A PROPOSAL FOR DRILLING AT AN ARC-RIDGE COLLISION ZONE IN THE CENTRAL NEW HEBRIDES ISLAND ARC (VANUATU)

by

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SUMMARY

The intra-oceanic New Hebrides island arc lies in the southwestern Pacific Ocean, marking the subduction zone of the Australia-India plate, which moves eastward beneath the North Fiji Basin and Pacific plate. In this proposal, we advocate ODP drilling in the central New Hebrides arc because within a relatively small geographic area, it provides numerous drilling sites for investigating the geologic processes of an island arc, one that may have undergone a reversal in the polarity of subduction. The complex tectonics of this arc involves the d'Entrecasteaux zone (DEZ), which is an aseismic ridge that collides with the central New Hebrides arc, clogging the trench, deforming the arc, and providing an opportunity to investigate in detail the processes governing such collisions. Other major geologic problems that can be investigated by drilling in this arc include: 1) the processes involved in the evolution of intra-arc basins; such basins within and outside of the zone of influence of arc-ridge collision can be studied and compared, 2) the magmatic evolution of arcs during major changes in tectonic environment, including arc-ridge collision and the possible change in the polarity of subduction, and 3) back-arc tectonics. A large amount of recent geophysical data, including about 3000 km of multichannel seismic reflection data, shows that the New Hebrides arc provides excellent drilling targets to investigate these processes.

The impingement of the DEZ against the arc has altered greatly the arc's morphology and structure in that near the impact zone, mountainous islands have risen adjacent to the trench. A large, intra-arc basin, substantially deeper than any other basin in this arc, formed directly east of the impact zone. Furthermore, in the back-arc area an extensional province that extends nearly continuously along the arc disappears abruptly directly east of the

collision. Clearly, the tectonics of the New Hebrides region includes a collision zone with widespread, profound influence on arc evolution. One aid to study of this collision zone is that the DEZ impinges nearly perpendicularly on the arc. This simple geometry obviates the need to drill holes distributed longitudinally along the arc to determine the history of arc-ridge interaction.

Drill sites in the forearc area, near the collision of the DEZ and arc, are designed in part to determine the influence ridge composition and structure have on the style of accretion and on the type of slope structures produced during collision. Near the New Hebrides trench, the DEZ comprises two sub-parallel, east-trending ridges. Paleogene mid-ocean ridge basalt (MORB) has been dredged from the north ridge. Although no samples are available from the south ridge, multichannel seismic reflection data show that rocks in this ridge include a great thickness (3 to 4 km) of layered rocks that are probably sedimentary. Thus, the two ridges apparently differ greatly in genesis and lithology. This lithologic difference is mirrored by the contrasting arc deformation caused by the collision of ridge and arc: the north ridge is being subducted beneath the forearc slope without formation of large "bow-wave" structures, whereas a large bathymetric high, the Bougainville Spur, lies along the eastward projection of the DEZ's south ridge. Seismic data do not show an obvious subduction zone near this spur. One possibility to explain the absence of such a zone is that ridge rocks or oceanic crust are being obducted over the slope. Two proposed drill sites will help characterize these contrasting mechanisms of subduction and accretion by showing the composition and age of rocks in each ridge. Two other sites will penetrate the slope rocks, not only to determine their lithology but also to provide an estimate of the amount of ridge rocks that are incorporated into the accretionary wedge. We also will attempt to determine the role of pore fluids in the development of collision structures by measuring pore-fluid pressure at these drill sites. A study of the provenance of sediment in a basin between the two ridges of the DEZ may show when arc-derived material was first incorporated into basin sediment, giving one of the better estimates of when the arc and the basin near the site first came close together.

To investigate the evolution of intra-arc basins, we propose to drill at three sites in the summit basins of this arc: two sites in the North Aoba and one in the Torres-Santa Cruz Basin. Both of these basins contain rocks of probable Miocene and younger age. The drill sites in the North Aoba Basin will show the provenance, age, paleobathymetry, and lithology of basin fill, from which we can derive the rate and timing of basin subsidence and filling. We believe that a major episode of basin subsidence correlates temporally with the beginning of collision of the DEZ with the arc. The site in the Torres-Santa Cruz basin is extremely important to this study of arc processes in that it provides a datum, from an area unaffected by collision, with which data from sites in the collision zone can be compared.

The magmatic evolution of this island arc can be investigated using data from the proposed drill sites in the intra-arc basins. The main goals are to establish major compositional trends of volcanic ashes and the timing of volcanic pulses. An important facet of this study is to relate volcanic processes to the unsteady tectonic environment of this arc caused by the collision of the DEZ and the hypothesized late Cenozoic flip in subduction polarity. The chronology and chemistry of volcanic ashes will be most useful when the results from sites near the collision zone of the DEZ are compared to results from the site away from this zone. If the polarity of subduction reversed, ash chemistry may show a distinct change that marked magma generation first from crust of the Pacific plate and Fiji Basin and later from crust of the Australia-India plate.

A back-arc trough extends almost the length of the New Hebrides arc except directly east of where the arc and DEZ collide. Back-arc structures include horsts and grabens with flat floors that are covered locally by volcanic seamounts. These grabens may reflect incipient formation of back-arc crust. Drilling in the grabens would elucidate the basic processes involved in the formation of this back-arc province: did new oceanic crust form during this extension, when did the rifing occur, and what is the tectonic connection between formation of the North Fiji Basin and development of the New Hebrides arc.

INTRODUCTION

The robust seismicity and volcanism of the central New Hebrides arc result from the eastward subduction of the Australia-India plate beneath the Pacific plate. This subduction occurs at about 10 cm/yr, nearly perpendicular to the arc. The drilling we propose is designed to investigate basic processes that govern the evolution of island arcs in general. We propose to drill at 13 sites: six sites in the collision zone of the New Hebrides arc with a major submarine mountain system, three sites in intra-arc basins to determine the evolution not only of the basins but of the magmatic arc as well, and four sites in the back-arc area to investigate the possible formation there of oceanic crust. These sites are all within short transit distances of each other, making detailed study of this arc an efficient way to determine the processes active in island-arc evolution.

REGIONAL GEOLOGIC SETTING OF THE NEW HEBRIDES ARC

The New Hebrides island arc is part of a narrow, sinuous, Cenozoic volcanic chain that extends from Papua New Guinea through the Solomon Islands, Vanuatu (New Hebrides), Fiji, Tonga, and the Kermadec Islands to New Zealand. The New Hebrides arc extends for a distance of 1,700 km from the Santa Cruz Islands (eastern part of the Solomon Islands) in the north to the Matthew and Hunter Islands (eastern part of the territories of New Caledonia) in the south. The territorial islands of Vanuatu extend for 1,450 km from north to south (Fig. 1).

The New Hebrides Trench trends northwest-southeast and marks the boundary between the Australia-India plate and the Pacific plate (Fig. 1). The maximum depth of this trench ranges from over 8,000 m in the north, near the west-trending San Cristobal Trench of the Solomon Islands, to about 7,500 m at its southern terminus near the east-trending Hunter Trench. The geomorphic trench is absent opposite Malakula and Espiritu Santo Islands where the d'Entrecasteaux Zone (DEZ) abuts the west flank of the arc.

Relative motion between the two plates is 10 cm/yr with the Australia-India plate moving N 75° E (Minster, Jordan, 1978; Pascal and others, 1978; Isacks and others, 1980). Absolute motion of the North Fiji Basin is 10 cm/yr northwestward (Minster and Jordan, 1978; AAPG, 1982), and west of Vanuatu, the Australia-India plate moves at approximately 6 cm/yr.

Between the southern New Hebrides Trench and the Loyalty Ridge to the west lies the North Loyalty Basin where the ocean is about 4,000-5,000 m deep. The Deep Sea Drilling Project drilled into rocks of this basin (DSDP Site 286) in 1973 and found that the basement consists of middle Eocene oceanic crust (Andrews, Packham and others, 1975). The Loyalty Ridge trends northwest through this oceanic basin and consists of island-arc volcanic rocks

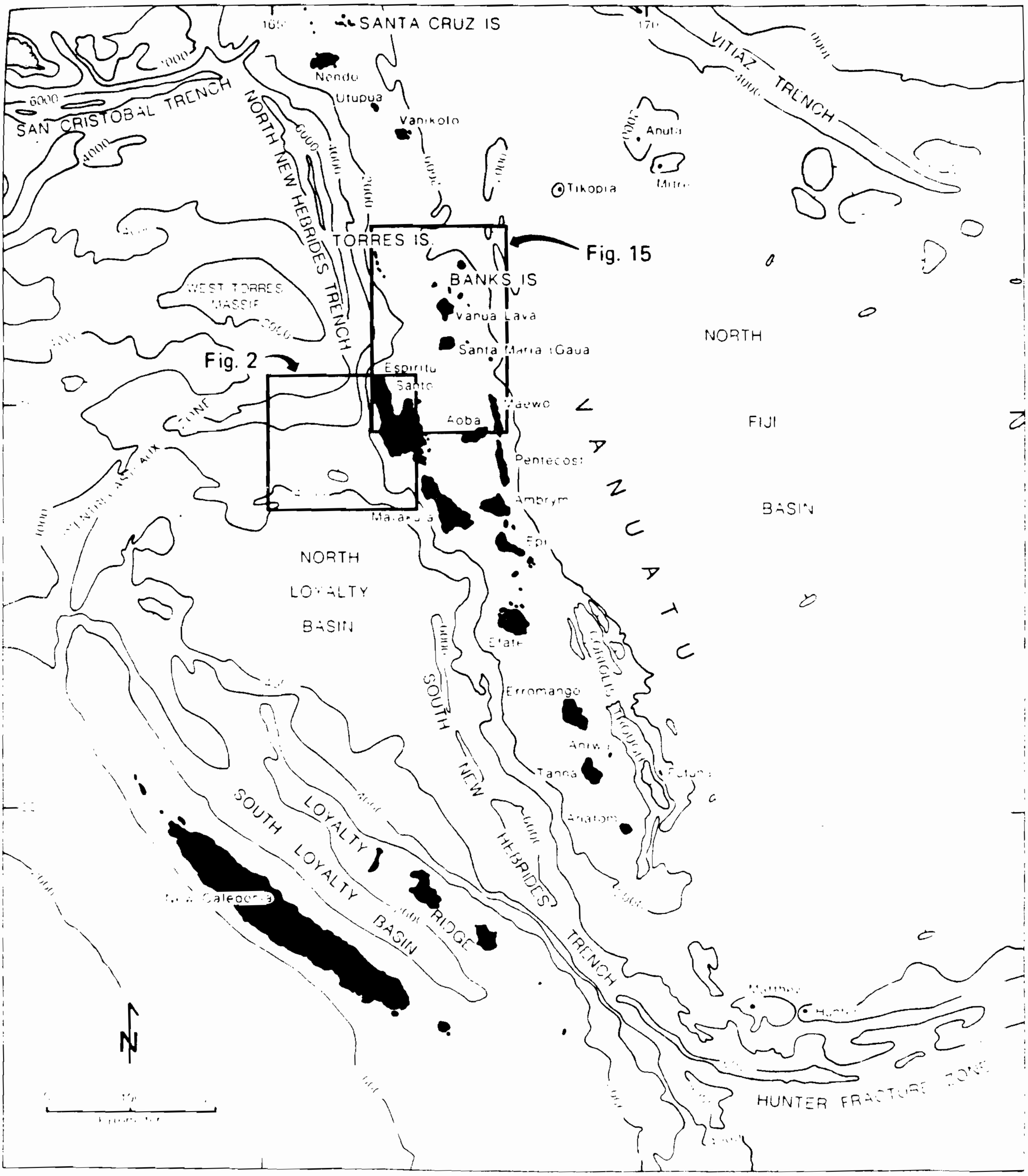

SANTA CRUZ IS
Nendo
Utupua
Vanikolo
Anuta
Tikopia
6000
4000
2000
SAN CRISTOBAL TRENCH
NORTH NEW HEBRIDES TRENCH
VITIAZ TRENCH
WEST TORRES MASSIF
TORRES IS.
Fig. 15
BANKS IS
Vanua Lava
Santa Maria (Gaua
NORTH FIJI BASIN
Fig. 2
Espiritu Santo
Aoba
Maewo
Pentecost
Ambrym
Epi
VANUATU
NORTH LOYALTY BASIN
Efate
Erromango
SOUTH NEW HEBRIDES TRENCH
Tanna
SOUTH LOYALTY BASIN
LOYALTY RIDGE
HUNTER

Figure 1

that are presently being subducted at the southern New Hebrides Trench (Carney and MacFarlane, in prep.).

West of the Loyalty Ridge lies the New Caledonia Ridge, which extends northwestward and becomes the submarine ridge of the DEZ. The DEZ may have been a subduction zone in the late Eocene that was uplifted and exposed in Miocene time (Daniel and others, 1977; Maillet and others, 1983). This arcuate ridge comprises horsts and grabens and is approximately 100 km wide. It extends eastward to end in the central New Hebrides Trench where it is presently being subducted near Malakula and Espiritu Santo Islands. Near these islands, the DEZ is composed of two east-trending ridges. Paleogene MORB was dredged from the north ridge of the DEZ and multichannel seismic reflection data show that the south ridge is made up of stratified, probably sedimentary rocks. This difference in lithology seems to be mirrored in the deformation the two ridges have induced in the accretionary wedge of the New Hebrides arc. The north ridge is being subducted without formation of any large slope structures. However, along the strike of the south ridge, a large bathymetric protruberance, the Bougainville Spur, projects 4,000 m above the oceanic plain. Seismic reflection data do not reveal a subduction zone beneath this spur, suggesting that some or most the south ridge is being accreted (Daniel and Katz, 1981). The east dipping Benioff zone is continuous despite the subduction of the DEZ (Pascal and others, 1978; Isacks and others, 1980; Louat and others, in prep.; Carney and Macfarlane, in prep.).

North of the DEZ lies the oceanic West Torres Plateau, which has unknown crustal affinity. Water depth over this plateau is as shallow as 1,000 m.

East of the New Hebrides arc lies the North Fiji Basin, an active marginal sea of middle to late Miocene age (Malahoff and others, 1982). It is a relatively shallow, open-ocean basin with water depths generally not greater than 3,000 m. The basin is floored by oceanic crust that exhibits high heat flow (Larue and others, 1982). The North Fiji Basin is bounded on the north by a ridge that supports the inactive volcanic islands of Mitre and Anuta, which may have been formed during Miocene southwestward subduction of the Pacific plate at the Vitiaz Trench (Jezek and others, 1977). The North Fiji Basin is separated from the Oligocene South Fiji Basin by the northeast-trending Hunter fracture zone.

The forearc of the New Hebrides islands includes a flat-topped ridge, 100-150 km wide, from which Malakula, Espiritu Santo and the Torres Islands project. South of the island of Anatom (Aneityum), the forearc ridge is poorly developed, consisting primarily of a narrow ridge with sharp relief along the crest (Karig and Mammerickx, 1972; Monzier and others, 1983). The volcanic arc lies east of the forearc area and consists of a chain of volcanoes, many of which are active. Most of the volcanoes lie 130-150 km east of the trench; however, volcanoes on Efate, Matthew, and Hunter Islands lie within 100 km of the trench. The back-arc area lies between the volcanic arc and the North Fiji Basin and includes an uplifted horst that supports the islands of Maewo and Pentecost. Also included in this area are the back-arc grabens; a series of northern grabens extends northward from Maewo, and a single southern graben, the Coriolis Trough, trends southward from Pentecost (Karig and Mammerickx, 1972; Dubois and others, 1978). The volcanic islands Vot Tande and Futuna are perched on the steep western scarp of the Coriohs trough.

The summit basins of Vanuatu were first described by Luyendyk and others (1974) who interpreted them as a late-stage extensional features. These basins form a nearly continuous "median sedimentary basin" (Ravenne and others, 1977). The North and South Aoba Basins have greater bathymetric expression than does any other basin on the New Hebrides arc summit. Both basins are over 70 km wide and lie beneath 2,000-3,000 m of water. They are divided by the active volcano forming Aoba Island (Carney and MacFarlane, 1980; Katz, 1981). Seismic-refraction data suggest that both basins contain 5 to 6 km of sedimentary rocks. Carney and MacFarlane (1980) described these basins as asymmetric in east-west cross-section and containing thick deposits of Miocene to Recent sediments.

Rocks exposed on the New Hebrides islands show that three volcanic arcs were active in different areas. The oldest arc yielded voluminous early Miocene volcanic rocks that are exposed chiefly along the western chain of islands -- Espiritu Santo and Malekula Islands. During the late Miocene and Pliocene, the volcanic arc lay along the eastern island chain formed by Pentecost and Maewo Islands. The youngest volcanic arc, active during and since the Pliocene, has built the middle chain of islands that extends from Efate to Vanua Lava Islands.

The evolution of the New Hebrides arc is poorly understood and many hypotheses have been advanced to explain formation of the forearc ridge, volcanic arc, and backarc (e.g., Chase, 1971; Pascal and others, 1973; Falvey, 1975; Coleman and Packham, 1976; Ravenne and others, 1977; Carney and MacFarlane, 1976, 1980, 1982; Katz, in prep.). In one hypothesis, a reversal of subduction polarity occurred in late middle Miocene time. Prior to this reversal, the Vitiaz Trench was an active subduction zone formed as a west-dipping slab of the Pacific plate was subducted beneath the Australia-India plate. The direction of subduction shifted to an east-dipping Benioff zone with the Australia-India plate being subducted beneath the Pacific plate (Chase, 1971; Carney and MacFarlane, 1976, 1980; MacFarlane and Carney, in prep.). In an alternative hypothesis, no shift in subduction direction occurred, and the present arc configuration is the result of a continuous east-dipping subduction zone (Luyendyk and others, 1974, Carney and MacFarlane, 1977; Hanus and Vanek, 1983; Katz, in prep.). On the basis of the distribution of earthquake foci along the New Hebrides Benioff zone, Hanus and Vanek (1983) concluded that two differently inclined slabs exist at intermediate depths. They argue that these slabs were produced from two consecutive subduction cycles of the same polarity and that these two cycles can explain the shifting volcanic axis and the formation of the North and South Aoba Basins. Similarly, Louat and others (in prep.) concluded that there has only been eastward subduction, and a steepening Benioff zone has been responsible for the migration of the volcanic axis.

The troughs at the rear of the New Hebrides island arc were discovered in 1966 during the cruise of the ORSTOM R/V Coriolis (de Chalvron and others, 1966; Puech and Reichenfeld, 1968, 1969). These troughs are shown on the bathymetric maps of Scripps Institute of Oceanography (Mammerickx and others, 1971), on the ORSTOM map (Monzier and others, 1982), and on the USGS maps constructed for the ANZUS Tripartite-CCOP/SOPAC investigations (Chase and others, in press). In the northern and southern parts of the arc, these troughs separate the island arc and the North Fiji Basin; they are absent in the central part of the arc, east of the islands of Maewo and Pentecost.

Karig and Mammerickx (1971) interpreted the back-arc structures as en-echelon inter-arc basins and Luyendyk and others (1974) believed them to be extensional features, although they could locate no new oceanic crust. Dubois and others (1975, 1978) proposed that these troughs formed by deep-seated magmatic and tectonic processes that involved considerable faulting. The most recent work in the area suggests that these troughs were caused by a change in the island arc's stress field, possibly due to the initial collision of the DEZ (Collot and others, 1985; Burne and others, in press).

The back-arc troughs south of the collision of the DEZ and arc generally include two grabens with a separating horst. Based on single-channel seismic reflection profiles, the troughs appear to be tensional features exhibiting two distinct morphologies: (1) narrow, flat bottomed grabens filled with deep sediment that returns strong reflections and is overlain at an angular unconformity by a less-reflective unit; and (2) wide, troughs with irregular floors, that contain no sediment returning strong, organized reflections. This absence of reflective sediment contrasts with the layered sedimentary rocks covering the seafloor of the North Fiji Basin and the thick sedimentary pile of the New Hebrides arc's eastern slope. Seamounts project locally above the floor of the back-arc troughs, and high magnetic anomalies over these seamounts suggest that they are of volcanic origin.

The back-arc troughs north of the collision zone of the DEZ and arc are not as well known as the southern ones. The northern troughs appear complex in that there may be as many as three sub-parallel troughs; their combined width being much greater than the width of the single southern trough (Fig. 21).

Seismic refraction data from the southern troughs (Pontoise et al, 1982) indicate that 2 to 3 km of low-velocity (2.0 to 3.5 km/s) rocks overlie a high-velocity (6.0 km/s) basement. In these troughs, single-channel seismic lines show weak disorganized reflections which appear to result from the heterogeneity and complexity of the tectonized structures. Thus, low velocities indicated by refraction data could represent the average velocities of rocks of varied origin and nature. Gravity modeling, (Collot and Malahoff, 1982) do not indicate a significant difference between the crust of the troughs and the crust of the North Fiji Basin, both of which are different than the crust of the New Hebrides island arc.

Shallow earthquakes occur along these troughs (Coudert and others, 1981; Chatelain, pers. com.). Well-defined hypocenters lie between 10 and 20 km depth, slightly deeper than mid-ocean ridge earthquakes. Locating events recorded by the ORSTOM-Cornell network is still in process (Chatelain, pers. comm.), but Coudert and others (1981) report that focal mechanisms show normal faulting on the southern flank of the trough.

A recent petrological study of dredged samples collected along the back-arc troughs shows that most of the samples are related to island arc volcanism (Vallot, 1984). However, some of the basalts dredged at 18°S latitude along the eastern scarps of the southern trough are clearly marginal-basin tholeitic basalts. To the south of Futuna Island and on the eastern scarp of the trough, samples dredged at 20°S latitude range from ankaramites and olivine basalts to plagioclase-rich basalts. These samples are geochemically similar to those derived from the volcano on Tanna Island and may result from an independent volcanic complex like that which crops out on Futuna Island.

The back-arc troughs of the New Hebrides arc are believed to represent well defined examples of crustal extension between an active island arc and the active, marginal North Fiji Basin. These troughs may have developed by the onset of a double-axis spreading system in the marginal basin or from a jump of the axis of extension. They represent the initial extension of the crust in a purely oceanic environment. No other example of Recent spreading in this tectonic context is known from the southwestern Pacific.

