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by

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Marine Geoscience and Petroleum Geology Program

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SUMMARY

The Norfolk Ridge and Vening-Meinesz Fracture Zone were surveyed by the French oceanographic research vessel N/O *L'Atalante* using wide-swath seafloor mapping and geophysical techniques. The survey was conducted during 24-30 October 1993 while the ship was in transit between Noumea (New Caledonia) and Auckland (New Zealand). The objective was to achieve a better understanding of the structural architecture and tectonic evolution of these major, poorly-known submarine features.

L'Atalante is a modern 85-m multi-purpose research vessel fitted with advanced technology survey equipment and computer facilities. The ship is owned by the Institut Français de Recherche pour l'Exploitation de la Mer (IFREMER). It is equipped with a SIMRAD Dual EM12 (EM12D) multi-beam 13 kHz echo-sounder system. This system maps bathymetry and produces acoustic images of the seafloor at a ship's speed of up to 10 knots or more. The swath width is ~7 times water depth; the maximum effective coverage in deep water (several kilometres or more) is about 20 km.

Approximately 2200 km of high-quality data were recorded along the western flank of the Norfolk Ridge and in a criss-cross pattern over the Vening-Meinesz Fracture Zone. The data acquired included EM12D bathymetry and images, 6-channel airgun reflection seismic, 3.5 kHz high resolution seismic, gravity and magnetics.

The survey showed that much of the western Norfolk Ridge is of uneven to rugged topography. The relief is due to canyon incision (often to a depth of several hundred metres), seafloor volcanism and widespread, relatively young faulting that approaches or intersects the seabed. These faults are mostly small-scale and of steep dip. Locally, some consistency in structural orientation is observed. Seafloor structures trend mainly in the range southwest to northwest.

Volcanic submarine terrain is most evident in the area adjacent to the Pliocene volcanic Norfolk and Philip Islands. The submarine volcanic cones and edifices are mainly 100-600 m high and 0.5-4 km across.

Observed sediment thickness on the Norfolk Ridge is typically 1.0-1.4 s twt; at least 2.0 s twt of sedimentary section is present in places. The section has been affected to varying degrees by faulting and folding.

The seafloor topography at the southern end of the Norfolk Ridge and along the Vening-Meinesz Fracture Zone is of extremely high relief (several thousand metres), with crustal blocks and ridges rising steeply above adjacent deep and relatively flat-floored troughs and basins. The structural grain trends northwest in the direction of the Fracture Zone. Large blocks of ?continental crust at the southwest margin of the South Norfolk Basin may have become detached by transform motion during opening of the basin. The Taranui Gap is underlain by a thick (at least 2.0 s twt) pile of sediment strongly deformed by ?Neogene transpressional wrenching.

INTRODUCTION

In October 1993, the Norfolk Ridge and Vening-Meinesz Fracture Zone (Figure 1) were surveyed by the French oceanographic research vessel (navire océanographic) N/O *L'Atalante* of IFREMER (Institut Français de Recherche pour l'Exploitation de la Mer). The swath-bathymetry and geophysical survey, named TRANSNOR, was of one week duration. The ship's complement of 39 included 4 marine geoscientists (Appendix 1). The ship left Noumea on Sunday 24 October 1993 and arrived in Auckland harbour on Saturday 30 October, at the end of the cruise. The survey work was undertaken in the Exclusive Economic Zones (EEZs) of France, Australia and New Zealand (Figure 2).

The scientific program developed from a proposal by cruise leader, Jean Mascle of Laboratoire de Géodynamique Sous-marine (Villefranche-sur-Mer), to utilise a Noumea-Auckland transit of the ship to map geological structure on the western flank of the Norfolk Ridge and along the Vening-Meinesz Fracture Zone with the aim of achieving a better understanding of the structural architecture and tectonic evolution of these major submarine features.

The transit ex-Noumea followed the successful conclusion of a series of major surveys in the Fiji/Solomons/Vanuatu area (including SOPACMAPS for the South Pacific Applied Geoscience Commission). The port call in Auckland was scheduled for the start of GEODYNZ, a 5-week France - New Zealand co-operative program in waters adjacent to New Zealand. This is to be followed by a 4-week survey of the mid-ocean ridge south of New Zealand (PACANTARCTIC). In mid-January 1994, the ship is scheduled to begin a major 6-week, AGSO-directed survey of the transform margin to the west and southwest of Tasmania (AGSO Project 121.44).

