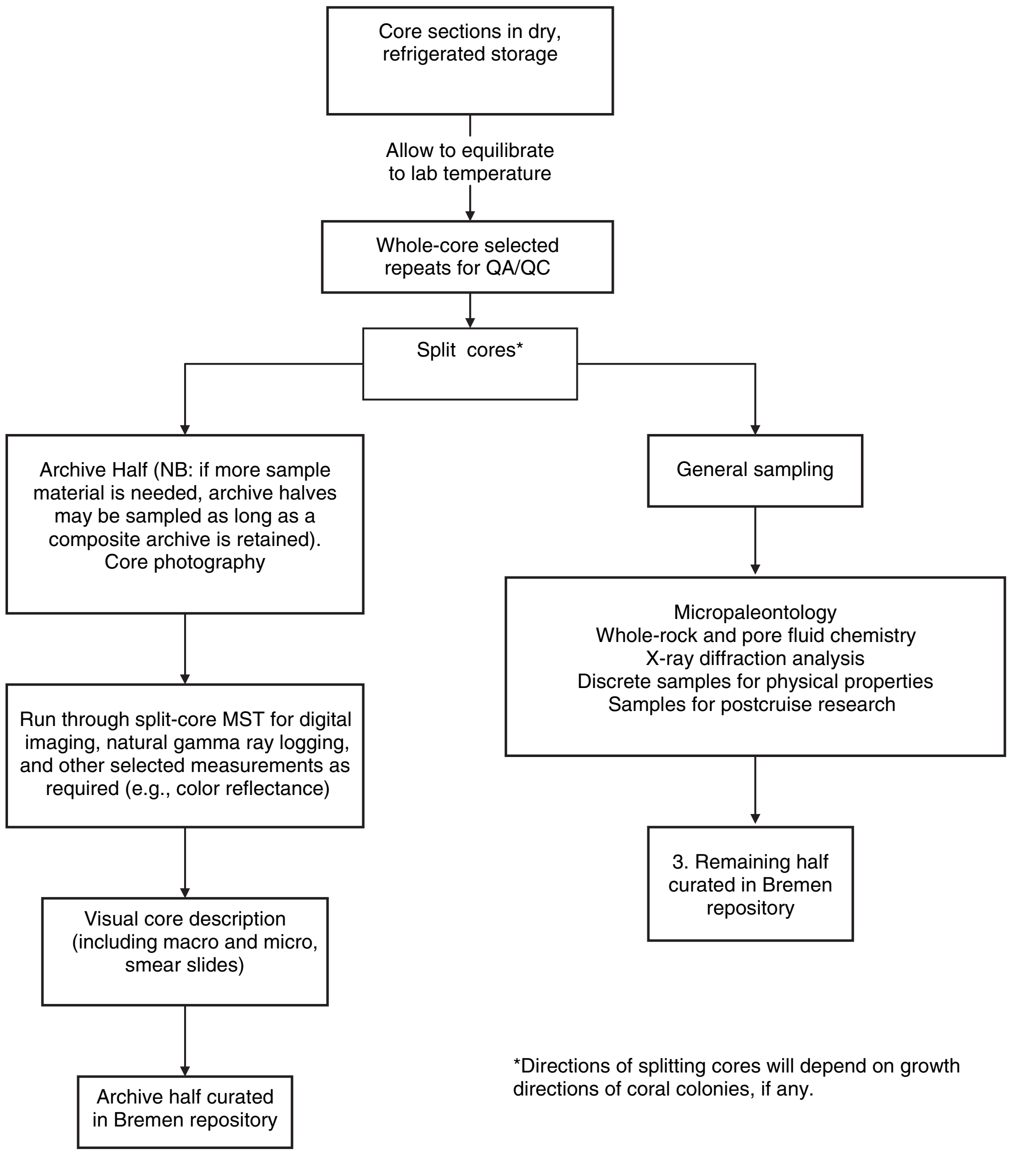
All the temperature-equilibrated core logging data acquired at sea will provide quality control/quality assurance checks when compared to repeat measurements planned for Bremen.

Downhole Logging

The following is a generic list of minimum and additional tools, based on formation properties discussed with proponents, and not on operator-based trademark names:

- Optical images: millimeter-scale geological description
- Acoustic images: centimeter-scale impedance and mesoscale porosity
- Spectral gamma logging: U, Th, K, and red algaes
- Acoustic velocity logging: V_P and V_S at 10–20 kHz
- Induction resistivity logging: pore fluid salinity and porosity
- Hydrochemical borehole fluid logging: pressure, temperature, pH, Eh, SP and fluid electrical conductivity to identify fluid circulation

Onshore Sampling and Analysis



Location

After due consideration, it has been decided that there will be no splitting of the cores at sea. The sampling party will take place at the new IODP Core Repository and Laboratory at Bremen University in combination with access to the laboratories at the Department of Geosciences, the Research Center for Ocean Margins (RCOM), and the Centre for Marine Environmental Research (MARUM).

Planned Analysis and Available Facilities

The following facilities will be available for the Expedition Scientists at the IODP Bremen Core Repository. Note that it is not considered prudent to transport all these facilities to the island or onto a drilling vessel:

- Core splitting: an archive half will be set aside as per IODP policy.
- Core description: ESO is working in cooperation with the IODP U.S. Implementing Organization (USIO) to implement a system that is at least equivalent to the IODP/ODP standard. For data entry, ESO will employ an OffshoreDIS system that is entirely compatible with others being used in IODP.
- Core photography: core shots on a routine basis, close-ups on request.
- Core sampling: a detailed sampling plan will be devised at the completion of the offshore phase and after the scientists have submitted their revised sample requests.
- Thin section and smear slide preparation: description and interpretation.
- Micropalaeontology: microscope laboratory (with hood for sample preparation if acids needs to be applied).
- Inorganic geochemistry: whole-rock and pore fluid chemistry using inductively coupled plasma–mass spectrometry (ICP-MS) and X-ray fluorescence (XRF); carbonate and total organic carbon content using a LECO analyzer.
- X-ray diffraction analysis (XRD): bulk mineralogy (e.g., carbonate mineralogy, etc.).
- Petrophysical measurements*:*
  - Selected repeat whole-core measurements for QA/QC.
  - Split-core multisensor core logger and natural gamma ray logging
  - Physical properties of discrete samples (moisture and density [MAD]): determination of index properties (velocity, wet bulk density, grain density, porosity, and void ratio). Following IODP procedures, core samples will be oven-dried, the dried sample volume quantified using a five-chambered pycnometer, and masses measured using a high-precision balance.
  - Color reflectance measurements: Minolta spectrophotometer.
  - Digital line-scan camera on split-core multisensor core logger track.