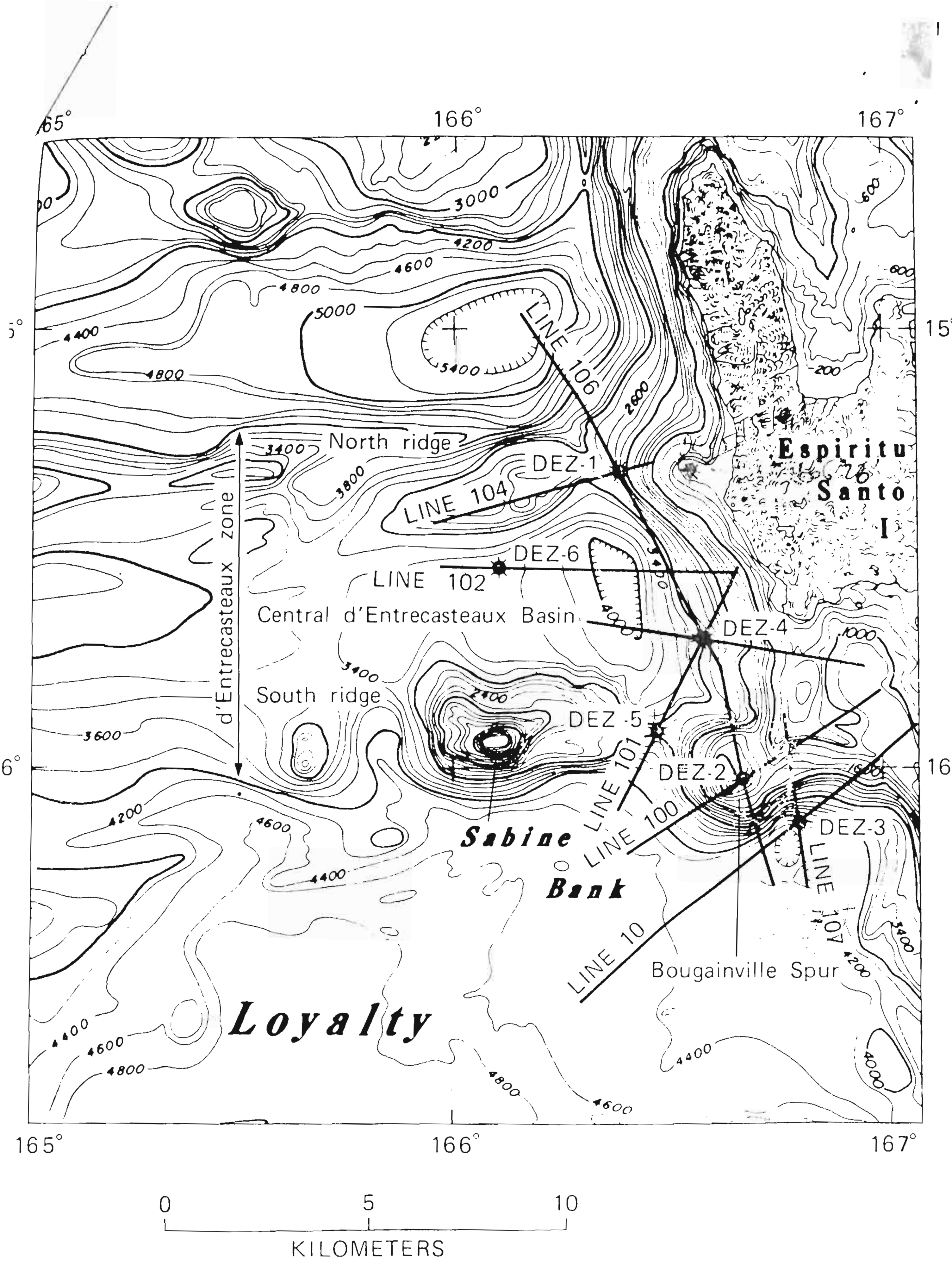
SITE PROPOSALS

In this section, proposed drill sites are arranged according to major themes of island-arc evolution. The sites for each theme are described in the order of their priority. We descibe first those sites with results bearing primarily on arc-ridge collision, then those sites concerning the evolution of magmatic arcs, subduction-polarity reversals, and intra-arc basins, and finally those sites that describe the development of back-arc areas.

Arc-Ridge Collision

We propose to drill six sites to investigate the timing and kinematics of arc-ridge collision as well as the style of accretion and deformation of rocks now part of the arc by dint of the collision (Fig. 2). Numerous high-standing features surmount the ocean floor in the South Pacific, suggesting that collisions of oceanic features with subduction zones occur commonly. Processes involved in such collisions probably constitute a fundamental force in the evolution of the forearc areas of island arcs. As described above, the collision zone of the New Hebrides arc and the DEZ is evident not only in anomalous forearc features but also in the structures of a summit basin and back-arc area. This clear, arc-wide expression gives this collision zone high priority in studies that seek to show the full spectrum of collision-related arc processes. Thus, it must be borne in mind that drill sites proposed herein and intended primarily to explain the formation of intra-arc basins and back-arc features will also contribute greatly to understanding the processes of forearc collision.

In the region of the central New Hebrides island arc the DEZ comprises two aseismic ridges, major arcuate mountains that extend as submarine eminences from near New Caledonia to their eastern end in the New Hebrides trench. Earthquake seismicity suggests that both ridges of the DEZ are being subducted beneath the arc without warping or disrupting the Benioff zone (Pascal and others, 1978; Isacks and others, 1980). Nevertheless, these ridges produce contrasting deformation in arc rocks: the north ridge is being



166°
167°
15°
16°
6°
165°
3000
4200
4600
4800
5000
4400
5400
LINE 106
2600
North ridge
3400
3800
DEZ-1
LINE 104
Espiritu
Santo
I
DEZ-6
LINE 102
Central d'Entrecasteaux Basin
DEZ-4
1000
d'Entrecasteaux zone
South ridge
2400
DEZ-5
3600
LINE 101
DEZ-2
LINE 100
DEZ-3
Sabine
Bank
LINE 107
LINE 10
Bougainville Spur
Loyalty
4000
0
5
10
KILOMETERS

Figure 2

subducted without development of large slope structures, whereas the south ridge has caused a large seamount to form and parts of this ridge or oceanic crust are apparently being obducted. The drill sites were chosen in part to establish what, if any, relationship exists between the style of forearc deformation and the physical properties of the impinging rocks. Another important goal of the drilling is to establish the time of onset of major deformation caused by collision, so that collision, magmatic evolution, summit-basin development, and back-arc tectonics can all be put into a temporal context.

Proposed Drill Site DEZ-1: This site is located within the collision zone of the DEZ, on the lower slope of the New Hebrides arc along the strike of the DEZ's north ridge. (Fig. 2). Crossing multichannel and high-resolution seismic lines are available for this site as are gravity and magnetic data. Seismic line 104 (Fig. 3) extends eastward along this ridges's crest, through the proposed drill site, to as close to Espiritu Santo Island as was safe for the ship to pass. The north ridge stands about 2 km above the abyssal oceanic plain and 1.5 km higher than the seabottom over the Central d'Entrecasteaux Basin (Fig. 2).

West of the arc's lower slope, some local reflections from the north ridge show that rocks there are coarsely layered and have an apparent west dip. Most of the ridge-forming rocks, however, are non-reflective, suggesting that a large part of the ridge is MORB, as indicated by dredged samples. The nearly horizontal reflection from the top of the ridge can be traced beneath the arc's lower slope. Thus, this ridge is being subducted without apparent major deformation of the ridge rocks. Reflections from the lower-slope rocks are incoherent. In fact, most seismic events from these rocks are

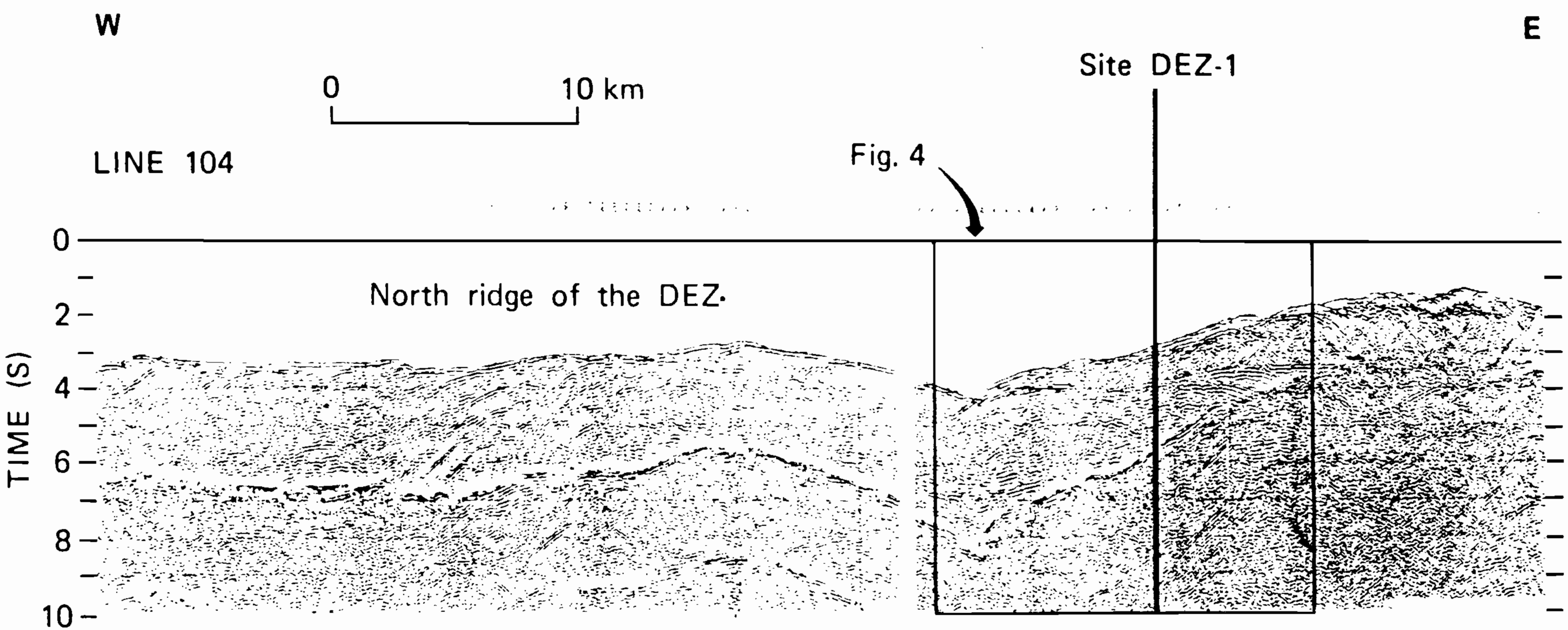

W
E
Site DEZ-1
0
10 km
LINE 104
Fig. 4
North ridge of the DEZ
0
2
4
6
8
10
TIME (S)

Figure 3

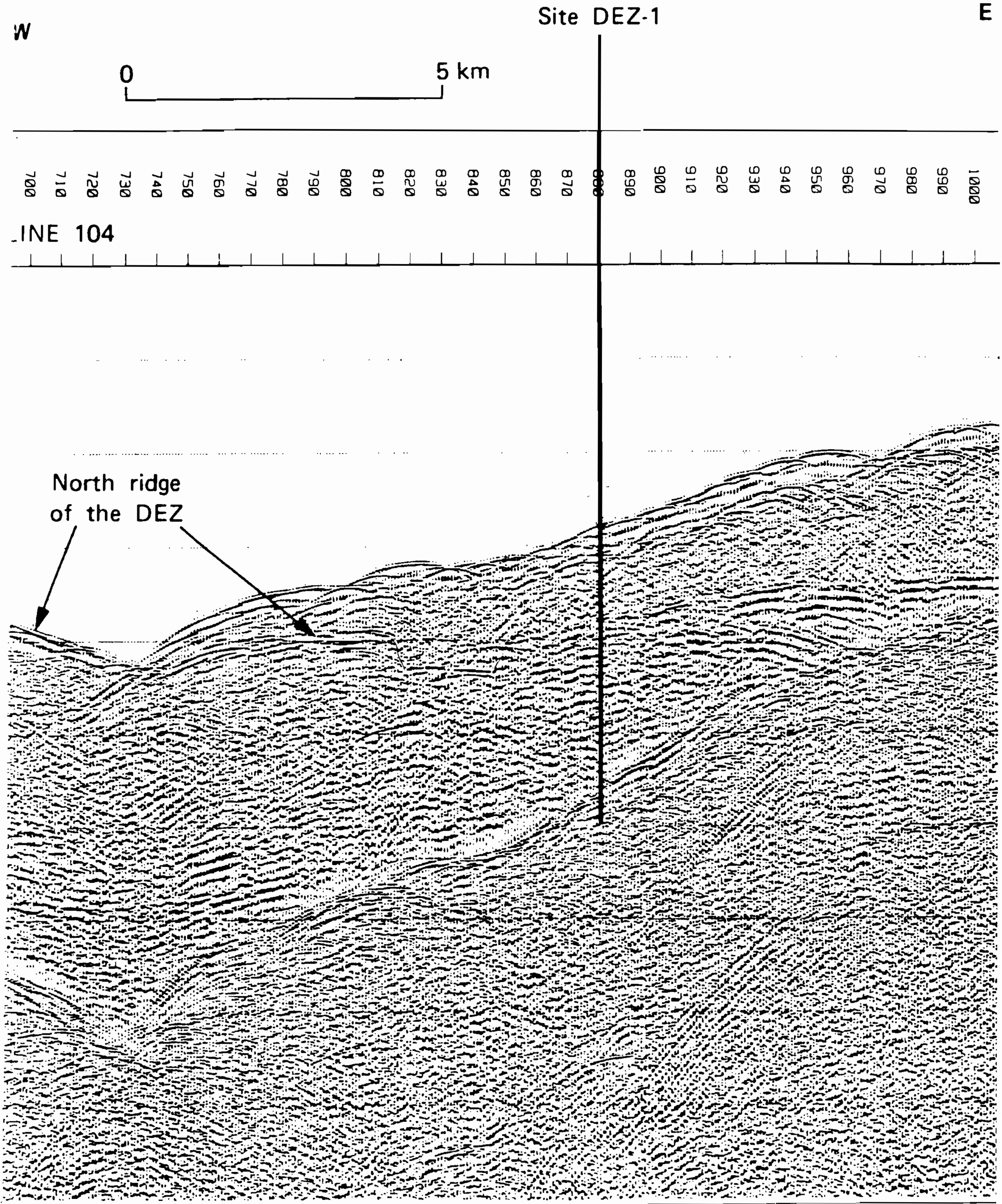

W
E
Site DEZ-1
0
5 km
700 710 720 730 740 750 760 770 780 790 800 810 820 830 840 850 860 870 880 890 900 910 920 930 940 950 960 970 980 990 1000
LINE 104
North ridge
of the DEZ

Figure 4

diffractions, suggesting that considerable stratal disruption has attended insertion of the north ridge. Conspicuously absent are large "bow-wave" structures that, in concept, form by slope rocks' being displaced by the ridge's volume. Other seismic lines in this area show a similar absence of large slope structures.

The purpose for drilling at this site is to investigate the basic processes involved in arc-ridge collision. Specifically, we want to determine when collision began and the amount and type of material accreted from the ridge to the arc. Rocks penetrated at proposed site DEZ-1 will include not only rocks in the arc's lower slope but those in the DEZ's north ridge as well. We will determine the lithology, induration, and age of ridge rocks; these physical properies may be related to the type of slope stuctures induced by collision. This lithologic identification of ridge rocks is also important to the understanding of the process of accretion in collision zones--what amount of material has been removed from the ridge and incorporated into the slope rocks. Analysis of the provenance of rocks in the Central d'Entrecasteaux basin (see description for site DEZ6) may help us to determine when the basin near this site came close to the arc by showing when arc-derived material first reached this basin. This time can be compared to the timing of magmatic pulses and changes in the chemistry of volcanic rocks to undertand deep-seated effects of collision.

<u>Proposed Drill Site DEZ-2</u>: This site is located near the summit of the Bougainville Spur, a large bathymetric feature formed on the lower arc slope along the strike of the south ridge of the DEZ (Fig. 2). Crossing multichannel and high-resolution seismic lines are available for this site as are gravity and magnetic data. Seismic line 100 (Fig. 5) shows that rocks

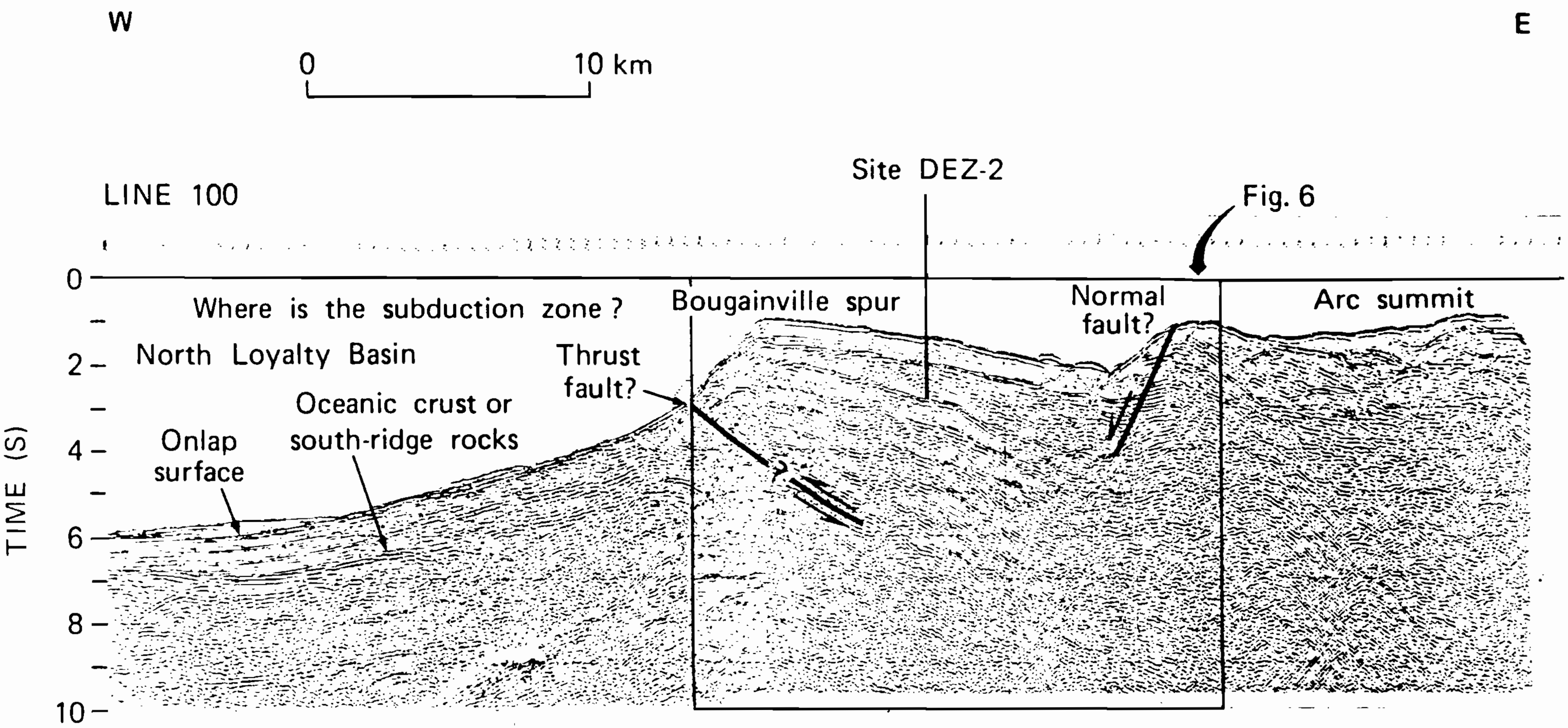

W
E
0
10 km
LINE 100
Site DEZ-2
Fig. 6
0
2
4
6
8
10
TIME (S)
Where is the subduction zone ?
Bougainville spur
Normal fault?
Arc summit
North Loyalty Basin
Thrust fault?
Oceanic crust or south-ridge rocks
Onlap surface

Figure 5

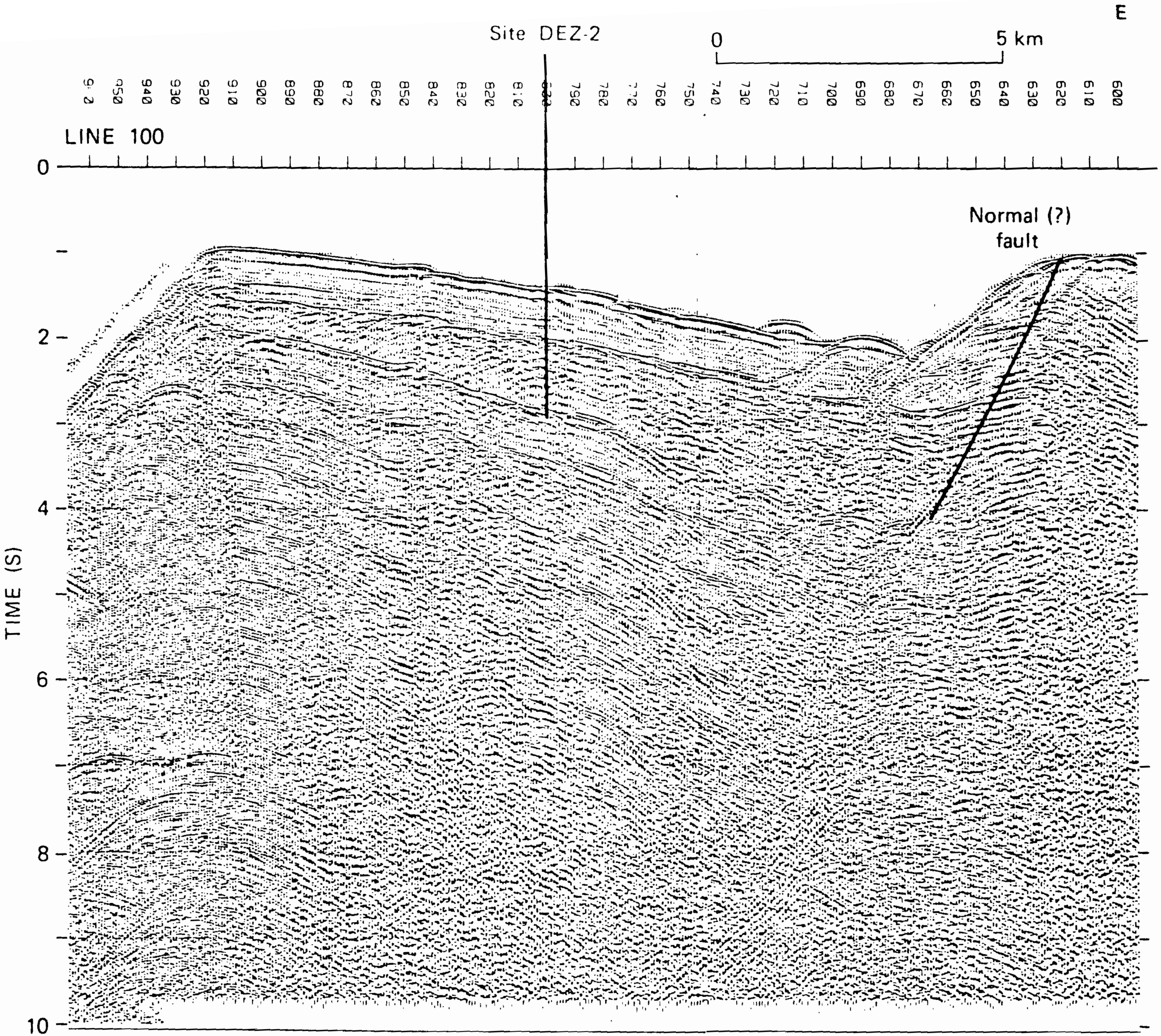


Figure 6

within the North Loyalty Basin rise toward the arc instead of dipping down to the east into a subduction zone. A strong reflection marks what is probably the top of the oceanic crust or of south-ridge rocks. These highly reflective rocks rise about 1000 m eastward toward the Bougainville Spur. The sedimentary section that lies above the highly reflective rocks thins gradually westward from the spur, possibly forming a large submarine fan. The youngest deep-water sediments, however, onlap this fan in abrupt discordant contact (Fig. 5). This contact probably marks the begining of uplift of the deep-water rocks as the Bougainville spur began to form.