The role of the author on this cruise was to, (i) participate in and contribute to the scientific program, (ii) act as Australian representative and ensure that copies of data collected in Australian waters were obtained, and (iii) become familiar with the swath-mapping and geophysical systems aboard *L'Atalante* so that the forthcoming AGSO survey off Tasmania could be planned and executed in the most efficient and effective manner.

This Record is a cruise report on the TRANSNOR survey. It provides background information, an account of the survey operations and details of scientific data collected. Though some preliminary results are presented in this report, results of detailed analysis and interpretation of the data will be left to future publications.

L'ATALANTE AND ITS SURVEY SYSTEMS

L'Atalante (Figure 3, Appendix 2) is a modern 85-metre multi-purpose research vessel. It was launched in 1990 and replaces the *Jean Charcot*. The laboratories onboard contain a massive array of scientific equipment and computer facilities for acquiring, processing, storing and displaying a wide range of geoscientific and oceanographic data. The ship has the capability of launching and operating manned submersibles, such as *Nautile*, in water depths up to 6000 m. *L'Atalante* was specifically built for high-technology seafloor mapping, and is equipped with the advanced SIMRAD Dual EM12 multibeam echo-sounder (Figure 3, Appendix 3). This system maps bathymetry and acoustic reflectivity of the seafloor at a ship's speed of up to10 knots or more. The swath width is ~7 times water depth; the maximum effective coverage in deep water (several kilometres or more) is about 20 km (Figure 4).

PHYSIOGRAPHY OF THE NORFOLK RIDGE SYSTEM

The main structural elements and bathymetry of the region between New Caledonia and the North Island of New Zealand are indicated in Figure 1.

The Norfolk Ridge system is a complex, elevated seafloor feature that extends from New Caledonia to the northern tip of New Zealand.

The northern, north-trending segment is the Norfolk Ridge (Figure 1). It is about 1000 km long, about 70 km wide, steep-sided and with a crestal depth mainly in the range 500-1500 m. There is a slight westward offset in the ridge just north of Norfolk and Philip Islands, located on the central portion of the ridge. These islands are the only subaerial parts of the ridge system. The Norfolk Ridge is flanked by the New Caledonia Basin to the west and the North and South Norfolk Basins to the east. These basins are all about 3500-4000 m deep.

The southern, northwest-trending segment of the Norfolk Ridge system is about 250 km wide and has a complex topography. It includes three main ridges - the West Norfolk Ridge, the central Wanganella Ridge and the eastern Norfolk-Reinga-South Maria Ridge system. A 2000-m deep bathymetric trough, the Taranui Gap (or Sea Valley) separates the Wanganella and Norfolk/Reinga Ridges. The northeastern side of the Norfolk-Reinga-South Maria Ridge system slopes steeply into the South Norfolk Basin from water depths of less than 500 m to more than 3500 m. The Vening-Meinesz Fracture Zone (Figure 1) is located along this northwest-trending ridge/basin margin.

REGIONAL GEOLOGICAL SETTING AND TECTONICS

The tectonic development of the New Caledonia - Norfolk Ridge - New Zealand region of the southwest Pacific has been discussed by Burns and Andrews (1973), Willcox et al. (1980), Ballance et al. (1982), Kroenke (1984), Eade (1988), Spörli and Ballance (1989) and Symonds and Colwell (1992). Results of early seismic surveys across the southern Norfolk Ridge system are outlined by Davey (1977). Plate reconstructions of the region for the Cretaceous-Cainozoic have been made by Kamp (1986), Walley and Ross (1991) and Walley (1992). The following account of the geology and evolution of the region is largely taken from the last two publications.

In the Early Cretaceous, prior to the breakup of eastern Gondwana, the New Zealand - New Caledonia region was part of a convergent margin. Most of the region was emergent at this time. Extension at the eastern Gondwana margin began in the late Early Cretaceous, with widespread terrestrial sedimentation taking place. The New Caledonia Basin is believed to have opened in the mid Cretaceous (~95 Ma). Seafloor spreading in the Tasman Sea during the Late Cretaceous to early Eocene (~86-56 Ma) was accompanied by regional subsidence and transgression.