Rocks that cap the Bougainville Spur are parallel bedded and do not thicken eastward toward the large normal(?) fault along which these rocks rotated downward, indicating that fault movement is recent (Fig. 6). One possible interpretation is that rocks near the peak of the spur were uplifted by a major, undetected, thrust fault that forms the suture between arc and deep-water rocks and that concurrently rocks east of the spur were dropped downward along the large, normal(?) fault. Rocks in the large rotated block that forms the spur have uncertain affinity: they could be previously obducted south-ridge or oceanic rocks, or they could be arc rocks.

The main purpose for drilling at site DEZ-2 is to understand the mechanism by which rocks from oceanic features are accreted or smeared onto island arcs. Most of the east dipping rocks near the summit of the spur predate rotation of this block and drilling at this site would provide critical information about the time of major deformation caused by the DEZ. Drilling would also determine the type of accretion or deformation that occured: whether a large block of south-ridge rocks was smeared along the slope or whether rocks in the spur are mainly derived from the arc.

Used in conjunction with results from drilling at site DEZ-3, data from site DEZ-2 would show how far deep-water rocks extend up the arc's slope and how far arc-derived rocks extend down toward the trench. The time of deformation determined from site DEZ-2 will be compared to the time of deformation of the intra-arc basin and to the time of magmatic episodes and chemistry changes to establish whether the collision and events in the intra-arc basin and magmatic arc were contemporaneous.

Proposed Drill Site DEZ-3: This drill site is located within the North Loyalty Basin, along the south flank of the DEZ's south ridge (Fig. 2). Crossing multichannel and high-resolution seismic lines are available for this site as are gravity and magnetic data. A major bathymetric feature, the Bougainville Spur (Fig. 2), projects above the arc's slope along the strike of the south ridge. The peak of this spur is as shallow as 750 m, and less than 16 km west of this peak, the seafloor plunges downward to a depth of about 4100 m, the level of the ocean plain. Rocks in the North Loyalty Basin were penetrated at DSDP site 286 (Andrews, Packham and others, 1975) and were found to be clastic rocks as old as Eocene overlying Eocene oceanic crust.

Seismic line 100 (Fig. 5) crosses east-west over the Bougainville Spur, where the New Hebrides trench would be located, if it were not clogged by the DEZ. Rocks from the ocean plain rise gradually toward the arc by about 1000 m. The strong reflection at the base of the abyssal section is most likely from the oceanic crust or from south-ridge rocks. The absence of strong magnetic anomalies over the spur suggest that the rising rocks are most likely sedimentary rocks of the south ridge. Reflections from the same rising, basal rocks are evident on seismic line 107 (Fig. 7), which crosses north-south over the spur and passes through the proposed drill site DEZ-3. Reflections from

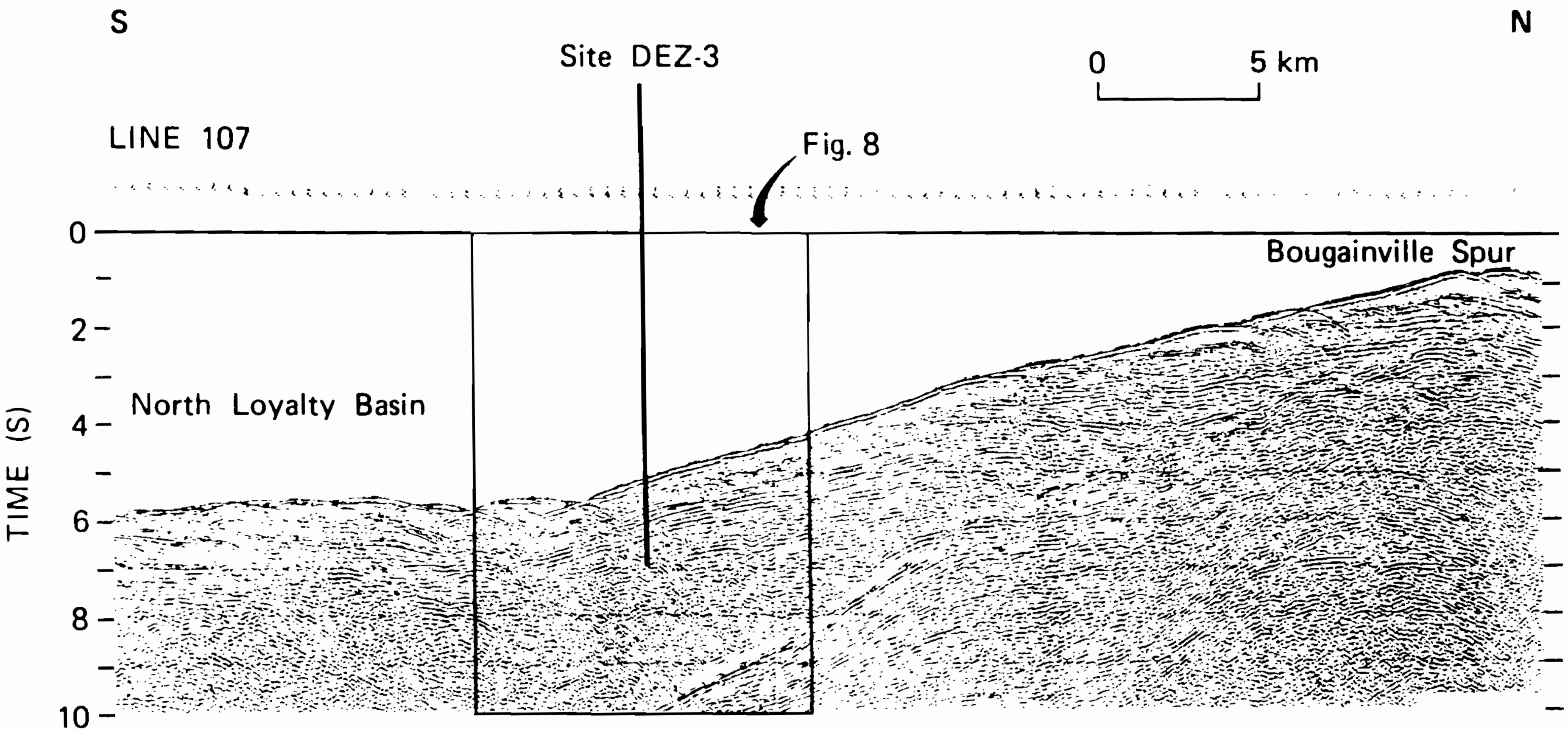
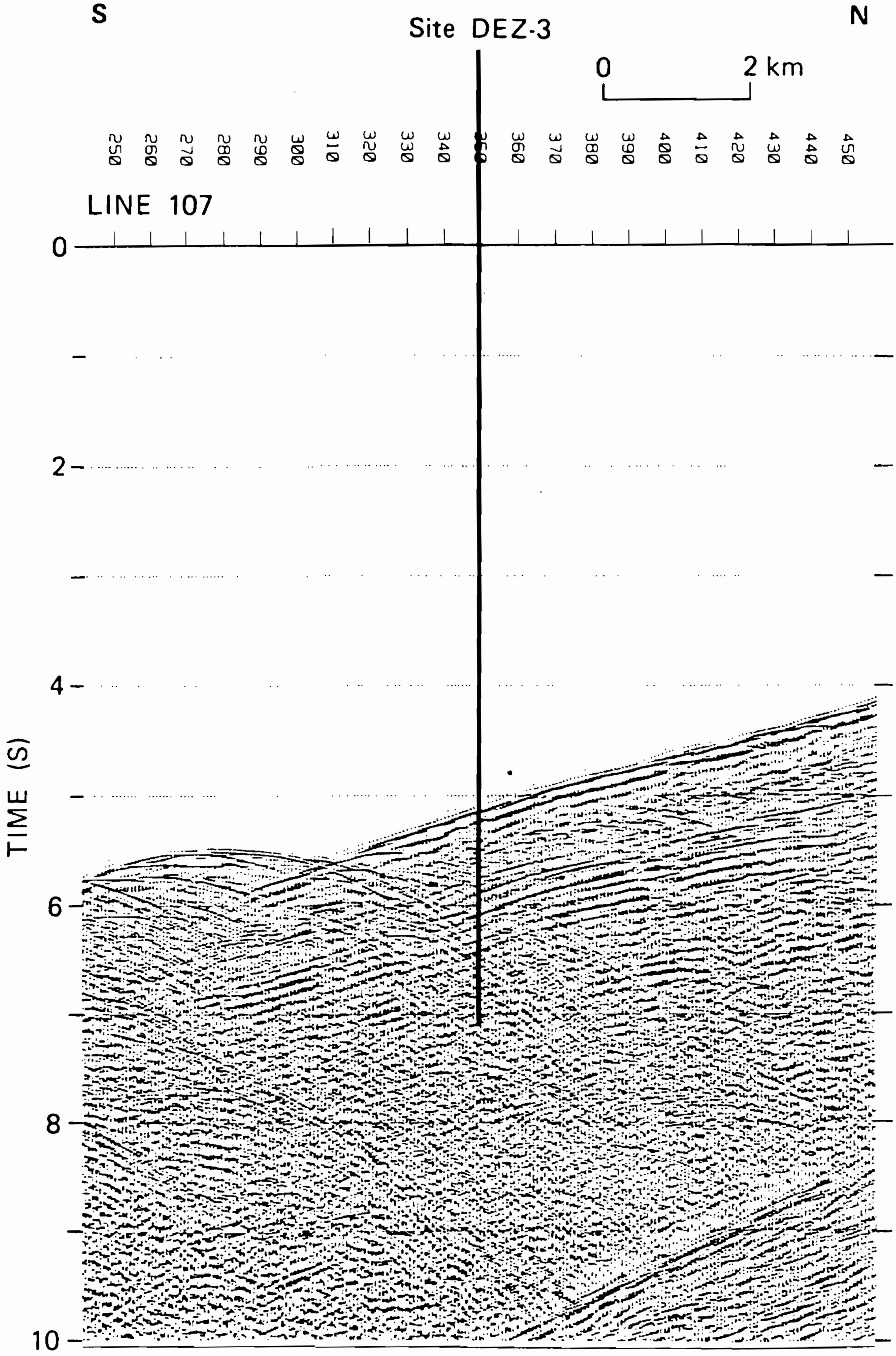

S
N
Site DEZ-3
0
5 km
LINE 107
Fig. 8
Bougainville Spur
North Loyalty Basin
TIME (S)
0
2
4
6
8
10

Figure 7



S
Site DEZ-3
N
0
2 km
250 260 270 280 290 300 310 320 330 340 350 360 370 380 390 400 410 420 430 440 450
LINE 107
0
2
4
6
8
10
TIME (S)

Figure 8

the basal rocks rise toward the arc, nearly joining with outwardly similar strong reflections from rocks within the Bouganville Spur that descend toward the oceanic plate. A zone of disrupted reflections separates the rising and descending reflection sequences and warns against correlating these sequences. This zone could mark a suture between presently obducting south-ridge rocks and either arc-derived rocks or previously obducted rocks.

The main benefits from drilling at site DEZ-3 lie in understanding the processes whereby rocks are accreted onto the slopes of island arcs. Rocks penetrated at site DEZ-3 will include not only the shallow sedimentary section, but also the basal, strongly reflective rock sequence (Fig. 8). This information may show the affinity of the basal rocks, whether south-ridge, oceanic, or arc, and thus, the style of accretion or deformation that has occurred. Results from site DEZ-3 will be most informative when used in conjunction with results from site DEZ-1, to help explain the difference in deformation at the two ridges, and in conjunction with site DEZ-2 to determine the amount of material accreted onto the arc slope or derived from the arc itself and involved in the deformation that produced the Bougainville Spur.

Proposed Drill Site DEZ-4: This site is located on the arc's slope, within the Central d'Entrecasteaux Basin (Fig. 2). Crossing multichannel and high-resolution seismic lines are available for this site as are gravity and magnetic data. The north and south ridges of the DEZ and the arc's slope confine this basin. The collision of the DEZ and arc is thought to have caused rapid uplift and deformation of rocks on Espiritu Santo and Malekula Islands. These rising land masses have shed considerable sediment to the east, into an intra-arc basin, and to the west, toward the trench. Seismic line 12 shows sediment that was transported toward the trench and forms a

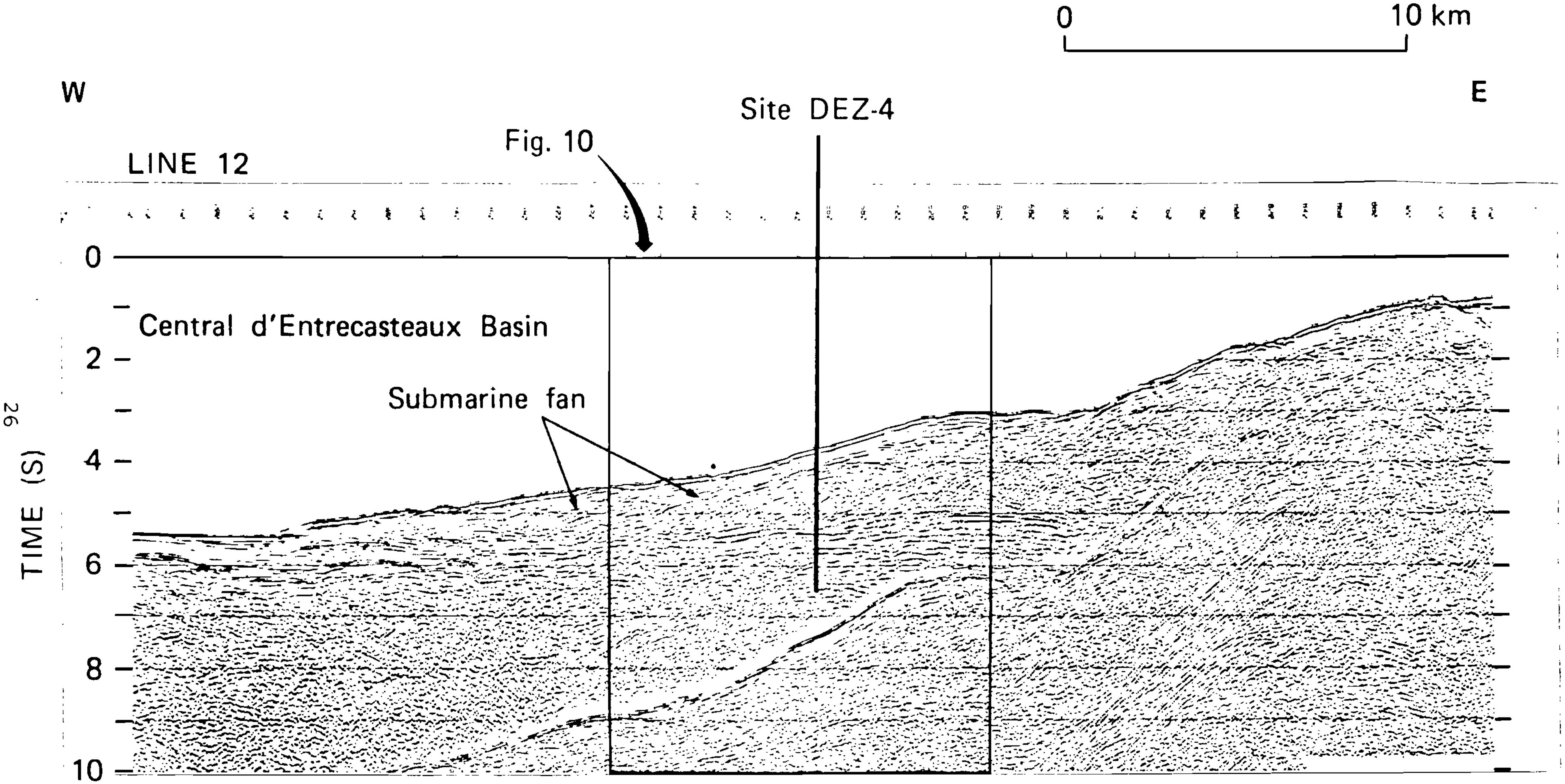

0
10 km
W
E
Site DEZ-4
Fig. 10
LINE 12
Central d'Entrecasteaux Basin
Submarine fan
TIME (S)
0
2
4
6
8
10

Figure 9

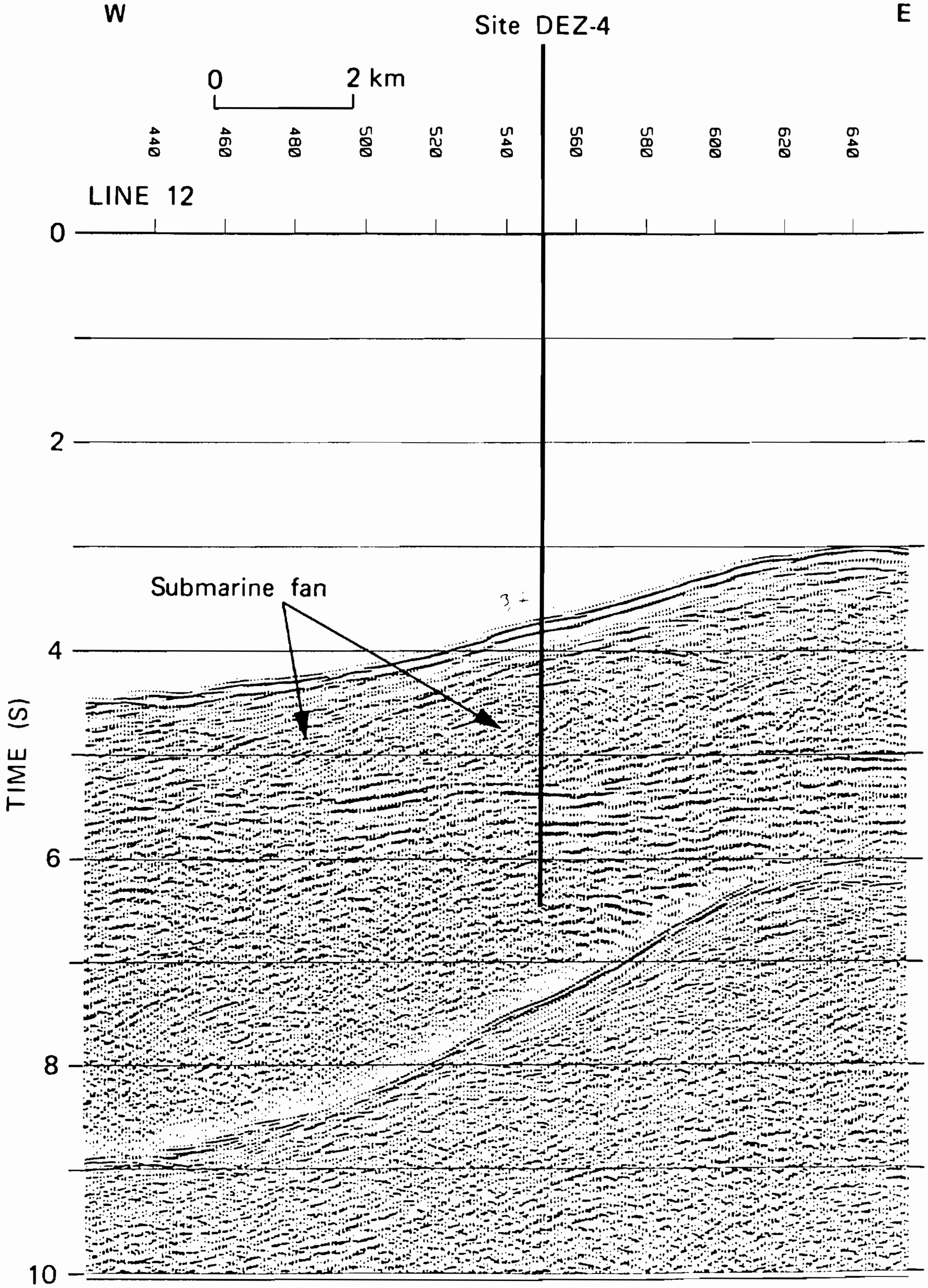

W
E
Site DEZ-4
0
2 km
440
460
480
500
520
540
560
580
600
620
640
LINE 12
0
2
4
6
8
10
TIME (S)
Submarine fan

Figure 10

large trenchward prograding fan that was deposited on top of lower-slope rocks (Figs. 9 and 10). This fan is locally disrupted by small thrust faults that attest to relative motion between rocks in the Central d'Entrecasteaux Basin and the arc. However, nearly all strata in the fan dip toward the trench. This dip direction and the small size of structures that deform the fan show that the main processes affecting fan development were depositional not structural. Parallel strata of the Central d'Entrecasteaux Basin that are now being subducted can be traced for at least 30 km beneath the lower arc slope.

The main reasons for drilling at site DEZ-4 are to determine the minimum time when collision of the DEZ started by dating the large slope fan and by showing the type of sediment delivered to the Central d'Entrecasteaux basin. At this site the drill will penetrate rocks in the fan and subducting rocks. By providing data for studies of the provenance of sediment in the Central d'Entreasteaux Basin (in conjunction with site DEZ-6), drilling at this site will show when arc-derived detritus first reached the basin near the drill site. The age of the oldest rocks in the slope fan should provide good constraints on the time of major deformation associated with uplift of the islands and, hence, with collision. This age can be compared with the times of magmatic outbursts and changes in ash composition to relate processes in the forearc to those in the magmatic arc. Data from this site can also help us establish the effect of collision on the DEZ by showing the depositional history of the Central d'Entrecasteaux basin.

Proposed Drill Site DEZ-5: This site is located on top of the south ridge of the DEZ (Fig. 2), where the ridge is a broad swell that stands about 1000 m above the adjacent seafloor. Only one multichannel-seismic and one high-resolution seismic line are available across this site. On seismic line 101

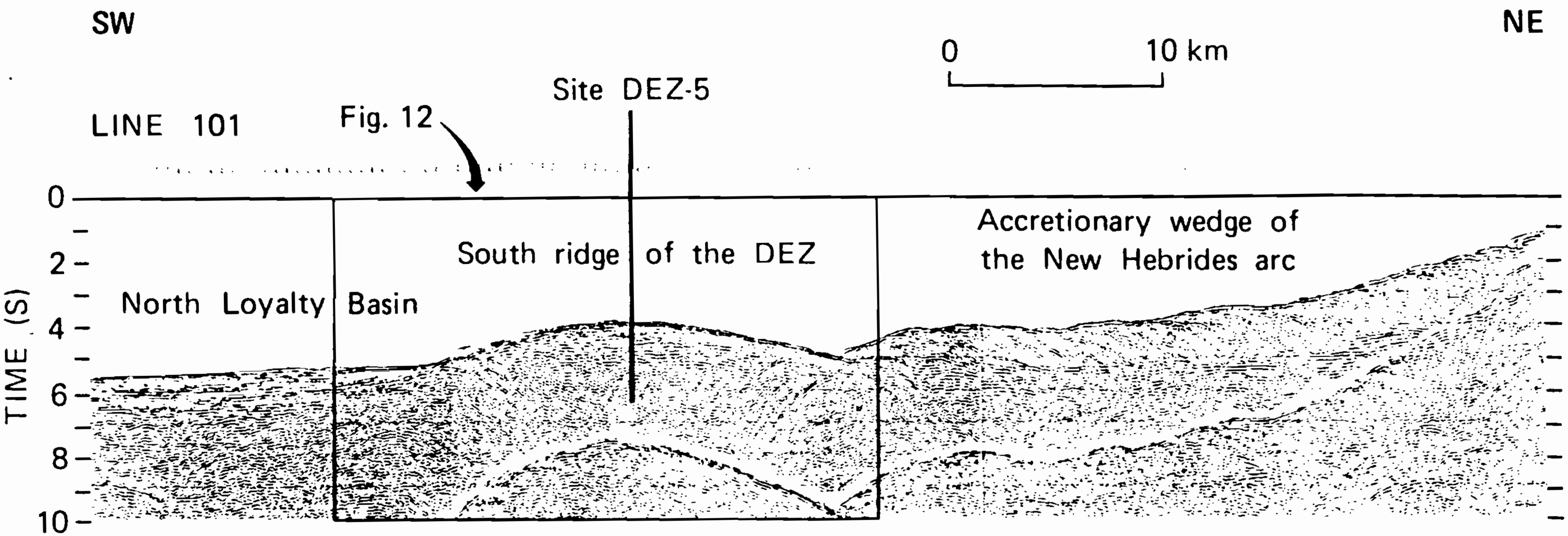

SW
NE
0
10 km
Site DEZ-5
LINE 101
Fig. 12
0
2
4
6
8
10
TIME (S)
North Loyalty Basin
South ridge of the DEZ
Accretionary wedge of
the New Hebrides arc

Figure 11

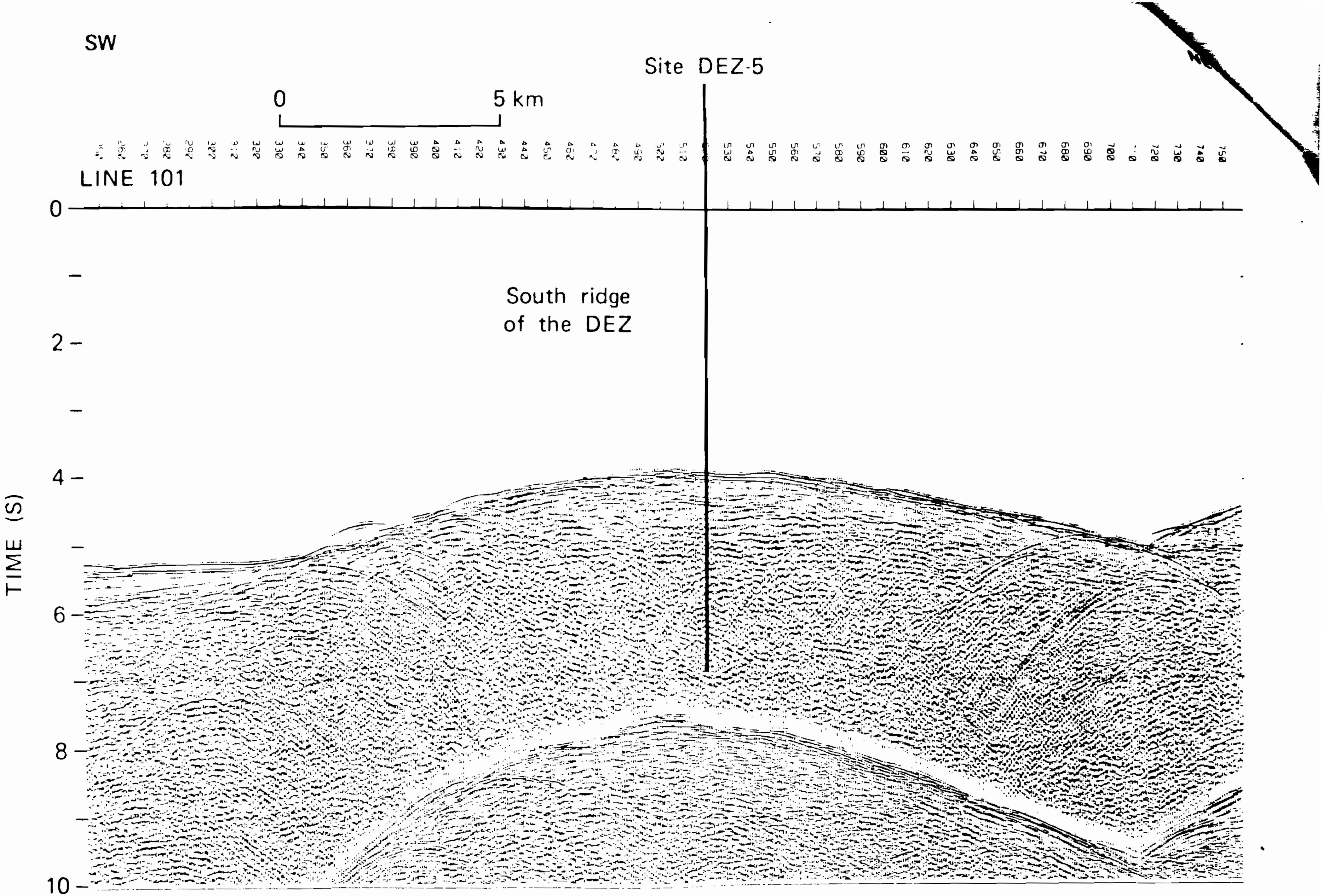

SW
Site DEZ-5
0
5 km
LINE 101
South ridge
of the DEZ
TIME (S)
0
2
4
6
8
10

Figure 12

(Fig. 11), rocks of the North Loyalty Basin, including Eocene clastic rocks and oceanic crust, lie southwest of the ridge. The accretionary wedge of the New Hebrides arc abuts the ridge on the northeast. Rocks within the ridge are poorly reflective and subhorizontally bedded. Other seismic data collected over this ridge show that rocks in this ridge dip consistently north and probably are 3 to 4 km thick. Below line 101, the poorly bedded ridge rocks are capped by 200 to 300 m of strata that return discontinuous, high-frequency reflections (Fig. 12).

The main purpose for drilling at site DEZ-5 is to determine the type of rock in the ridge to understand the processes involved in collision. We will compare rocks at the site with those within the Bougainville Spur. Data from this site will help us understand why the south ridge has produced greater slope deformation than the north ridge and why the style of accretion differs greatly in the collision zone. Drilling here would establish the age, lithology, and induration of rocks in the south ridge for comparison to similar data from the north ridge. This comparison may indicate the role ridge composition plays in the modification of forearc areas by collision. The south ridge is part of the provenance of sediment in the Central d'Entrecasteaux Basin, and a study of sediment provenance may yield an indication of when the arc and basin first came together. Finally, data from this site would show whether present concepts about the great disparity in genesis of the DEZ's two ridges are correct.

Proposed Drill Site DEZ-6: This site is within the Central d'Entrecasteaux Basin close to the north ridge of the DEZ (Fig. 2). Only one multichannel seismic and one high resolution seismic line across this site are available. Seismic line 102 (Fig.13) shows that sedimentary rocks at the proposed site

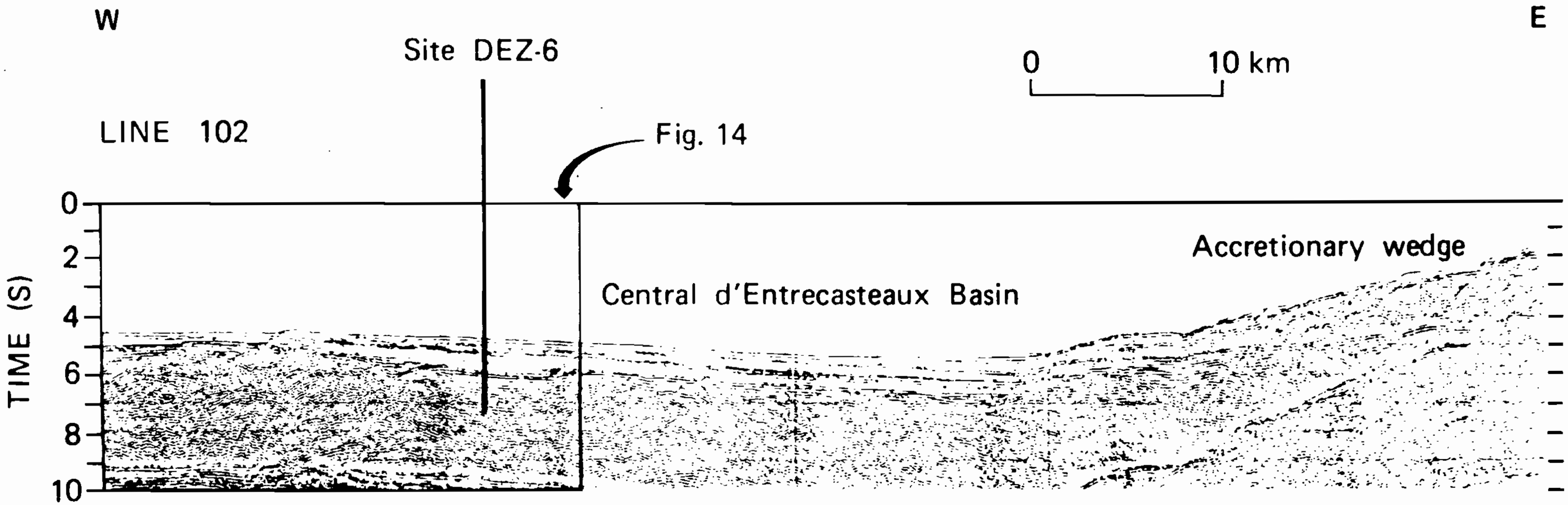

W
E
Site DEZ-6
0
10 km
LINE 102
Fig. 14
0
2
4
6
8
10
TIME (S)
Accretionary wedge
Central d'Entrecasteaux Basin

Figure 13

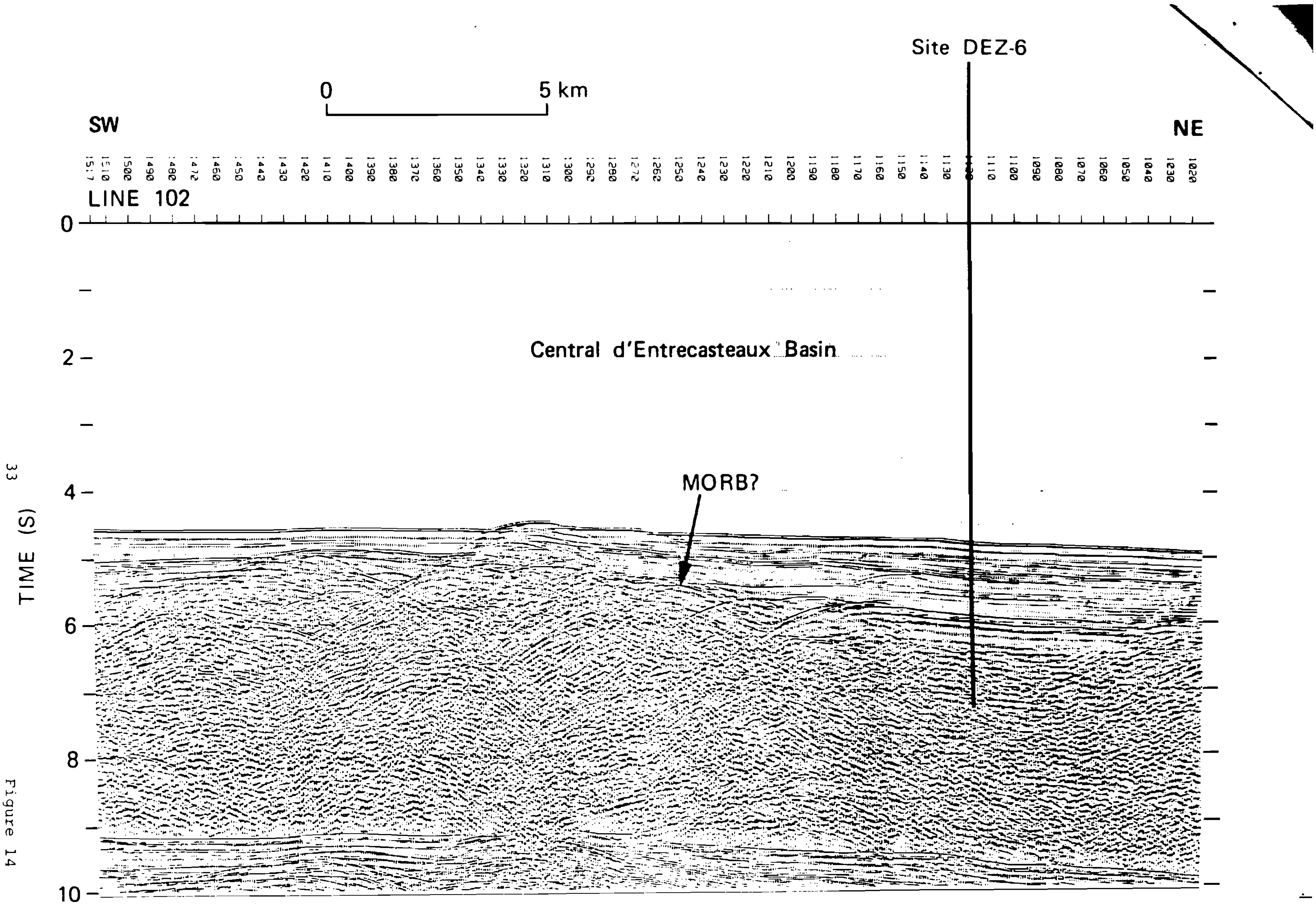

Site DEZ-6
0
5 km
SW
NE
LINE 102
Central d'Entrecasteaux Basin
MORB?
TIME (S)
0
2
4
6
8
10

Figure 14

are about 1 km thick and thicken toward the New Hebrides arc. They overlie an irregular basement surface; inasmuch as the north ridge of the DEZ is composed of MORB, the irregular basement surface is probably the top of basalt.

The main reason for drilling in this basin is to establish the time when the Central d'Entrecasteaux basin and the DEZ first came close together. This time is critical to unraveling events in the evolution of the intra-arc basin and magmatic arc and illustrating how processes governing this evolution are modified by collision. The age and composition of rocks from the arc would be known from drilling at propose site DEZ-3; located on the large submarine fan that forms the lower arc slope in this basin. The composition of debris from the ridges of the DEZ would be known from the drilling at sites DEZ-1 and DEZ-5, located on the north and south ridges of the DEZ, respecively. The time when arc-derived detritus first mixed with debris from the DEZ would approximate the time when basin and arc were close.

Evolution of the Magmatic Arc and Development of Intra-Arc Basins

We propose to drill at three sites within the summit basins of the New Hebrides arc to investigate the processes active during the development of intra-arc basins and the evolution of the magmatic arc (Fig. 15). One major goal of this proposed drilling program is to compare the evolution of basins and volcanoes near the collision of the DEZ and arc with similar features outside of this zone. This comparison will show how collision modifies the development of shallow and deep parts of the island arc. Moreover, the New Hebrides arc may have undergone a flip in the polarity of subduction during the last 10 Ma, and drilling at these sites may show how this flip affected magma genesis. As the collision of the DEZ and arc may have begun just 2 Ma. ago, the polarity flip and the collision appear to have been separated in time, and we may be able to separate the effects each of these events exerted on the development of the island arc.

Proposed Drill Site IAB-1: This site is located within the North Aoba Basin (Fig. 15), which lies beneath significantly deeper water than does any other basin near this arc's summit. Crossing multichannel and high-resolution seismic lines are available for this site as are gravity and magnetic data. Although seismic-refraction data suggest that sedimentary rocks in this basin are about 5 km thick, seismic reflection data show basin geology only down to the travel time of the water bottom multiple (Figs. 16 and 17). The deepest rocks evident in seismic-reflection data are about 3 to 4 km below the seabottom and are mainly flat lying beneath the basin. Their attitide within the western basin flank is uncertain, but within the eastern flank they dip west, toward the basin axis. These deepest rocks have been dated with great uncertainty as early or middle Miocene, on the basis of seismic stratigraphy. Over the flat lying rocks is a submarine fan that progrades from the west, from the high standing Espiritu Santo Island. This fan probably includes upper Miocene and Pliocene strata, as suggested by a comparison of onshore and seismic stratigraphy. Rocks above the fan blanket the western flank of the basin, dip less steeply toward the basin than do strata in the fan, and show evidence for widespread slumping. These rocks may be Pliocene and possibly Quaternary. They are overlain at an abrupt angular unconformity by rocks that onlap the lowest part of the western basin flank. This angular contact is probably overlain by Quaternary rocks and suggests that this basin underwent a period of rapid subsidence. The onlapping rocks are strongly reflective, and gravity cores show that the rocks contain much volcanic ash and Holocene microfossils.