Rifting and seafloor spreading of the eastern Australian margin during the Cretaceous has recently been interpreted in terms of a continental margin detachment model (Etheridge et al., 1989; Lister et al., 1991). The model implies that a detachment system underlies the whole region, with the Lord Howe Rise and Norfolk Ridge composed of variously extended upper continental crust and thinned lower crust / upper mantle. Small intervening basins such as the New Caledonia Basin may be in part floored by highly-thinned lower continental crust. The crustal thickness beneath the Norfolk Ridge is 21 km (Shor et al., 1971), which is greater than for a volcanic arc and somewhat thinner than for typical continental crust. Based on crustal thickness, seismic character and magnetic signature, Eade (1988) concluded that the Norfolk Ridge is likely to be of continental or continental margin origin.

Cessation of seafloor spreading in the New Caledonia Basin (perhaps coincident with Tasman Basin opening), may have led to onset of east-dipping subduction along the western side of the north Norfolk Ridge. Back-arc basins developed in New Caledonia and to the east of the Norfolk Ridge creating the North and South Norfolk Basins. In this version of events (Walley and Ross, 1991), the Vening-Meinesz Fracture Zone was a transform fault separating continental crust of the Reinga Ridge from newly formed oceanic crust of the South Norfolk Basin. Launay et al. (1982) and Eade (1988) suggest the North and South Norfolk Basins opened from ~85-75 Ma. However, other interpretations - including that of Rigolot (1989) and CPCEMR (1991) - indicate an Eocene age, with the implication that opening of these basins immediately followed the end of spreading in the Tasman.

East-dipping subduction resulted in opening of back-arc basins northeast of New Caledonia between Early and late Middle Eocene. Convergence increased from late Middle Eocene to Early Oligocene, and following a change in plate boundary configuration the marginal basin development ceased and newly-formed oceanic crust was obducted from the northeast onto New Caledonia (Brothers and Lillie, 1988). Transpression and associated dextral strike-slip movement along the western Norfolk Ridge is inferred (Rigolot, 1989).

In the mid-Late Eocene (at the same time as oblique plate convergence was taking place along the northern Norfolk Ridge), a zone of extension developed through western New Zealand, leading to the accumulation of coal measures in fault-controlled basins. This was followed by regional subsidence and transgression during the Oligocene.

The South Fiji Basin opened between 36-26 Ma (Malahoff et al., 1982) as a back-arc basin to an arc along either the Three Kings Rise (Kroenke and Eade, 1982) or the Colville-Lau Ridge. The Vening-Meinesz Fracture Zone would have been an active transform fault during this tectonism.

The modern convergent Indo-Australian/Pacific plate boundary was established in New Zealand in the latest Oligocene / earliest Miocene (~23 Ma). At this time the Indo-

Australian/Pacific plate boundary began to propagate through New Zealand as a convergent boundary. Dextral shear between the two halves of the North Island linked into the Vening-Meinesz Fracture Zone. The transpression resulted in southwest-directed ophiolite obduction onto the North Island in the latest Oligocene - earliest Miocene (Brothers and Delaloye, 1982).

Norfolk and Philip Islands, on the central Norfolk Ridge, were formed by Pliocene volcanic activity dated at 3.1-2.3 Ma (Jones and McDougall, 1973; Aziz-Ur Rahman and McDougall, 1973).

SCIENTIFIC PROGRAM AND DATA ACQUIRED

Some modifications to the original cruise proposal were made in Noumea immediately prior to departure. Further minor modifications were made during the survey as new structural detail and trends were revealed, and because of survey time constraints.

The survey comprised 17 lines, TN01 to TN17. A time-annotated track map is presented in Figure 5. Figure 6 shows the line locations and also the way-points used during the survey. Line and way-point details are provided in Appendix 4 and 5, respectively.

During the TRANSNOR survey, geophysical data were acquired concurrently with the EM12D swath-mapping data acquisition. These geophysical data comprised gravity, magnetics, 3.5 kHz echo-sounder profiles and 6-channel GI gun seismic. The seismic data were digitally recorded and displayed on two strip-chart monitors (fast and slow). Survey and navigation equipment details are provided in Appendix 6. Also provided are the geophysical acquisition parameters (Appendix 7) and the acquisition geometry (Figure 7).