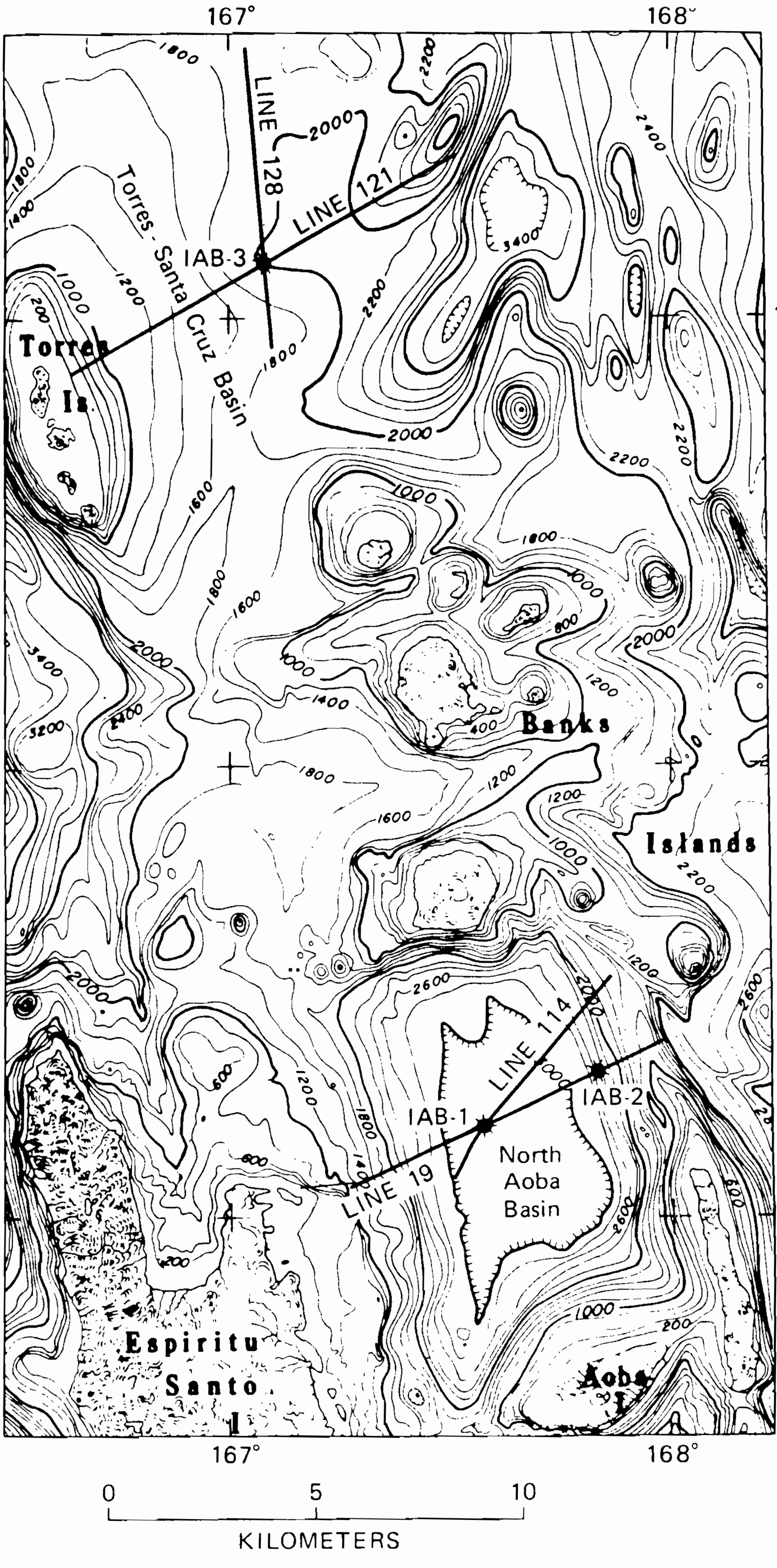

167°
168°
13°
14°
15°
LINE 128
LINE 121
IAB-3
Torres - Santa Cruz Basin
Torres Is.
Banks Islands
LINE 114
LINE 19
IAB-1
IAB-2
North Aoba Basin
Espiritu Santo I
Aoba I
0
5
10
KILOMETERS

Figure 15

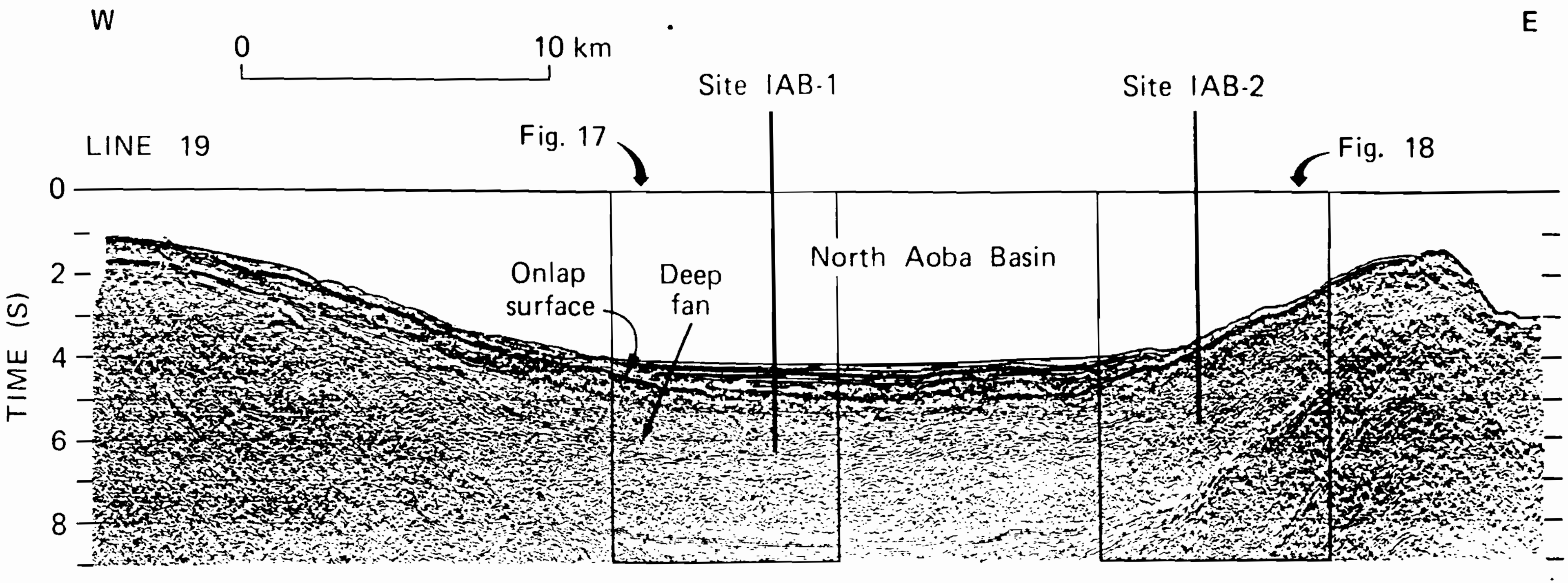

W
E
0
10 km
Site IAB-1
Site IAB-2
LINE 19
Fig. 17
Fig. 18
North Aoba Basin
Onlap surface
Deep fan
TIME (S)
0
2
4
6
8

Figure 16

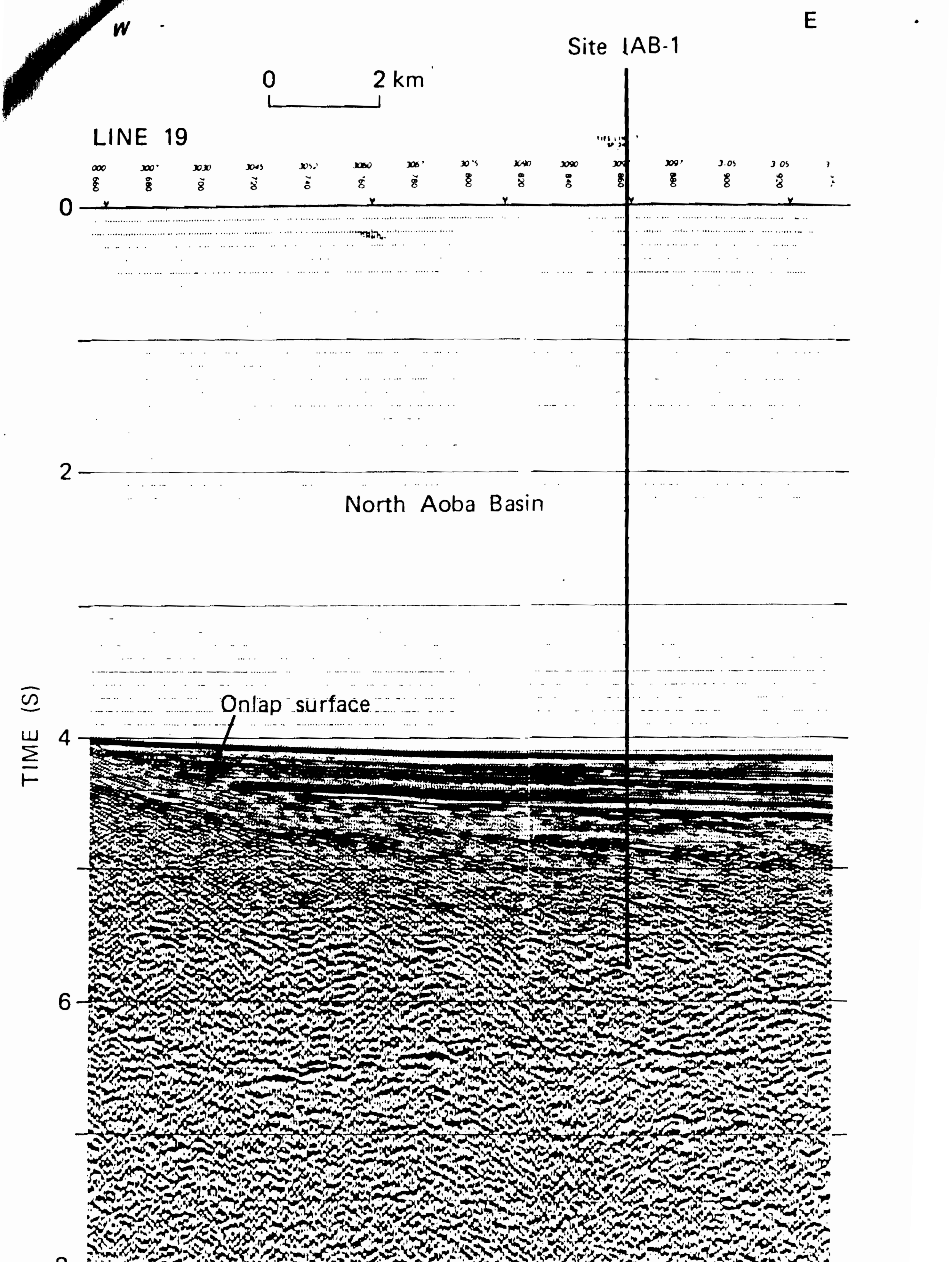

W
E
Site IAB-1
0 2 km
LINE 19
0
2
4
6
8
TIME (S)
North Aoba Basin
Onlap surface

Figure 17

The main reason for drilling at site IAB-1 is to increase understanding of the processes involved in the development of an intra-arc basin that is within the region affected by arc-ridge collision. One main objective is to determine the timing of the basin subsidence and the paleobathymetry and age of rocks above and below the angular unconformity. The age of this unconformity will be compared to our best estimate of the time when collision began. The volume and chemistry of volcanic ashes recovered at this site will indicate what relationships exists between arc-ridge collision and magmatic evolution and whether a major change in magma source occurred as would be expected from a flip in the polarity of subduction. Basin development and magmatic-arc evolution can be compared for areas within and outside of the region affected by collision to separate "normal" arc processes from the "anomalous" effects of collision.

Proposed Drill Site IAB-2: Site IAB-2 is located on the eastern flank of the North Aoba Basin, along the horst from which Pentecost and Maewo Islands protrude (Fig. 15). Only one multichannel and one high-resolution seismic reflection line cross this site. In outcrop along the islands of Maewo and Pentecost are Miocene and younger clastic and volcanic rocks and ophiolite. The ophiolite may indicate that back-arc oceanic crust was obducted onto the arc, or the ophiolite may be part of the arc's basement. Reflections from the deepest rocks (of questionable early or middle Miocene age) observed in seismic sections from the North Aoba Basin rise and thin gradually eastward within the eastern flank (Figs. 18 and 19). The shallow basin fill pinches out more sharply than do deep strata. Even the shallowest basin fill is deformed into small anticlines.

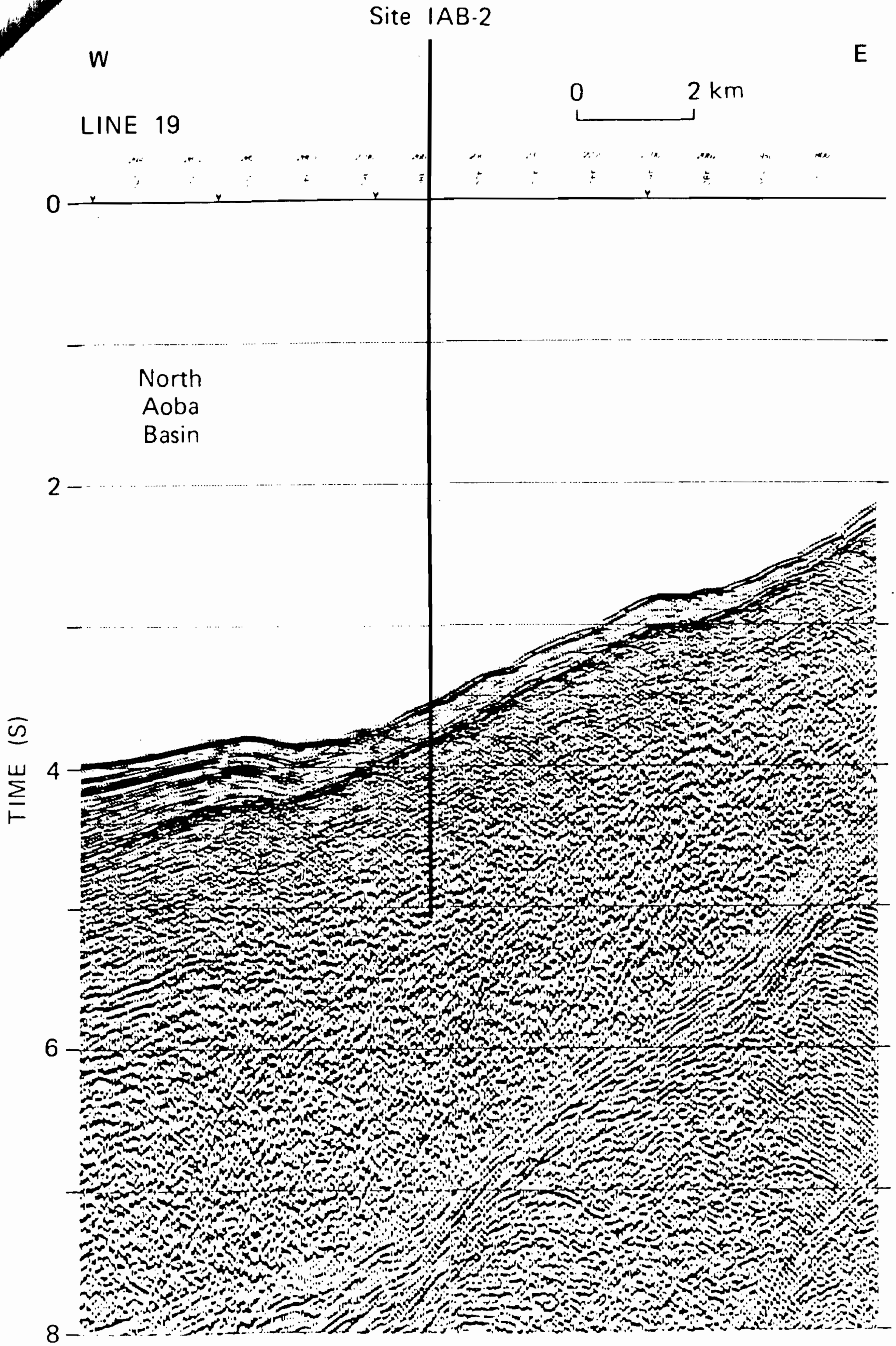


Figure 18

The main purpose for drilling at this site is to sample the deepest basin units, which are at shallow depth within this flank. From these rocks we can determine the evolution of the magmatic arc and basin before the beginning of arc-ridge collision. Information from this site and from IAB-1 will yield a composite stratigraphic record that straddles chronologically the collision and may predate the hypothesized flip in subduction polarity. From this record, changes in volcanism and basin sedimentation can be investigated and related to regional tectonic events. These data are crucial to unraveling the effect of collision on the arc. Furthermore, data from this site may show when debris from the ophiolite on Pentecost Island were first deposited in the basin, yielding a minimum age for emplacement or exposure of these rocks. Data from this site will also be used in conjunction with the results from the site located in the Torres-Santa Cruz basin to compare basin evolution inside a collision zone with that outside.

Proposed Drill Site IAB-3: This site is located within the Torres-Santa Cruz basin (Fig. 15), where the sedimentary fill is about 5 to 6 km thick, based on seismic-refraction data. The oldest rocks in this basin are probably of early to middle Miocene age, inasmuch as such rocks are exposed locally on islands fringing the basin. Crossing multichannel and high-resolution seismic lines are available for this site as are gravity and magnetic data. Low structural and volcanic ridges bound this intra-arc basin on the east and west, with the basin forming a broad sag inbetween. Rocks within this basin are deformed only locally by faults and small anticlines (Figs. 20 and 21). The sedimentary rocks in the basin return only moderately continuous reflections, suggesting the presence of highly variable lithology. Rocks less than 500 m below the seafloor overlie a strong reflecting horizon, which may mark the base of the Quaternary.

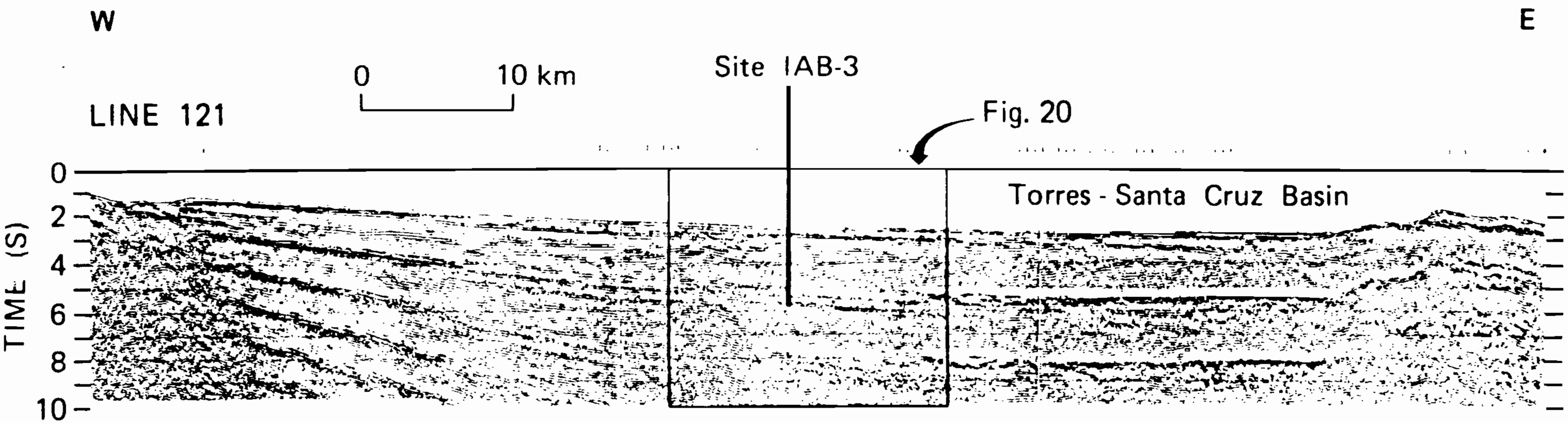

W
E
LINE 121
0
10 km
Site IAB-3
Fig. 20
Torres - Santa Cruz Basin
TIME (S)
0
2
4
6
8
10

Figure 19

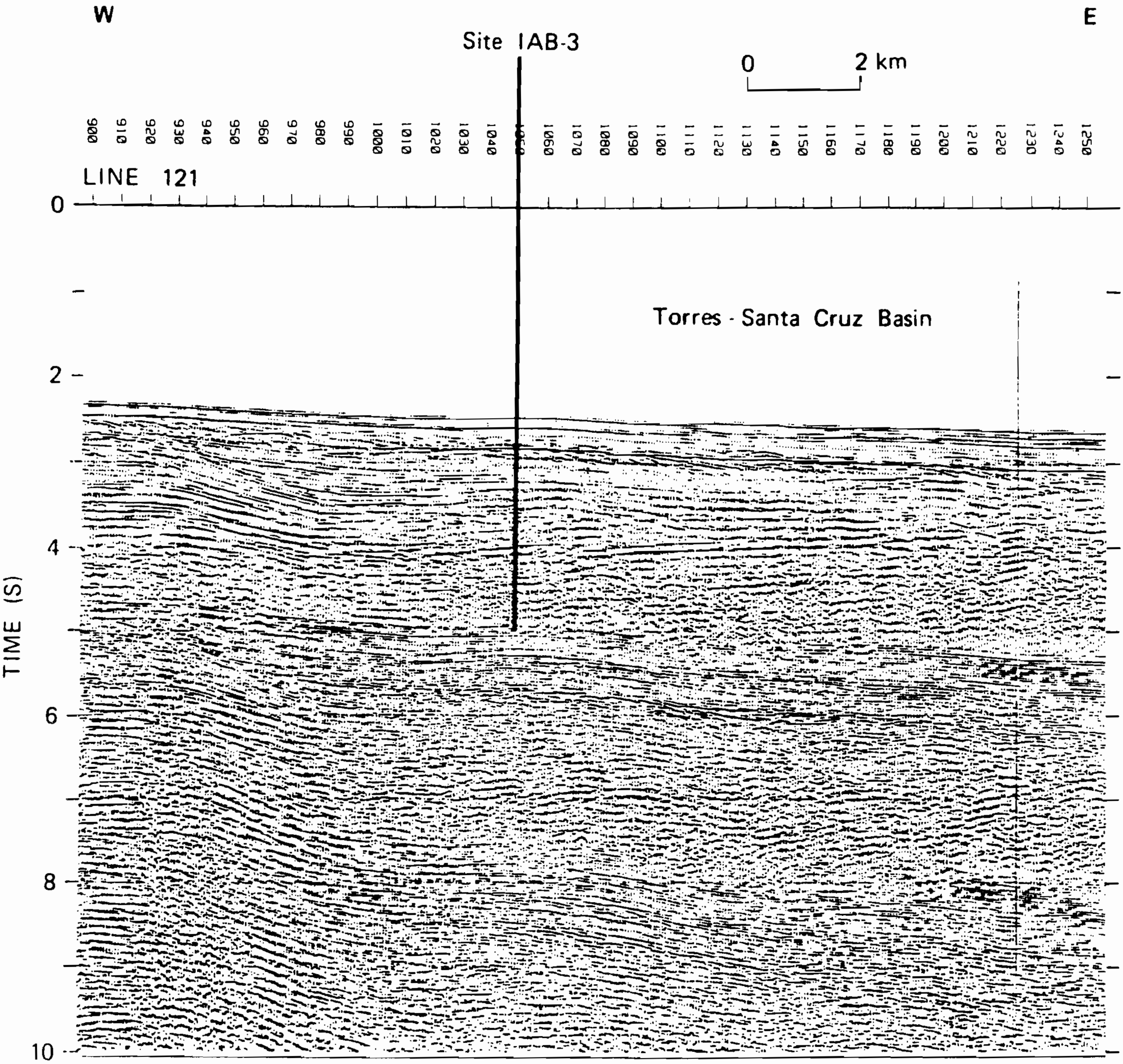

W
E
Site IAB-3
0 2 km
LINE 121
Torres - Santa Cruz Basin
TIME (S)
0
2
4
6
8
10

Figure 20

The main reason for drilling at site IAB-3 is to obtain reference data on the development of the intra-arc basin away from the collision of the DEZ and arc. Specific drilling objectives include basin subsidence rate and lithology and age of basin fill. The chemical and temporal variation of volcanism away from the collision zone is important to understanding the evolution of the magmatic arc.

Back-Arc Tectonics

We propose to drill four sites in the back-arc area of the New Hebrides island arc to investigate the processes that cause back-arc troughs to form. Drilling in the central part of the troughs would indicate whether the initial stages of back-arc magmatism results from the activity of the island arc, from an early stage of oceanic accretion, or from contamination of the arc's magmatic reservoir by material produced during the oceanic accretion. One hole will be drilled to provide a reference geologic section that shows the magmatic evolution of the southern part of the New Hebrides arc. Data from other sites should indicate the age of rifting, reveal the timing and tectonic relationship of the island arc to development of the North Fiji Basin, and assist in establishing the time of initial collision of the DEZ with the arc.

Only single channel data from lines AUS 112 and AUS 113 are presented, however, 12-channel data are also available. A proposal for funding the processing of these lines will be submitted to the French agencies by the beginning of 1985. During October and November, 1985, the research vessel the J. Charcot (Seapso project) will obtain a detailed single-channel survey of the drill sites proposed herein. Sea beam data and dredge hauls will also be collected.

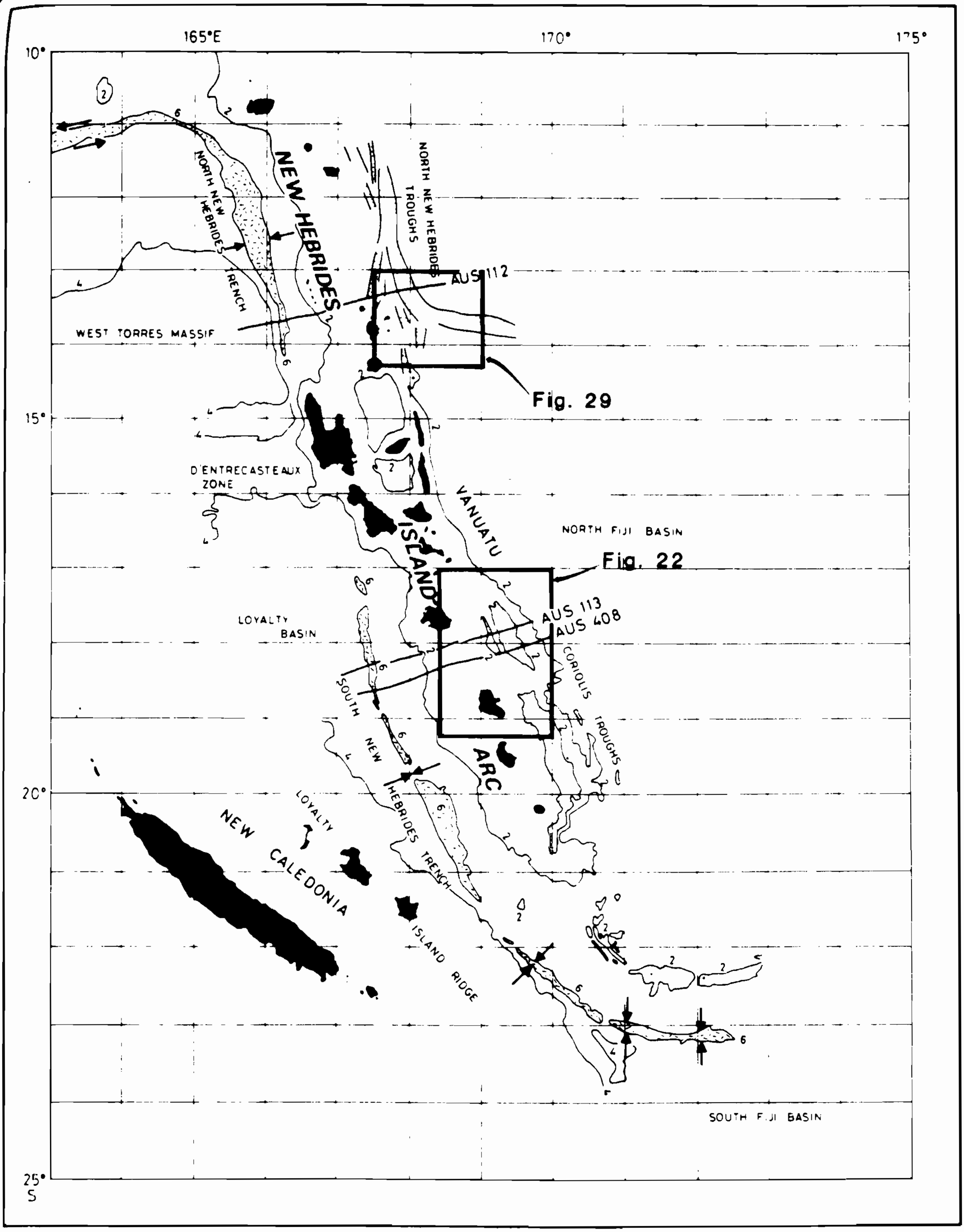

165°E
170°
175°
10°
15°
20°
25° S
NEW HEBRIDES
NORTH NEW HEBRIDES TRENCH
NORTH NEW HEBRIDES TROUGHS
AUS 112
WEST TORRES MASSIF
Fig. 29
D'ENTRECASTEAUX ZONE
VANUATU
NORTH FIJI BASIN
ISLAND
Fig. 22
AUS 113
AUS 408
LOYALTY BASIN
CORIOLIS TROUGHS
SOUTH NEW HEBRIDES TRENCH
ARC
NEW CALEDONIA
LOYALTY ISLAND RIDGE
SOUTH FIJI BASIN

Figure 21

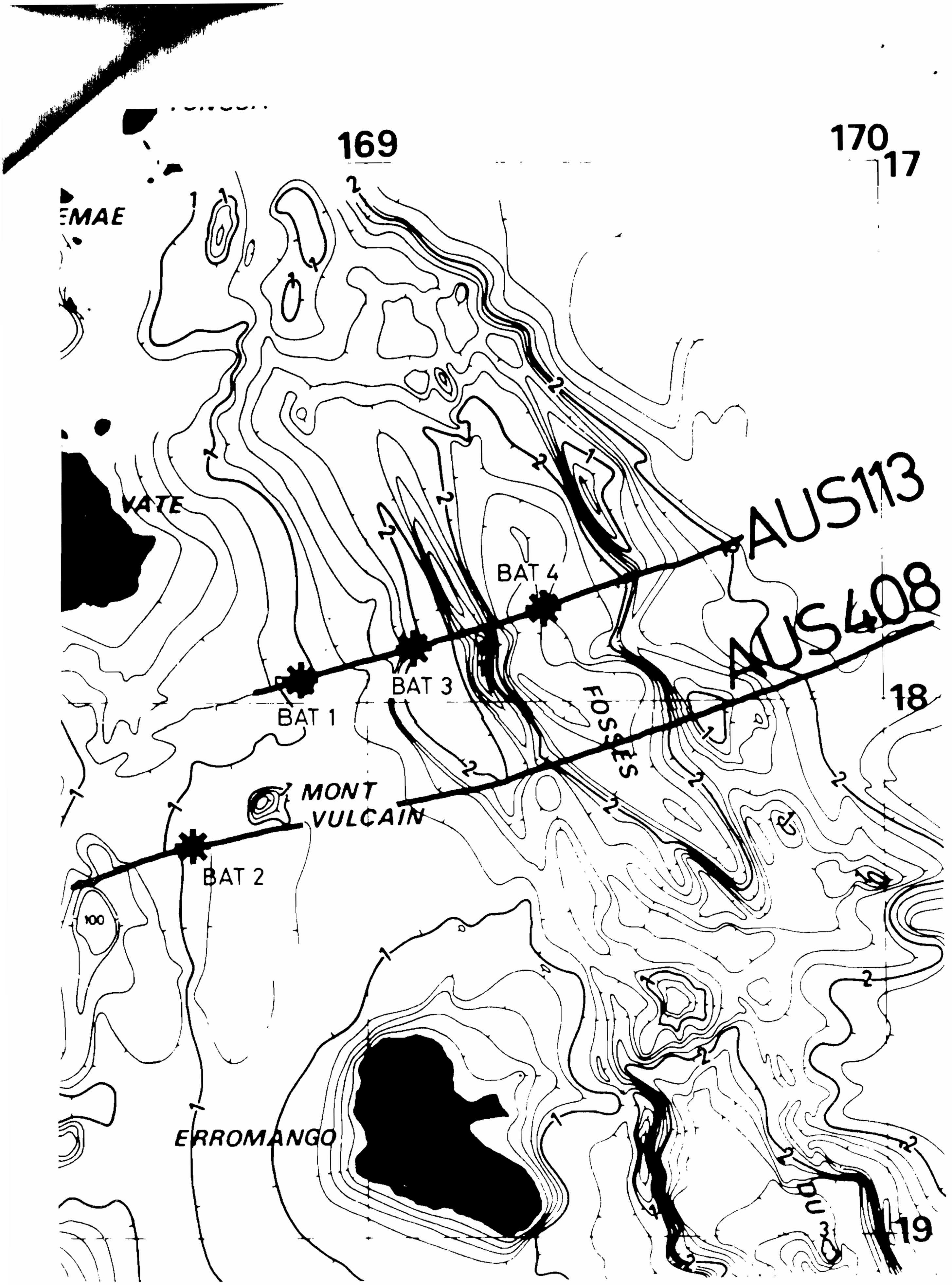

169
170
17
18
19
EMAE
VATE
AUS113
AUS408
BAT 4
BAT 3
BAT 1
BAT 2
FOSSES
MONT
VULCAIN
100
ERROMANGO

Figure 22

Proposed Drill Site BAT-1: This site is located on the eastern slope of the New Hebrides island arc, southeastward of Efate island, where water is about 1000 m deep (Figs. 21 and 22). A single-channel seismic line is available for this site as are magnetic data.

Seismic line AUS 113 (Figs. 22 and 23) shows that well bedded strata, attaining a maximum thickness of 500 m, overlie a strong reflector (Fig. 24), and the entire reflective series dips generally to the east. The strong reflecting horizon probably delimits the top of Upper Pliocene rocks because such rocks (The Pumice Formation) are exposed on Efate island.

The main reason for drilling at this site is to obtain reference data on the development of the southern New Hebrides arc, away from the back-arc tensional zone and the DEZ collision zone. Drilling deeper than the main strong reflector would provide information about the pre-late Pliocene geologic history of this portion of the arc. Results from this site will be compared to results from sites within the back arc troughs and with site IAB-1 and IAB-3 to help answer such questions as: is the southern New Hebrides subduction zone younger than that of the northern New Hebrides, and has the hypothesized flip in polarity of subduction influenced the southern part of the new Hebrides island arc, as could be inferred from a major change in the chemistry of volcanic ash deposits?

Proposed Alternate Drill Site BAT-2: This alternate site is located at the crest of the south New Hebrides arc, midway between Efate and Erromango Islands (Fig. 22). One single-channel seismic line crosses this site (line AUS 408; Fig. 25) and shows that a thick, well-stratified sequence lies within a summit basin of the southern arc. A small submarine volcano, Mont Volcain, lies in the middle of the basin. On the western part of the line, a horst

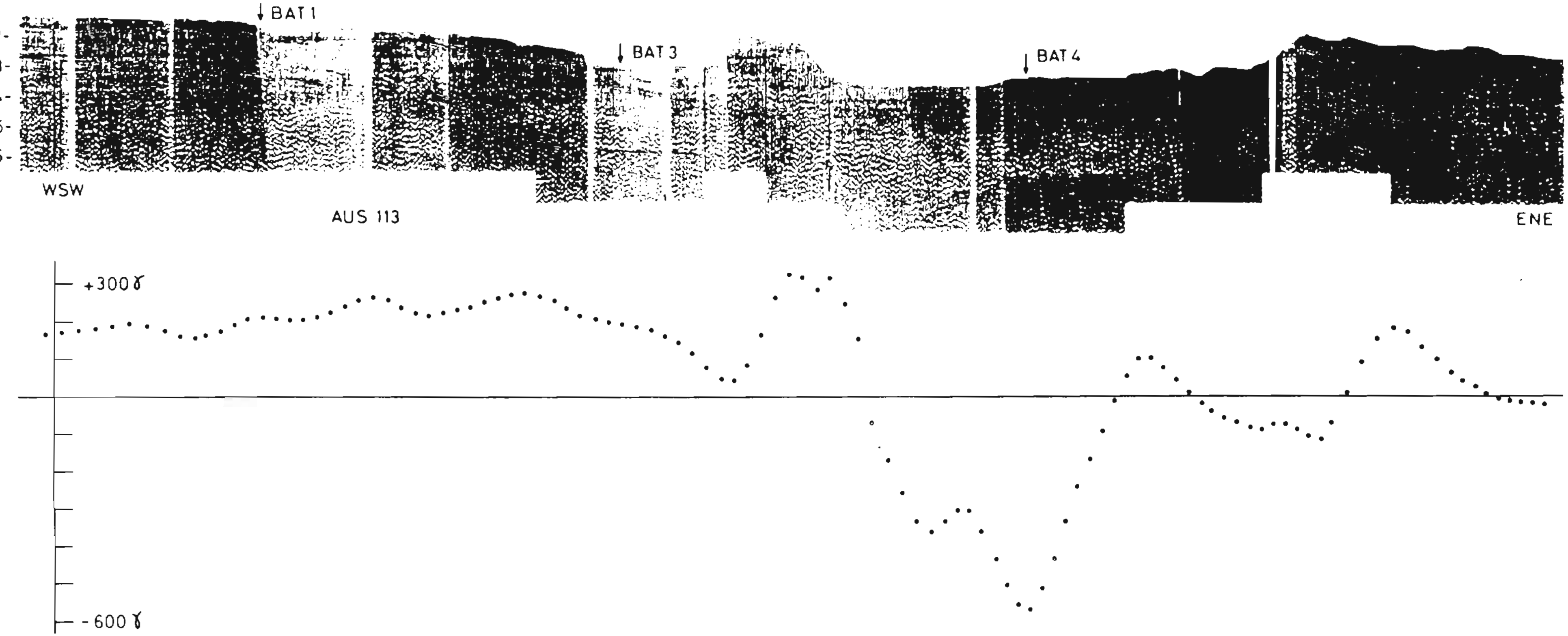


Figure 23

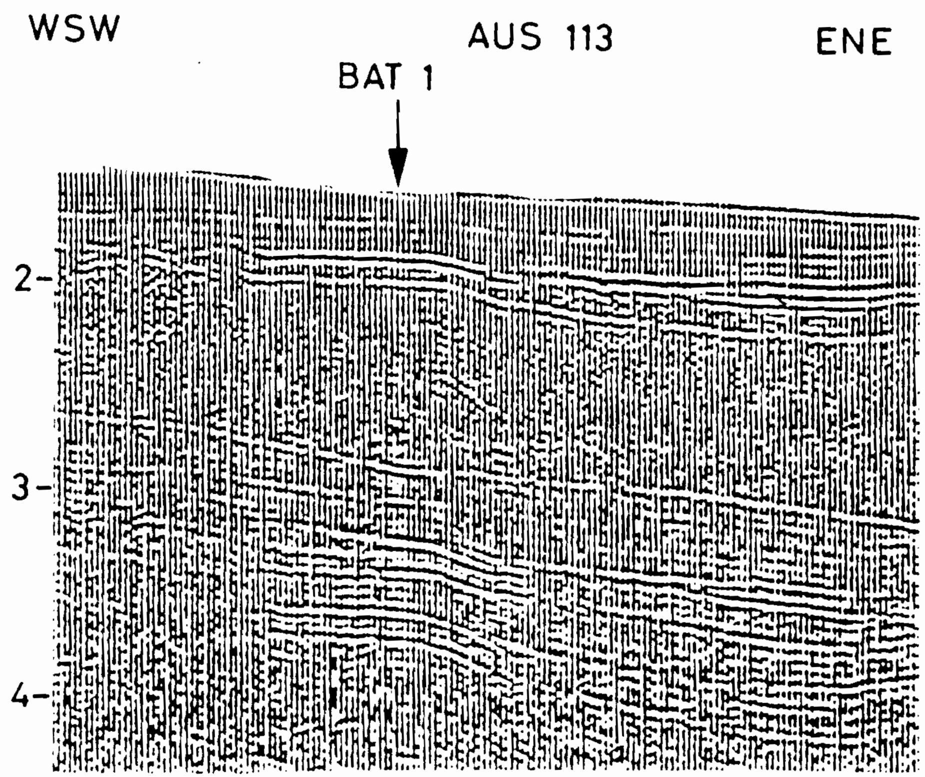


Figure 24

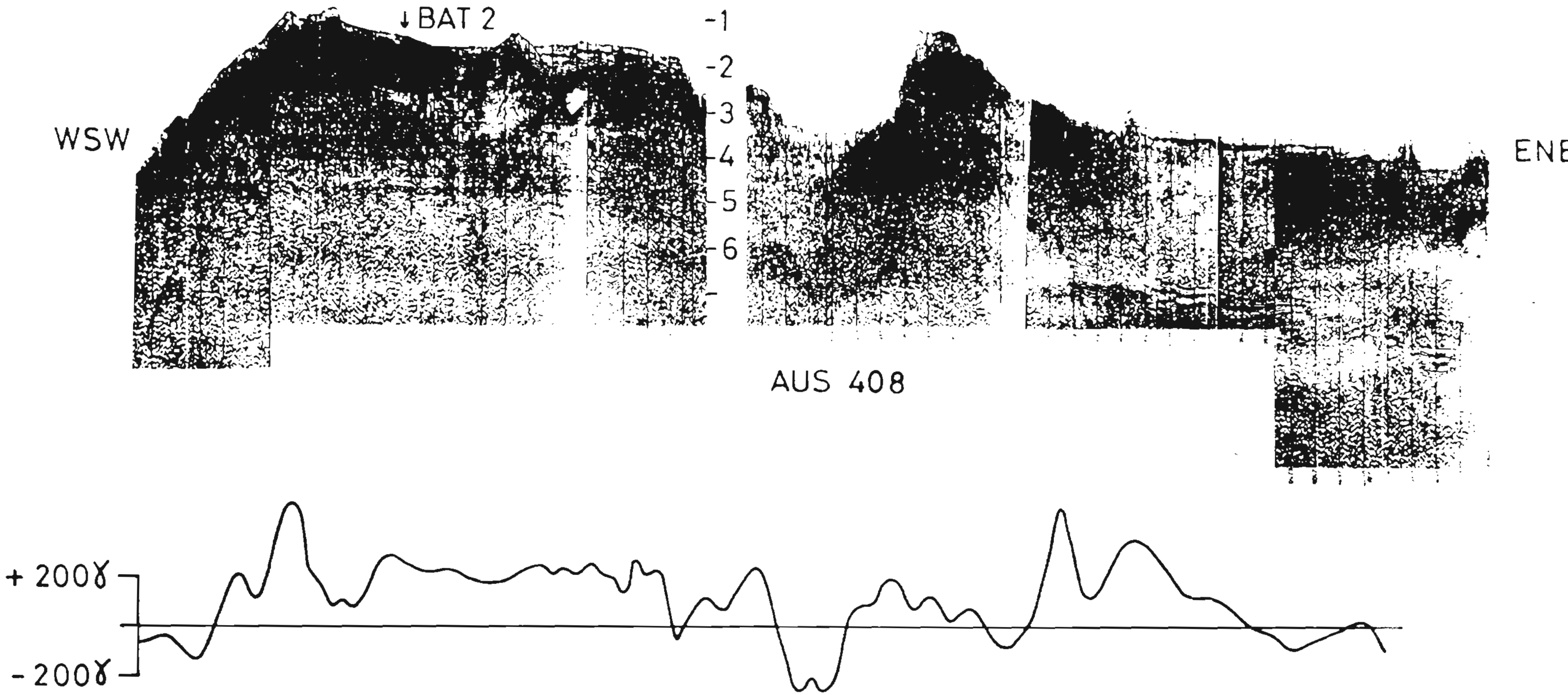


Figure 25

lying under shallow water (100 m) deformed and uplifted the thick basin fill (Fig. 26). An angular unconformity truncates beds where uplift was greatest. The unconformity is covered by Recent deposits probably related to the emergence of the horst.

The main reasons for drilling at this site are the same as for site BAT-1. At alternate site BAT-2, however, the drill will encounter thinner recent sediment than observed on line AUS 113, and will penetrate older rocks than those below site BAT-1. Although the reflections observed on line 408 are more difficult to follow toward the back-arc province than on line AUS 113, site BAT-2 should provide data on the lithology and age of the uplift of the horst. These data will be compared with results from drill sites IAB-1 and IAB-3 to establish whether the summit basins evolved differently longitudinally along the arc.

Proposed Drill Site BAT-3: This site is located in the small flat-bottomed back-arc trough east of Efate Island (Fig. 2). Crossing single channel lines are available for this site, as are magnetic data.

Seismic line AUS 113 (Fig. 27) shows an angular unconformity at the top of old arc-slope sediment that has been dropped downward into the graben. Thus, this trough was a major trap for arc-derived sediment since the initiation of back-arc extension.

The purpose for drilling at this site is to investigate the age of the unconformity to determine when back-arc extension began. Rocks penetrated at proposed site BAT-3 will include not only the strong reflector from the unconformity, but also the pre-rift arc-slope deposits. Results from site BAT-3 will be most informative when used in conjunction with results from sites BAT-1 and BAT-4 to explore the pre-rift geologic history of the arc.