The EM12D data were acquired digitally on the ARCHIV system. Bathymetry contour maps (25 m contour interval and 1:100,000 scale) were plotted automatically almost in real time on a large Benson flat-bed plotter with a selection of coloured pens. The main recorder that displays the acoustic images was not operational on this cruise.

A total of approximately 2200 km of data (EM12D, gravity, magnetics, 3.5 kHz and airgun seismic) were collected during the cruise. Data quality was very good.

Digital navigation, EM12D, gravity, magnetics and airgun seismic data were made available on 8 mm EXABYTE cartridge. The 6-channel airgun seismic data were in SEG-Y format. The gravity data are based on the IGSN 71 datum and normal gravity given by the formula

$$G_N = 978030 + 5186\sin^2\phi - 7\sin^2 2\phi \text{ mGal, where } \phi = \text{latitude.}$$

CRUISE NARRATIVE

The time and nature of significant events that occurred during the cruise are indicated below. Times and dates are in GMT (UTC), unless specifically shown as being local.

23 October

2300 *L'Atalante* left Noumea (1000 hrs local Friday 24 October)

24 October

0015 Ship passed through outer reef off Noumea

0034 Start of line TN01; collecting gravity and EM12D data

0108 Magnetometer fish deployed

0345 Reduced speed for Sippican temperature profile; magnetometer retrieved for deployment of the airguns

0406 Guns deployed

0409 Deployment of streamer started

0426 Guns firing

0430 Increasing ship's speed and redeploying the magnetometer

0438 Start of line TN02

0442 Slowing to 6 knots to recover port gun (not firing)

0500 Recording with 1 gun

0551 Slowing down to redeploy gun

0602 Gun in the water

0632 Slowing to 6 knots to recover port gun

0646 Recording with 1 gun

0718 Port gun back in the water

0731 Both guns deployed and firing okay

1107 Changed seismic tape (now #2)

1744 Changed seismic tape (now #3)

2105 Reduced speed to 6 knots for Sippican temperature profile

[Weather conditions during day: SSE winds of ~ 20 knots, seas moderate-rough]

25 October

0015 Changed seismic tape (now #4)

0647 Changed seismic tape (now #5)

1314 Changed seismic tape (now #6)

1800 West of Norfolk Island

1851 Slowing to 6 knots for Sippican measurement

1911 Speed back to normal

1942 Changed seismic tape (now #7)

2325 Changed seismic tape (now #8)

[Weather conditions during day: SE winds ~ 20 knots at first, then dropping to ~10 knots and swinging to the east]

26 October

0543 Changed seismic tape (now #9)

0744 End of line TN02; changed seismic tape (now #10); start of TN03

1409 Changed seismic tape (now #11)

1513 End of line TN03; start of TN04 (at 1517)

1743 End of line TN04; start of TN05 (at 1745)

2006 End of line TN05; changed seismic tape (now #12); start of TN06

2130 40+ knot winds; ship's speed down to about 7.5 knots

2303 End of line TN06; start of TN07 (at 2313)

[Weather conditions during day: the winds (from the NNE) increased in strength to over 40 knots, very rough seas]

27 October

0244 Changed seismic tape (now #13)

0527 Speed reduced to 6 knots for Sippican measurement

0706 End of line TN07; changed seismic tape (now #14); start of TN08 (at 0713)

1003 End of line TN08; start of TN09

1252 End of line TN09; start of TN10 (at 1257)

1341 Changed seismic tape (now #15)

1441 End of line TN10; start of TN11 (at 1446)

1939 Reducing speed to recover leaking port air-gun

2000 Sippican measurement

2009 Changed seismic tape (now #16)

2027 Reduced speed to 6 knots to redeploy port gun

2034 Port gun back in the water and ship's speed increased

2251 End of line TN11; changed seismic tape (now #17); start of TN12 (at 2258)

[Weather conditions during day: the NW-northerly winds gradually abated to ~15 knots, seas were moderate-rough on a large swell]