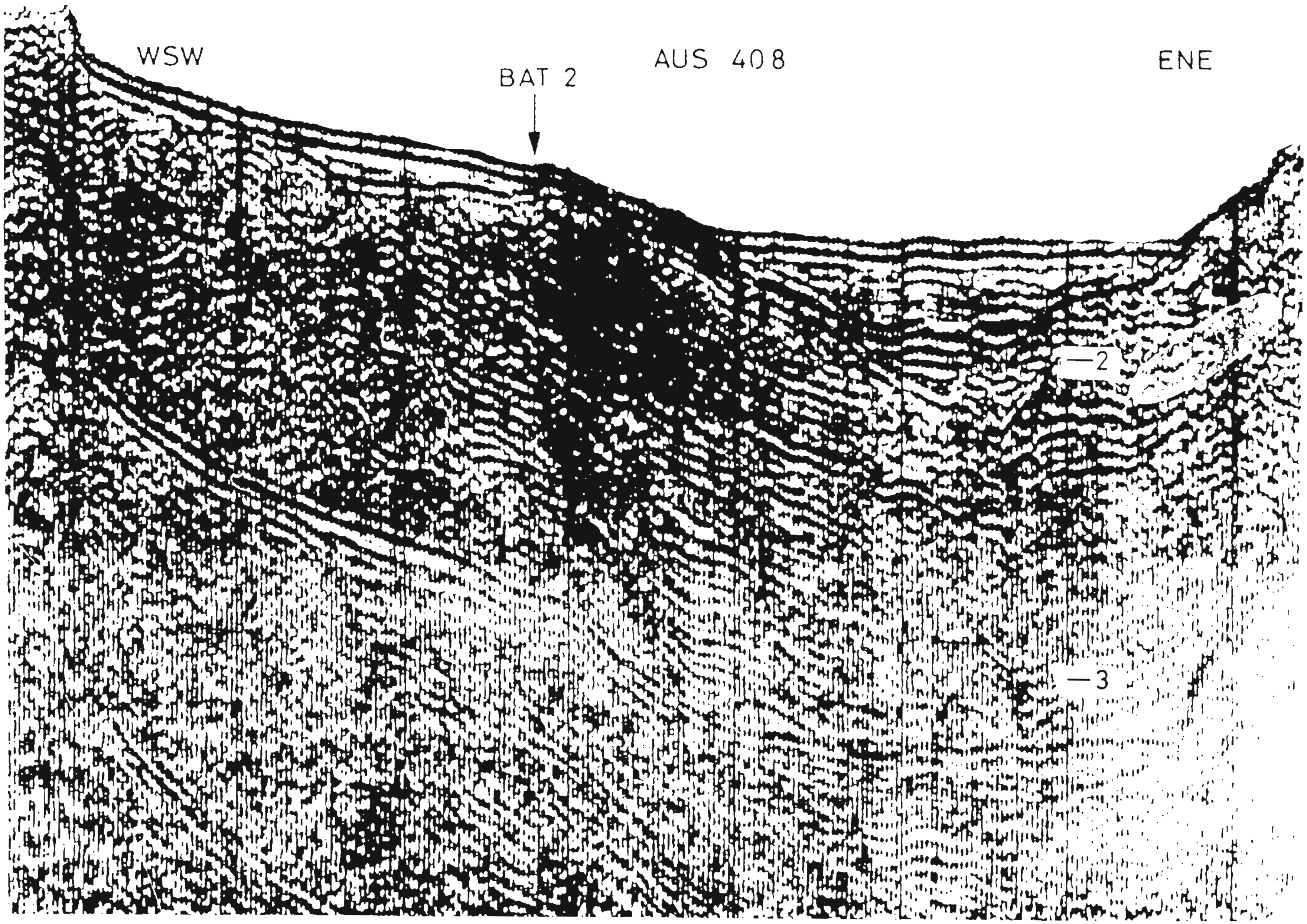


Figure 26

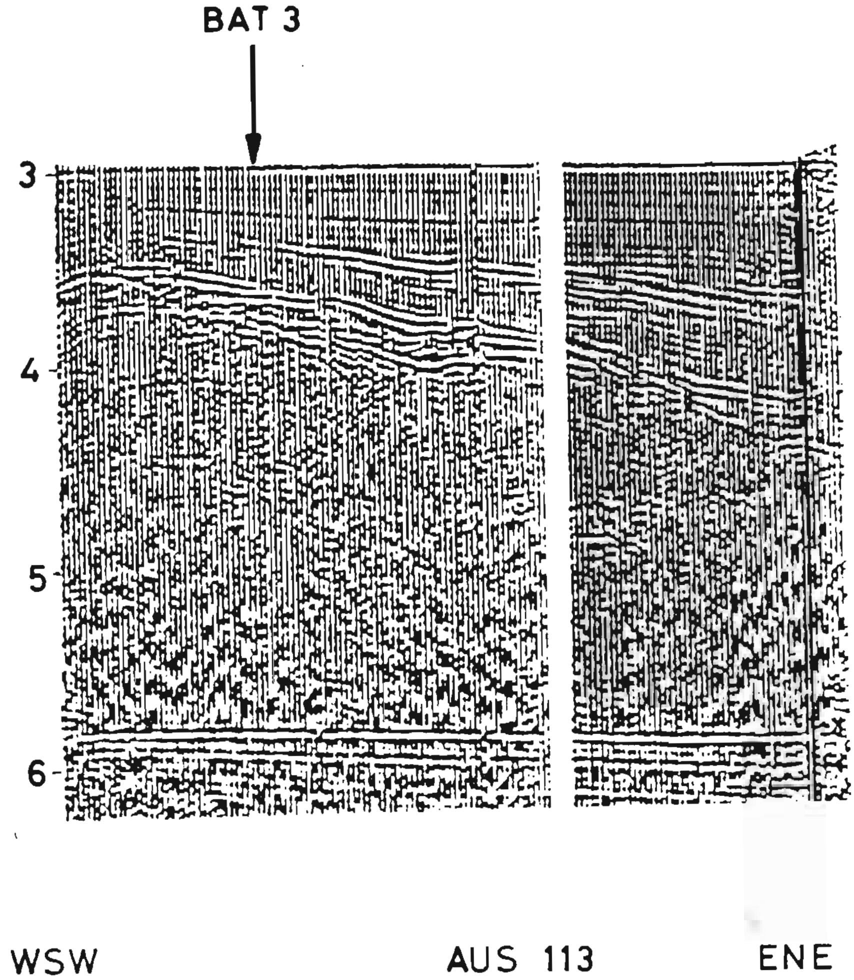


Figure 27

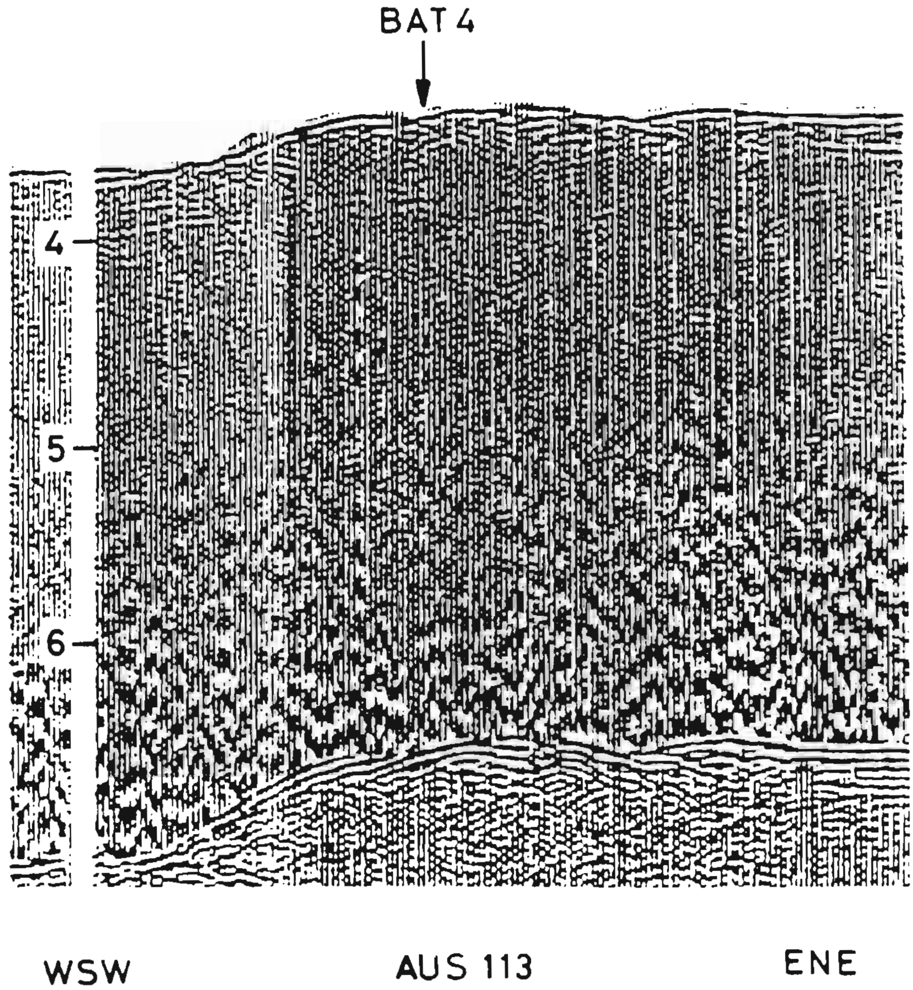


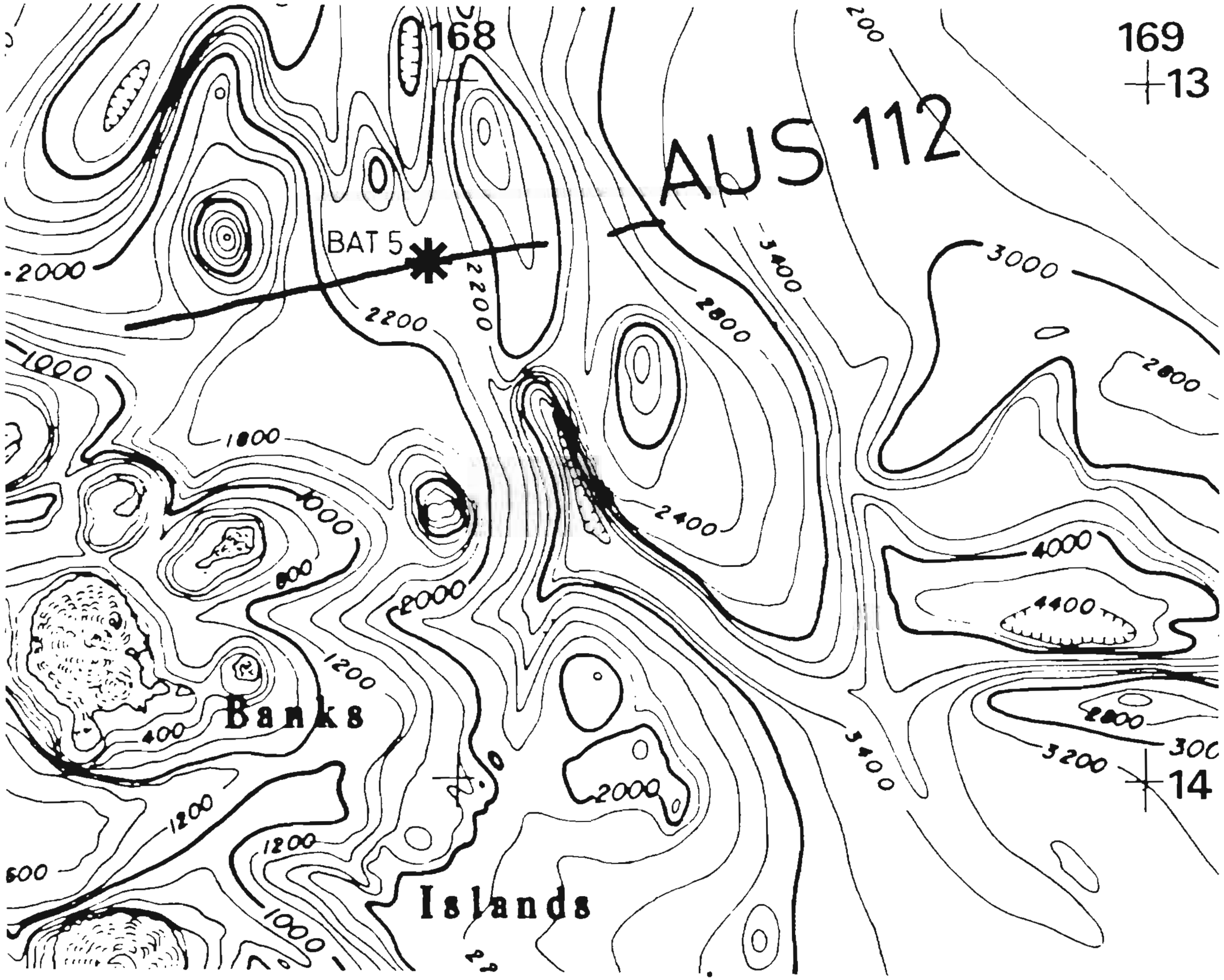
Figure 28

Proposed Drill Site BAT-4: This site is located in the wide back-arc trough east of Efate island (Fig. 22). Crossing single channel lines are available for this site as are magnetic data.

In the back-arc trough, line AUS 113 (Fig. 23 and 28) shows a few weak, disrupted reflectors that contrast not only with the well layered deposits covering the seafloor of the adjacent North Fiji Basin but also with the thick sedimentary pile that blankets the eastern arc slope and caps the horst located immediately to the west of the trough. Thus, the sedimentary sequence, which originates from the arc, has been down dropped and deformed by back-arc extension. Inasmuch as the lithosphere as a whole is rifted, intruded mantle material may be encountered by the drill as suggested by the highly irregular magnetic field measured over the trough.

The main reasons for drilling at site BAT-4 are to determine the nature and degree of deformation of trough strata, as well as to determine whether these strata are intruded by dikes or interbedded with volcanic sills. If such volcanic rocks are present, their chemistry may indicate the stage of oceanization of the troughs. Development of this back arc trough, and its magmatic evolution can be compared with results obtained in the northern back arc trough (drill site BAT-5).

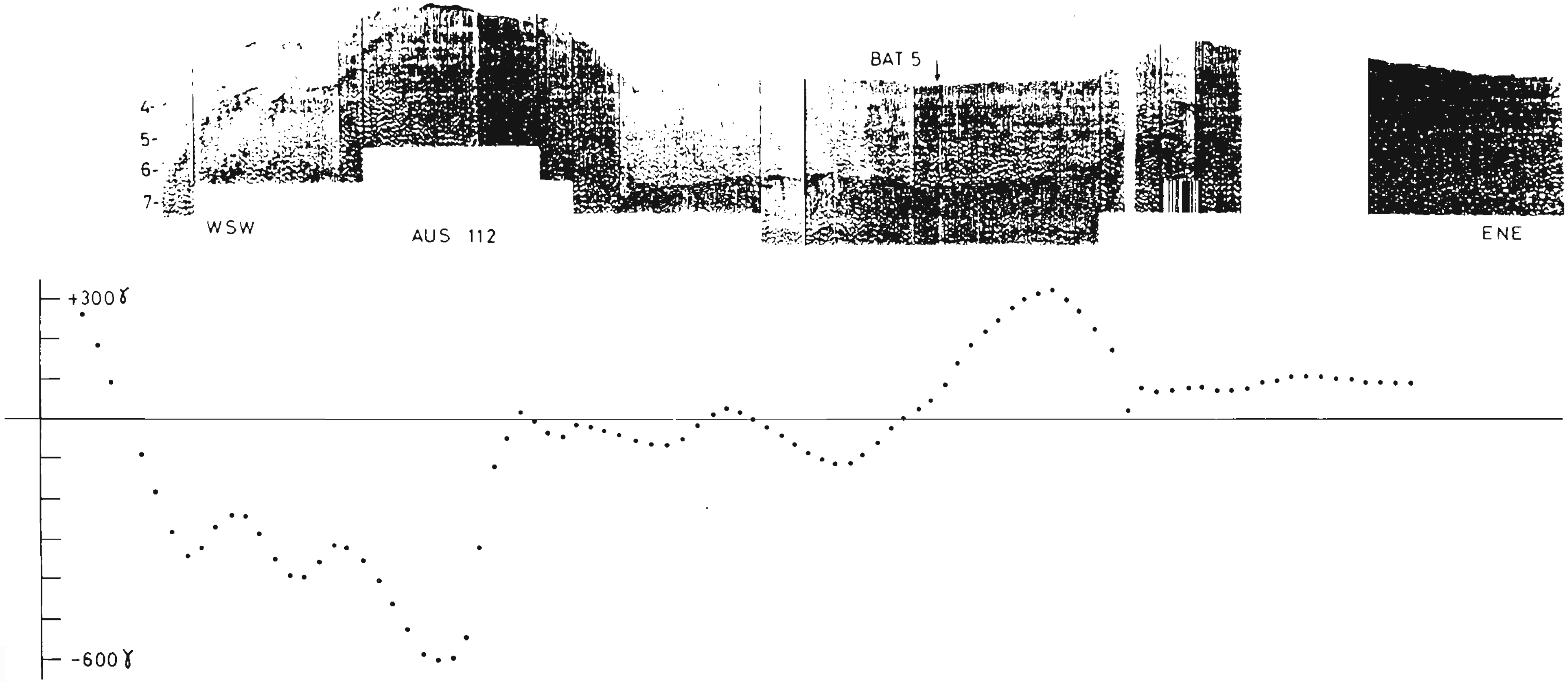
Proposed Drill Site BAT-5: This site is located in the wide back-arc trough north of the collision of the DEZ and northeast of the Bank islands (Fig. 29). Crossing single channel lines are available for this site as are magnetic data. This trough is similar in size and characteristics to the wide trough, located east of Efate, where proposed drill site BAT-4 is located. Seismic line AUS 112 (Figs. 30 and 31) shows only weak and incoherent



168
169
13
AUS 112
BAT 5
2000
2200
2200
1000
1800
3000
2800
3400
2800
2400
1000
800
2000
4000
4400
1200
Banks
400
2800
3200
14
3400
2000
1200
1200
600
1000
Islands

Figure 29

Figure 30



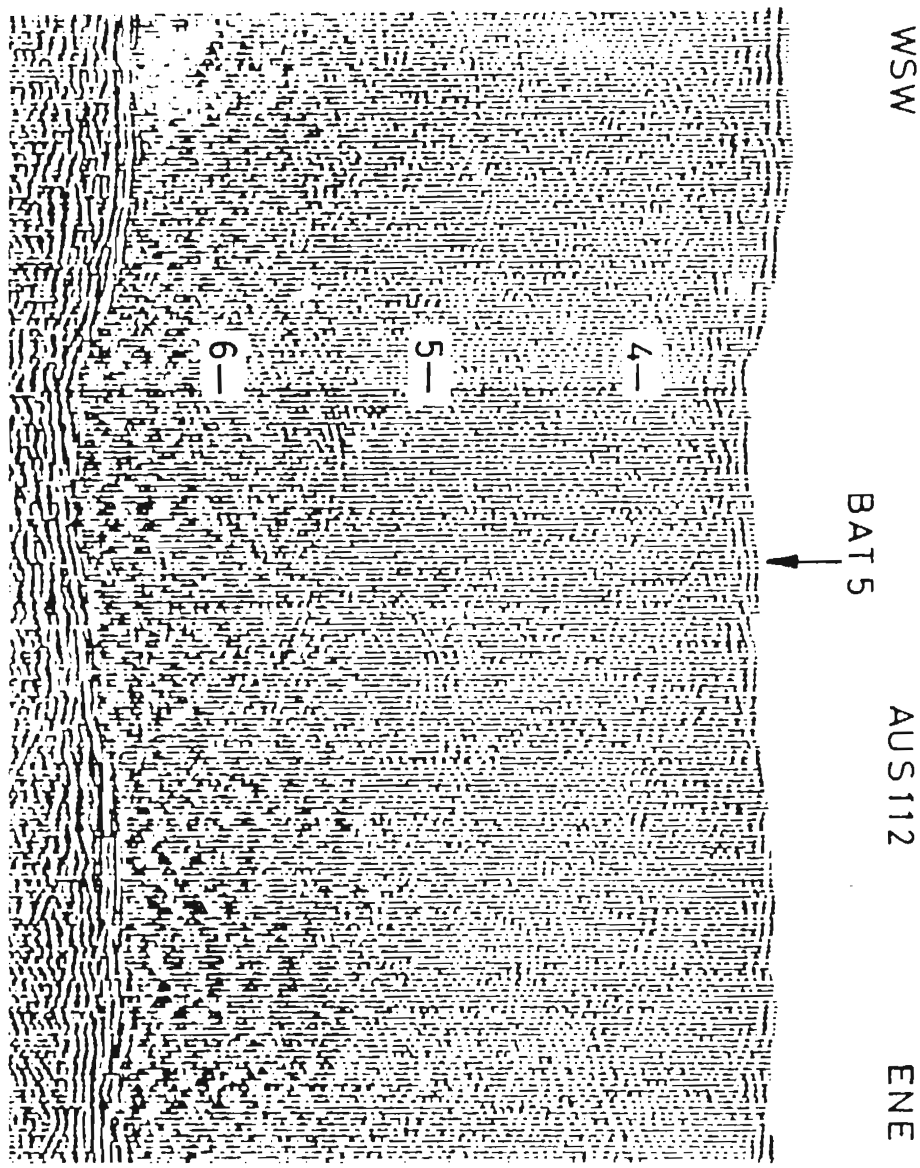


Figure 31

reflections from rocks near this site. In the eastern part of the trough, numerous hyperbolic events suggest that lava flows may be interbedded with sediment. A few weak reflections from below the probable volcanic rocks suggest that sedimentary rocks lie at depth. In contrast to the thin fill in this trough, the North Fiji Basin contains 1000 m of strongly reflective and well bedded sediments.

The purpose for drilling at site BAT-5 is to test whether the trough has been oceanized. This test entails examining the products of magmatism to show whether they are related either to an incipient oceanic spreading center or to island-arc magmatism. The stage of back-arc evolution may not be the same north and south of the collision zone of the DEZ, nor may rifting of the back-arc province and collision of the DEZ be coeval. These relationships can be investigated using data obtained at this site.

Existing Geophysical and Geological Data Base

Many marine geophysical investigations have been taken place in and around the New Hebrides Island arc. Much of these data are available and have recently been examined during the ANZUS (Australia, New Zealand, and U.S.) Tripartite investigation in the region. These data consist of the following:

1. Single channel seismic reflection profiles - Magellan Petroleum Australia, Ltd., 1969.
2. Multi-channel seismic reflection profiles - Mobile Oil Co., early 1970.
3. Multi-channel seismic reflection profiles - Gulf Oil Co., early 1970.
4. Single channel seismic reflection profiles - Institut Francaise Petrole with CEPM (Comite d'Estudes Petrolieres Marines) and ORSTOM

(Office La Recherche Scientifique et Technique Outre-Mer) - Austradec - 1, 1972.

5. Multi-channel seismic reflection profiles - Western Geophysical, 1973.
6. Single channel seismic reflection profiles - Woods Hole Oceanography Institution, R/V Chain, 1973.
7. Single channel seismic reflection profiles - ORSTOM-CCOP/SOPAC, Geovan investigation, R/V Vauban, 1980.
8. Multi-channel seismic reflection profiles - USGS under ANZUS Tripartite-CCOP/SOPAC investigation, R/V Lee, 1982 and 1984.
9. Single channel seismic reflection profiles - ORSTOM-CCOP/SOPAC investigation, R/V Coriolis, 1982.