28 October

0320 End of line TN12; changed seismic tape (now #18); start of TN13 (at 0325)

0932 End of line TN13; changed seismic tape (now #19); start of TN14 (at 0937)

1020 EM12D disk error; 15 minutes data lost

1142 End of line TN14; start of TN15 (at 1146)

1248 End of line TN15; start of TN16 (at 1249)

1605 End of line TN16

1606 Changed seismic tape (now #20)

1617 Start of line TN17

1857 Slowing to 6 knots for Sippican temperature profile

2241 Changed seismic tape (now #21)

[Weather conditions during day: wind direction and strength were variable, but average speed was ~15 knots from the NE; seas were rough on a large swell; rain squalls]

29 October

0025 Stopped seismic acquisition to put new roll of paper in the fast recorder

0032 Again recording seismic

0040 Airguns not firing correctly, compressor problem

0110 Seismic restored

0246 Reducing speed prior to recovering the magnetometer and seismic gear

0300 Recovering outboard geophysical gear (magnetometer, airguns and seismic streamer)

0319 All gear aboard, ship's speed increased (10+ knots); now acquiring only EM12D and 3.5 kHz data as ship makes for Auckland

0700 Effective end of data acquisition

L'Atalante docked in Auckland at 1100 hrs local on Saturday 30 October; customs clearance completed at 1200 hrs local.

PRELIMINARY RESULTS

Some preliminary results of the TRANSNOR survey are presented in this section. The results are based on the raw shipboard data (without post-processing), mainly the EM12D bathymetry contour plots and the seismic monitor records.

The survey showed that much of the western Norfolk Ridge is of uneven to rugged topography. The relief is due to canyon incision, seafloor volcanism and widespread, relatively young faulting that approaches or intersects the seabed. These faults are mostly small-scale and of steep dip. No pronounced, consistent structural orientation is observed in the EM12D bathymetry contours on the Norfolk Ridge as a whole. Some local consistency in structural orientation is observed, however. Seafloor structures trend mainly in the range southwest to northwest.

Volcanic seafloor terrain is most evident in the area adjacent to Norfolk and Philip Islands. This suggests that most of the volcanic activity may be of Pliocene age.

Observed sediment thickness on the Norfolk Ridge is typically 1.0-1.4 s twt; at least 2.0 s twt of sedimentary section is present in places. The section has been affected to varying degrees by faulting and folding.

An area of thick, relatively mildly deformed sedimentary section was encountered about 250 km south of New Caledonia (at ~24° 40' S). The section may be representative of the general stratigraphy of the Norfolk Ridge. Here, an upper sequence of sub-horizontal beds overlies a prominent unconformity at ~0.8 s twt sub-bottom that has small but pronounced relief. It may correspond to the regional late Oligocene unconformity observed in DSDP drilling (Burns and Andrews, 1973). The underlying sequence is about 1.0 s twt thick and consists of sub-parallel to wavy beds that show some deformation. This is in turn underlain by a basal layer of chaotic reflection character. The boundary between the two layers is not sharp, but the change in reflection character is distinctive. No deeper, strong reflectors that might indicate 'true' basement are visible in the monitor data. The basal layer may consist of volcaniclastics that mask deep basement.

The seafloor topography at the southern end of the Norfolk Ridge and along the Vening-Meinesz Fracture Zone is of extremely high relief (several thousand metres), with crustal blocks and ridges rising steeply above adjacent deep and relatively flat-floored troughs and basins. The structural grain trends northwest in the direction of the Fracture Zone. The Taranui Gap is underlain by a thick (at least 2.0 s twt) pile of strongly deformed sediments. The style of deformation suggests wrenching (Symonds and Willcox, 1989), probably active during the Neogene when transpressive tectonism was active on the North Island (N.Z.).

Specific examples of data collected during the cruise are presented in Figures 8-17 and discussed below.

Canyon development on the northern Norfolk Ridge. EM12D bathymetry contours (Figure 8)

This area is of rugged topographic relief. Canyon development shows southwest and northwest trends into the New Caledonia Basin. The canyons are more than 20 km long and at least 450 m deep.

Volcanic edifices on the central Norfolk Ridge SSW of Norfolk Island. EM12D bathymetry contours (Figure 9)

Numerous volcanic cones and other ?volcanic edifices rise from a seafloor that appears to be eroded and shows evidence of canyon cutting. The area has strong magnetic expression.

The cones and edifices vary in size from 100-600 m high and 0.5-4 km across.