During the ANZUS Tripartite investigations the following data were collected and have been interpreted.

1. Multi-channel seismic reflection profiles - L4-82-SP and L5-84-SP, R/V Lee, 1982, 1984.
2. Single channel seismic reflection profiles - L4-82-SP and L5-84-SP, R/V Lee, 1982, 1984.
3. High resolution, Uniboom, seismic reflection profiles.
4. High resolution, 3.5 kHz seismic reflection profiles.
5. 12 kHz bathymetric profiles.
6. Magnetic profiles
7. Gravity profiles
8. Dredge samples
9. Gravity core samples

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FIGURE CAPTIONS

Figure 1.	Geography of the southwest Pacific Ocean near the New Hebrides island arc (Vanuatu).
Figure 2.	Location of proposed sites DEZ-1 through DEZ-6 to be drilled mainly to investigate arc-ridge collision.
Figure 3.	Seismic line 104 showing location of site DEZ-1.
Figure 4.	Detail of site DEZ-1.
Figure 5.	Seismic line 100 showing location of site DEZ-2.
Figure 6.	Detail of site DEZ-2.
Figure 7.	Seismic line 107 showing location of site DEZ-3.
Figure 8.	Detail of site DEZ-3.
Figure 9.	Seismic line 12 showing location of site DEZ-4.
Figure 10.	Detail of site DEZ-4.
Figure 11.	Seismic line 101 showing location of site DEZ-5.
Figure 12.	Detail of site DEZ-5.
Figure 13.	Seismic line 102 showing location of site DEZ-6.
Figure 14.	Detail of site DEZ-6.
Figure 15.	Location of proposed sites IAB-1 through IAB-3 to be drilled mainly to investigate evolution of an intra-arc basin and magmatic arc and the possibility of a flip in subduction polarity.
Figure 16.	Seismic line 19 showing locations of sites IAB-1 and IAB-2.
Figure 17.	Detail of site IAB-1.
Figure 18.	Detail of site IAB-2.
Figure 19.	Seismic line 121 showing location of site IAB-3.
Figure 20.	Detail of site IAB-3.

ed Site: DEZ-1

General Objective: Investigate the processes involved in arc-ridge collision.

neral Area: Central New Hebrides arc
sition: 166°21.7'E, 15°19.2'S
ernate Site:

Thematic Panel interest: TCHP, SOHP
Regional Panel interest: WPAC

ecific Objectives: To drill through the lowermost accretionary wedge where the north ridge of DEZ is subducting. Drilling data will show the amount of material stripped from the ridge, effect of ridge composition on the type of slope structures formed, and the approximate ne when arc-ridge collision began.

ckground Information:
egional Data:
Seismic profiles: Crossing multichannel and high-resolution seismic lines

Other data: Bathymetric, gravity, and magnetic data

ite Survey Data - Conducted by: U.S. Geological Survey
Date: 1984
Main results: The top of the north ridge of the DEZ can be traced beneath the lower slope, showing that this ridge is being subducted.

erational Considerations

ater Depth: (m) 2130 Sed. Thickness: (m) 950 Total penetration: (m) 1300

PC ____ Double HPC ____ Rotary Drill x Single Bit x Reentry ____

ature of sediments/rock anticipated: Unconsolidated to semi-consolidated sedimentary rocks and possibly volcanic rocks at the bottom of the hole.
eather conditions/window: Cyclone season is February through May.

rritorial jurisdiction: Vanuatu

her:

ecial requirements (Staffing, instrumentation, etc.)

oponent:

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15-856-7108	New Caledonia	415-856-7049	New Caledonia	

Date submitted to JOIDES Office:

Rev. 0:

Site: DEZ-2

General Area: Central New Hebrides arc
Position: 166°40.5'E, 16°01'S
Alternate Site:

General Objective: Investigate processes involved in arc-ridge collision

Thematic Panel interest: TCHP, SOHP
Regional Panel interest: WPAC

Specific Objectives: Drill through a shallow, parallel-bedded sequence to determine the time when possible obduction occurred. Drilling into rocks would show whether rocks in the Bougainville spur are obducted oceanic crust or deformed ridge rocks. This information will help us understand what type of accretion or deformation accompanies arc-ridge collision.

Background Information:
Regional Data:
Seismic profiles: Crossing multichannel and high-resolution seismic lines.

Other data: Bathymetric, gravity, and magnetic data.

Site Survey Data - Conducted by: U.S. Geological Survey
Date: 1984
Main results: The Bougainville spur might be composed of obducting oceanic crust, rocks of the south ridge of the DEZ, or island arc rocks.

Operational Considerations

Water Depth: (m) 1100 Sed. Thickness: (m) 700 Total penetration: (m) 300

HPC ____ Double HPC ____ Rotary Drill x Single Bit x Reentry ____

Nature of sediments/rock anticipated: semi-consolidated and consolidated rock.

Weather conditions/window: Cyclone season is February through May.

Territorial jurisdiction: Vanuatu

Other:

Special requirements (Staffing, instrumentation, etc.)

Proponent:
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Rev. 02

...te:	DEZ-3	General Objective:	Investigate the processes involved in arc-ridge collision
;eneral Area:	Central New Hebrides arc		
osition:	$166^{\circ}21.7'E$, $15^{\circ}19.2'S$	Thematic Panel interest:	TCHP
lternate Site:		Regional Panel interest:	WPAC

›ecific Objectives: To drill through rocks at the base of the slope where the south ridge of ıe DEZ is subducting. These rocks may be obducting oceanic crust or ridge rocks, or they ıy be deformed arc rocks. This information will help show the style of deformation or ·cretion that accompanies arc-ridge collision.

ıckground Information:

?egional Data:

Seismic profiles: Crossing multichannel and high-resolution seismic lines.

Other data: Bathymetric, gravity and magnetic data

;ite Survey Data - Conducted by: U.S. Geological Survey

Date: 1982 and 1984

Main results: Oceanic rocks rise from abyssal depth toward the arc, suggesting that these rocks may be obducting.

›erational Considerations

ater Depth: (m) 3890 Sed. Thickness: (m) 850 Total penetration: (m) 1000 m

PC ____ Double HPC ____ Rotary Drill __x__ Single Bit __x__ Reentry ____

ature of sediments/rock anticipated:

eather conditions/window: Cyclone season February through May

:rritorial jurisdiction: Vanuatu

:her:

·ecial requirements (Staffing, instrumentation, etc.)

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oponent:

Date submitted to JOIDES Office:

ichael Fisher	Jean-Yves Collot	H. Gary Greene	Jacques Recy	J.N. Carney
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ed Site: DEZ-4

General Objective: Investigate processes involved in arc-ridge collision

neral Area: Central New Hebrides arc
sition: 166°35.5'E, 15°42.1'S
ernate Site:

Thematic Panel interest: TCHP, SOHP
Regional Panel interest: WPAC

ecific Objectives: Drill through lower slope rocks between the ridges of the DEZ, where the wer slope is blanketed by a trenchward prograding fan. The age of the oldest rocks in the n will give the time when major deformation associated with arc-ridge collision began. illing data will also support sediment provenance studies by showing the type of debris ed from the arc to the Central d'Entreasteaux Basin. This provenance data will be used to lp date the time of collision.

ckground Information:
egional Data:
Seismic profiles: Crossing multichannel and high-resolution seismic lines.

Other data: Bathymetric, gravity, and magnetic data.

ite Survey Data - Conducted by: U.S. Geological Survey
Date: 1982, 1984
Main results: Lower trench slope is made up of a submarine fan the progrades trenchward and is only mildly deformed by thrust faults.

erational Considerations

ater Depth: (m) 3000 Sed. Thickness: (m) 1400 Total penetration: (m) 1500

PC ____ Double HPC ____ Rotary Drill x Single Bit x Reentry ____

ature of sediments/rock anticipated: Semiconsolidated sedimentary rocks

eather conditions/window: Cyclone season is February through May.

erritorial jurisdiction: Vanuatu

ther:

ecial requirements (Staffing, instrumentation, etc.)

roponent: Date submitted to JOIDES Office:

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Jacques Recy, ORSTOM, Noumea, New Caledonia

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Rev.

ite: DEZ-5

General Objective: Investigate processes involved in arc-ridge collision

ieral Area: Central New Hebrides arc
ition: 166°30.2'E, 15°52.6'S
ernate Site:

Thematic Panel interest: TCHP, SOHP
Regional Panel interest: WPAC

---

cific Objectives: Drilling here will help determine what effect ridge composition has on the ·le of deformation that occurs in collision zones, whether south-ridge rocks have been lucted onto the arc's slope, and what type of sediment would be derived from the south lge. Sediment provenance studies may help determine when the arc and ridge came close jether.

---

ckground Information:
.egional Data:
Seismic profiles: A multichannel and a high-resolution seismic line across the site.

Other data: Bathymetric, gravity, and magnetic data.

ite Survey Data - Conducted by: U.S. Geological Survey
Date: 1984
Main results: The south ridge of the DEZ is covered by 300-400 m of sedimentary rock that overlie ridge rock that are poorly reflective.

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perational Considerations

ater Depth: (m) 3600 Sed. Thickness: (m) 400 Total penetration: (m) 600

PC ____ Double HPC ____ Rotary Drill x Single Bit x Reentry ____

ature of sediments/rock anticipated: Semi-consolidated sedimentary rocks and volcanic(?) and volcaniclastic rocks.

eather conditions/window: Cyclone season is February through May.

erritorial jurisdiction: Vanuatu

ther:

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pecial requirements (Staffing, instrumentation, etc.)

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roponent:

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ite: DEZ-6

General Objective: Investigate processes involved in arc-ridge collision

eneral Area: Central New Hebrides arc
osition: 165°57.5'E, 15°32.1'S
ternate Site:

Thematic Panel interest: TCHP, SOHP
Regional Panel interest: WPAC

ecific Objectives: Drill through fill in the Central d'Entrecasteaux Basin to determine when e basin and the arc first came close together. Other sites will show the types of sediment rived from the DEZ and arc to allow separation of arc-derived component.

ckground Information:

egional Data:

Seismic profiles: A multichannel and a high-resolution seismic line.

Other data: Bathymetric, gravity, and magnetic data.

ite Survey Data - Conducted by: U.S. Geological Survey

Date: 1984

Main results: The d'Entrecasteaux Basin is filled with about 1 km of sediment that overlies presumed MORB basement.

erational Considerations

ater Depth: (m) 3400 **Sed. Thickness: (m)** 950 **Total penetration: (m)** 1000

PC ____ Double HPC ____ Rotary Drill x Single Bit x Reentry ____

ture of sediments/rock anticipated: Semi-consolidated rocks and probable MORB at bottom.

ather conditions/window: Cyclone season is February through May.

rritorial jurisdiction: Vanuatu.

her:

ecial requirements (Staffing, instrumentation, etc.)

oponent:

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Rev. 02

: IAB-1

ɛneral Area: Central New Hebrides arc
ɔsition: 167°35.0'E, 14°47.5'S
!ternate Site: 167°43.1'E, 14°44.0'S

General Objective: 1) Investigate the evolution of an intra-arc basin, and the magmatic arc near the arc-ridge collision, and 2) the subduction-polarity reversal.

Thematic Panel interest: TCHP, SOHP
Regional Panel interest: WPAC

ɛecific Objectives: To determine whether the age of a major unconformity within the North Aoba sin correlates with the time of arc-ridge collision, showing perhaps how collision modifies e evolution of an intra-arc basin. The chemistry of volcanic ashes may show how magmatic-arc ocesses are modified by collision and help to determine when and whether subduction polarity ipped.

ıckground Information:

Regional Data:

Seismic profiles: Crossing multichannel and high-resolution lines.

Other data: Bathymetric, gravity, and magnetic data.

ite Survey Data - Conducted by: U.S. Geological Survey
Date: 1982
Main results: Thick basin fill includes a major unconformity that marks the onset of major basin subsidence.

ɔerational Considerations

ater Depth: (m) 3075 Sed. Thickness: (m) 1000 Total penetration: (m) 1000

ɔC ____ Double HPC ____ Rotary Drill x Single Bit x Reentry ____

ıture of sediments/rock anticipated: Semi-consolidated sedimentary rocks.

eather conditions/window: Cyclone season is February through May.

ɛrritorial jurisdiction: Vanuatu

her:

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ecial requirements (Staffing, instrumentation, etc.)

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oponent:
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ite: IAB-2

eneral Area: Central New Hebrides arc
osition: 167°55.0'E, 14°38.3S
lternate Site:

General Objective: Investigate 1) the evolution of an intra-arc basin and the magmatic arc near the arc-ridge collision, 2) the subduction-polarity reversal.

Thematic Panel interest: TCHP, SOHP
Regional Panel interest: WPAC

ecific Objectives: Drilling at this site would sample the deep fill in the Aoba basin to give a mposite stratigraphic section (with data from site IAB-1) that straddles chronologically the c-ridge collision and possible flip in subduction polarity. Basin history and evolution of e magmatic arc during this time of unsteady geologic environment can be studied.

ckground Information:

egional Data:

Seismic profiles: A multichannel and a high-resolution seismic line.

Other data: Bathymetric, gravity and magnetic data.

ite Survey Data - Conducted by: U.S. Geological Survey

Date: 1982

Main results: Deep-basin strata rise to shallow depth in the eastern flank of the North Aoba basin.

erational Considerations

ater Depth: (m) 2600 Sed. Thickness: (m) 1000 Total penetration: (m) 1000

PC ____ Double HPC ____ Rotary Drill x Single Bit x Reentry ____

ature of sediments/rock anticipated: Semi-consolidated sedimentary rocks

eather conditions/window: Cyclone season is February through May.

rritorial jurisdiction: Vanuatu

her:

ecial requirements (Staffing, instrumentation, etc.)

oponent: Date submitted to JOIDES Office:

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British Geol. Surv.
London, England

A. Macfarlane
British Geol. Su
London, England

ite: IAB-3

:neral Area: Central New Hebrides arc
sition: 167°04.7'E, 12°51.6'S
ternate Site:

General Objective: Investigate 1) the evolution of an intra-arc basin and the magmatic arc away from the collision of arc and ridge, and 2) the subduction-polarity reversal.

Thematic Panel interest: TCHP, SOHP
Regional Panel interest: WPAC

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ecific Objectives: This site is outside of the arc-ridge collision zone, so it will provide a ference for holes drilled within the collision zone. Basin development and magmatic arc olution within and outside of the collision zone can be compared.

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ckground Information:
.egional Data:
Seismic profiles: Crossing multichannel and high-resolution seismic lines.

Other data: Bathymetric, gravity, and magnetic data.

ite Survey Data - Conducted by: U.S. Geological Survey
Date: 1984
Main results: Thick basin fill includes an unconformity that may correlate with the one in th North Aoba basin.

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erational Considerations

.ter Depth: (m) 1900 Sed. Thickness: (m) 1500 Total penetration: (m) 1500

'C ____ Double HPC ____ Rotary Drill x Single Bit x Reentry ____

ture of sediments/rock anticipated: Semi-consolidated sedimentary rocks.

ather conditions/window: Cyclone season is February through May.

rritorial jurisdiction: Vanuatu

ner:

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ecial requirements (Staffing, instrumentation, etc.)

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oponent: Date submitted to JOIDES Office:

Gary Greene	Michael Fisher	David A. Falvey	J.N. Carney	A. Macfarlane
GS	USGS	BMR	British Geol. Surv.	British Geol.Su
nlo Park,94025	Menlo Park,94025	Canberra, Australia	London, England	London, England

ODP SITE PROPOSAL SUMMARY FORM

·oposed Site: BAT 1 / BAT 2

General Objective: Investigate the evolution of the back arc troughs and of a young magmatic arc

ɜneral Area: Southern New Hebrides arc
ɔsition: 168° 52' E, 17° 57'5 S
:ternate Site: 168° 39,5 , 18° 16' S

Thematic Panel interest: SOHP TECP
Regional Panel interest: WPAC

·ecific Objectives: This site is outside of both the back arc tensional zone and the arc-ridge collision zone, thus it will provide a reference on the development of the southern New Hebrides arc away from back-arc and arc / ridge collision zone.

.ckground Information:
:egional Data:
Seismic profiles: Crossing single channel seismic lines

Other data: Unprocessed 12 channels seismic lines, bathymetric, gravity, seismic refraction and magnetic data

ite Survey Data - Conducted by: ORSTOM / IFP
Date: 1972-1982
Main results: The arc is covered by a tilted stratified sedimentary sequence. This include an angular unconformity probably outlined by an an erosional surface

erational Considerations

ter Depth: (m) 1000 m Sed. Thickness: (m) 1300 m Total penetration: (m) 1500 m

C ____ Double HPC ____ Rotary Drill X Single Bit X Reentry ____

ture of sediments/rock anticipated: Semi consolidated rocks and volcaniclastic rocks

ather conditions/window: Cyclone season is December trough April

·ritorial jurisdiction: VANUATU

ıer:

·cial requirements (Staffing, instrumentation, etc.)

·ponent:

Date submitted to JOIDES Office:

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BPA 5
Noumea New Caledonia

H.G. Greene M.A. Fisher
USGS
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Menlo Park, CA 94025
USA

ODP SITE PROPOSAL SUMMARY FORM

roposed Site: BAT 3	General Objective: Investigate the back arc processes
eneral Area: Southern New Hebrides arc osition: 169° 05'5 E , 17° 54 S ternate Site:	Thematic Panel interest: LITHP SOHP TECP Regional Panel interest: WPAC

ecific Objectives: Drilling this site will help to determine when extension began. This will be correlated with Arc / Ridge collision time and magmatic pulses of the arc.

ckground Information:

egional Data:

Seismic profiles: Crossing single channel seismic lines

Other data: Unprocessed 12 channels seismic lines, bathymetric, gravity and magnetic data.

te Survey Data - Conducted by: ORSTOM / IFP

Date: 1972-1982

Main results: Seismic profile displays an angular unconformity between old arc slope sediments down dropped in the trough and more recent sedimentary deposits.

erational Considerations

er Depth: (m) 2100 m • Sed. Thickness: (m) 1500 m Total penetration: (m) 1500 m

C ____ Double HPC ____ Rotary Drill X Single Bit X Reentry ____

ure of sediments/rock anticipated: Semi consolidated rocks and volcaniclastic rocks

ther conditions/window: Cyclone season is December trough April

itorial jurisdiction: VANUATU.

r:

al requirements (Staffing, instrumentation, etc.)

onent: Date submitted to JOIDES Office:

ecy M. Monzier P. Maillet Jean-Yves Collot M.A. Fisher

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ODP SITE PROPOSAL SUMMARY FORM

roposed Site: BAT 4	**General Objective:** Investigation of the back-arc processes
eneral Area: Southern New Hebrides arc **osition:** 169° 20, 5 E, 17° 49' 8 S **lternate Site:**	**Thematic Panel interest:** LITHP SOHP TECP **Regional Panel interest:** WPAC

ecific Objectives: Drilling the central part of the seismically active back-arc will show the chemical composition and age of volcanic rocks that were injected into the troughs during the initial stage of formation of new oceanic crust. The age of the sedimentary section associated with the volcanic rock will help date the onset of back-arc extension.

ckground Information:

egional Data:

Seismic profiles: Crossing single channel seismic lines

Other data: Unprocessed 12 channel seismic line, bathymetric, gravity, magnetic and seismic refraction data

ite Survey Data - Conducted by: ORSTOM/IFP

Date: 1972 - 1982

Main results: Seismic lines show weak, disrupted reflections from rocks within the trough that contrast with the well layered deposits covering the seafloor on both sides of the trough. Magnetic anomalies measured over the trough suggest the presence of igneous rocks.

erational Considerations

ater Depth: (m) 2600 m Sed. Thickness: (m) ? Total penetration: (m) 500 - 1500 m

PC ____ Double HPC ____ Rotary Drill X Single Bit X Reentry ____

ature of sediments/rock anticipated: Volcaniclastics rocks, lava flows and volcanic sills.

eather conditions/window: Cyclone season is December through April

rritorial jurisdiction: VANUATU

her:

ecial requirements (Staffing, instrumentation, etc.)

oponent:

Date submitted to JOIDES Office:

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ODP SITE PROPOSAL SUMMARY FORM

...ed Site: BAT 5

General Objective: Investigation of the back arc process

...neral Area: Southern New Hebrides arc
...sition: 167° 57' E, 13° 15' S
...ternate Site:

Thematic Panel interest: LITHP SOHP TECP
Regional Panel interest: WPAC

...ecific Objectives: This site is located within a back-arc trough of the Arc/Ridge collision zone. Drilling at this site will provide information about the stage of formation of new oceanic crust and about the timing of the back arc extension. The stage of formation and timing for the troughs north and south of the collision zone can be compared.

...ckground Information:
...egional Data:
Seismic profiles: Crossing single channel seismic line.

Other data: Unprocessed 12 channel seismic line, bathymetric, and magnetic data.

...ite Survey Data - Conducted by: ORSTOM/IFP
Date: 1972-1982
Main results: Well developed trough contains many weak, incoherent reflectors as well as a possible lava flow. The trough is flanked by well stratified sedimentary sequences laying on the arc slope and on the North Fiji basin crus...

...erational Considerations

...ter Depth: (m) 2550 m Sed. Thickness: (m) ? Total penetration: (m) 500 to 1500 m

...C ____ Double HPC ____ Rotary Drill X Single Bit X Reentry ____

...ture of sediments/rock anticipated: Volcaniclastic rocks, lava flows and volcanic sills

...ather conditions/window: Cyclone season is December through April

...ritorial jurisdiction: VANUATU

...her:

...cial requirements (Staffing, instrumentation, etc.)

...ponent:

Date submitted to JOIDES Office:

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ODP SITE PROPOSAL SUMMARY FORM

sed Site: BAT 5	**General Objective:** Investigation of the back arc process
eneral Area: Southern New Hebrides arc **osition:** 167° 57' E, 13° 15' S **lternate Site:**	**Thematic Panel interest:** LITHP SOHP TECP **Regional Panel interest:** WPAC

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Fisher M.A., Greene H.G., Collot Jean-Yves, Récy Jacques. (1986).

A proposal for drilling at an arc-ridge collision zone in the central New Hebrides island arc (Vanuatu).

Nouméa : ORSTOM, 79 p. multigr.