Detached ?continental block adjacent to the Vening-Meinesz Fracture Zone, Reinga Ridge - EM12D bathymetry contours (Figure 10)

The bathymety contours define a large (60 km long and 13 km wide) elevated block located just off the northwest-trending escarpment that marks the trace of the Vening-Meinesz Fracture Zone at the southwest margin of the South Norfolk Basin. The elongated block rises from the adjacent basin at 4000 m depth to less than 1000 m below sea-level.

Local highs are located along the top of the escarpment, and these may be fault-bounded blocks or volcanic edifices.

The large isolated block may represent a continental sliver that was torn from the Reinga Ridge during transform faulting as the South Norfolk Basin opened.

Preliminary EM12D acoustic image of the Taranui Gap / Reinga Ridge area, lines TN04-08 (Figure 11)

In this image areas of high acoustic backscatter (reflectivity) are shown dark and, conversely, areas of low backscatter are light toned.

The image covers part of the detached block seen in the bathymetry of Figure 10. The light areas generally represent sedimented seafloor. Such areas include the floor of the deep submarine valley between the block and the Reinga Ridge escarpment, the floor of the South Norfolk Basin and much of the top of the Reinga Ridge. The steep escarpments and some areas of the seabed in the Taranui Gap are seen in the image as being dark and structured. These dark areas probably represent exposed bedrock surfaces and perhaps volcanics.

Prominent angular unconformity above a thick disturbed sedimentary succession (total section >1.8 s twt), central Norfolk Ridge - line TN02 seismic section (Figure 12)

A major unconformity, 0.3-0.45 s twt sub-bottom, separates a thick lower sequence of hummocky to sub-parallel reflection configuration from an upper sequence of strong parallel/sub-parallel reflectors. The upper sequence (?pelagics) consists of two units; the upper onlaps the lower. Minor steep faults extend upward to the shallower unconformity in the upper sequence.

Thick (>1.5 s twt) sedimentary section and ?volcanics beneath the central Norfolk Ridge, line TN02 seismic section (Figure 13)

The sedimentary section thickens locally in a broad trough located about 50 km northwest of Norfolk Island. The southeastern flank of the trough appears to have been intruded by volcanics which have erupted onto the seafloor. Several prominent seismic horizons (including at least two angular unconformities) are present in the sedimentary section.

Thick (>2.0 s twt), mildly-moderately deformed sedimentary section west of the southern Norfolk Ridge, line TN02 seismic section, (Figure 14)

The seismic section in Figure 14 is located NNW of the Taranui Gap and roughly along the trend of this structure. A deep, narrow Geosat gravity low, which coincides with the Taranui Gap, extends NNW to the location of the seismic section. The gravity low is a reflection of the very thick sedimentary section observed here. The sediments at this location are significantly less deformed than at the Gap (compare with Figures 15 and 16). Diffraction hyperbolae deep in the section and to lesser extent within the mid section suggest volcanics.

Strongly deformed sedimentary section (>1.8 s twt thick) beneath the Taranui Gap adjacent to the northern Wanganella Ridge, line TN03 seismic section (Figure 15)

The section shows complex folding and faulting. The deformed section is exposed on the seafloor or covered by no more than a veneer of younger sediment. The rough seafloor is probably a product of both structural deformation and submarine erosion.

Highly faulted and folded sedimentary section in the Taranui Gap adjacent to the Norfolk (extreme southern)/Reinga Ridge, line TN05 seismic section (Figure 16)

The highly deformed sedimentary section exceeds 1.2 s twt in thickness. Tilted fault blocks are exposed on the seafloor. A thin layer (to ~100 m) of relatively undeformed sediment unconformably overlies the faulted/folded section, forming a blanket that smooths much of the pre-existing rough seafloor topography. The deformation is likely to be Neogene in age.

Thick (>1.7 s twt), structurally-disturbed pile of sediment overlying ?volcanic basement at the southern margin of the South Norfolk Basin, line TN09 seismic section (Figure 17)

Acoustic basement in this profile lies deeper than 6.5 s twt. Its indistinct upper surface suggests it may be volcanic (?oceanic). The reflectors in the thick overlying sedimentary section are mainly discontinuous and hummocky, and show some faulting. The section probably contains deep-sea fans and turbidites shed from the marginal escarpment immediately adjacent to the southwest.

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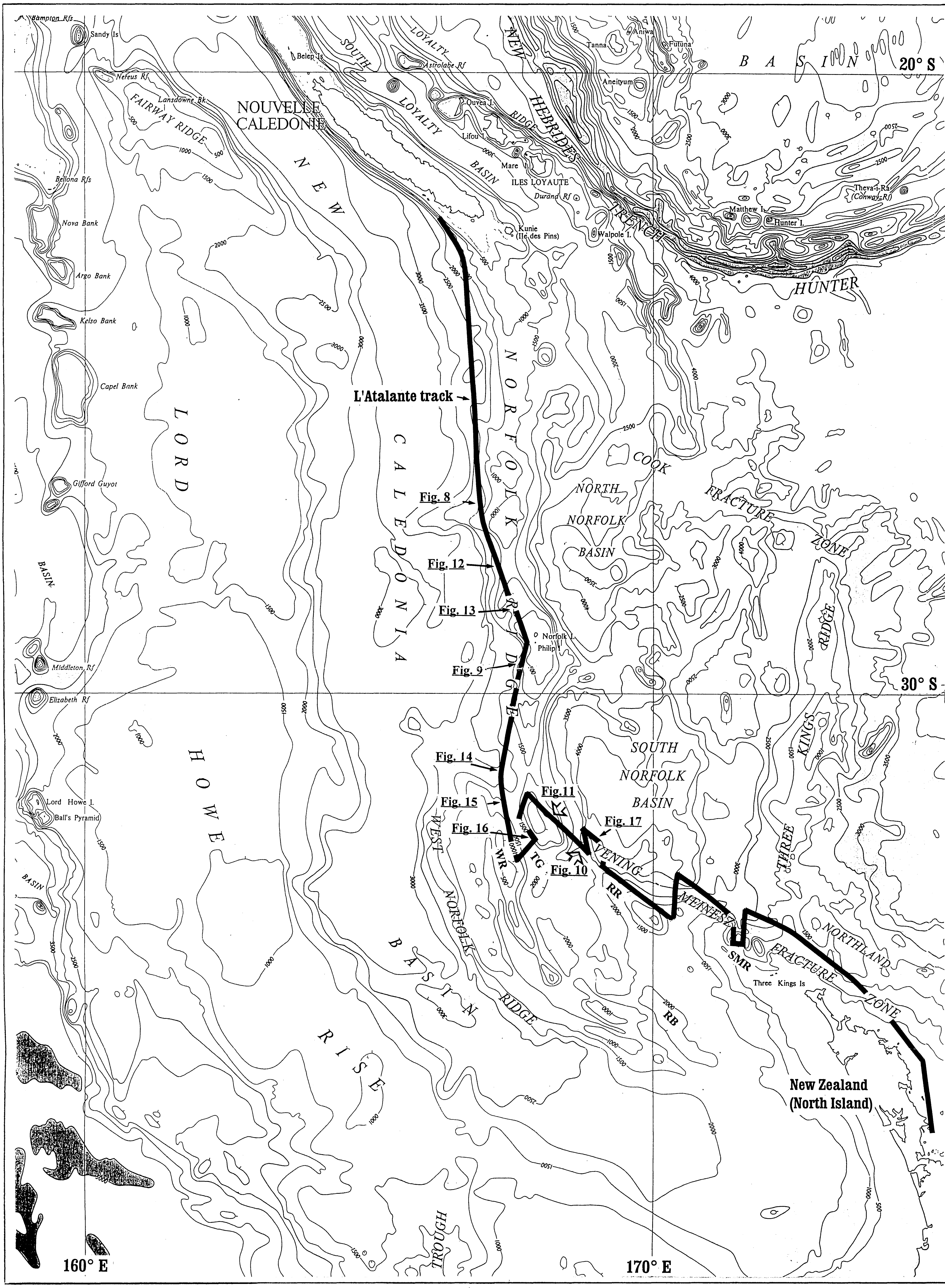
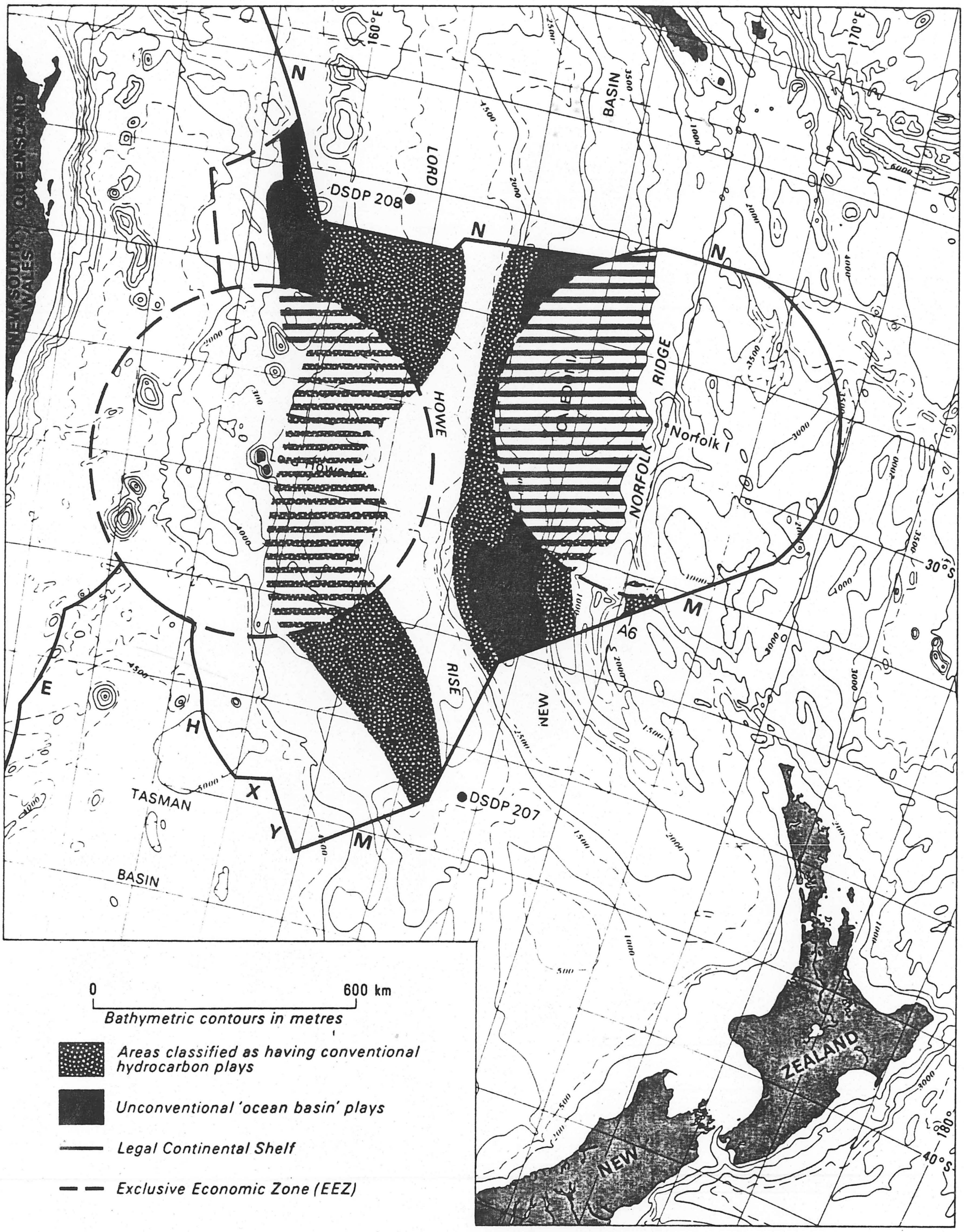


RR	Reinga Ridge
TG	Taranui Gap
WR	Wanganella Ridge
RB	Reinga Basin
SMR	South Maria Ridge

FIGURE 1. TRANSNOR survey location map, regional structural elements and bathymetry (base map after Kroenke et al., 1983; bathymetry in metres).



The criteria used to define a Legal Continental Shelf are: E = EEZ, H = Hedberg Line, X = 350 nautical mile cutoff, Y = 100 nautical mile beyond 2500 m isobath cutoff; N = negotiated boundary, M = median line with the adjacent coastal state.

FIGURE 2. Australian seabed boundaries in the Norfolk and Lord Howe Islands region (after Symonds and Willcox, 1989).

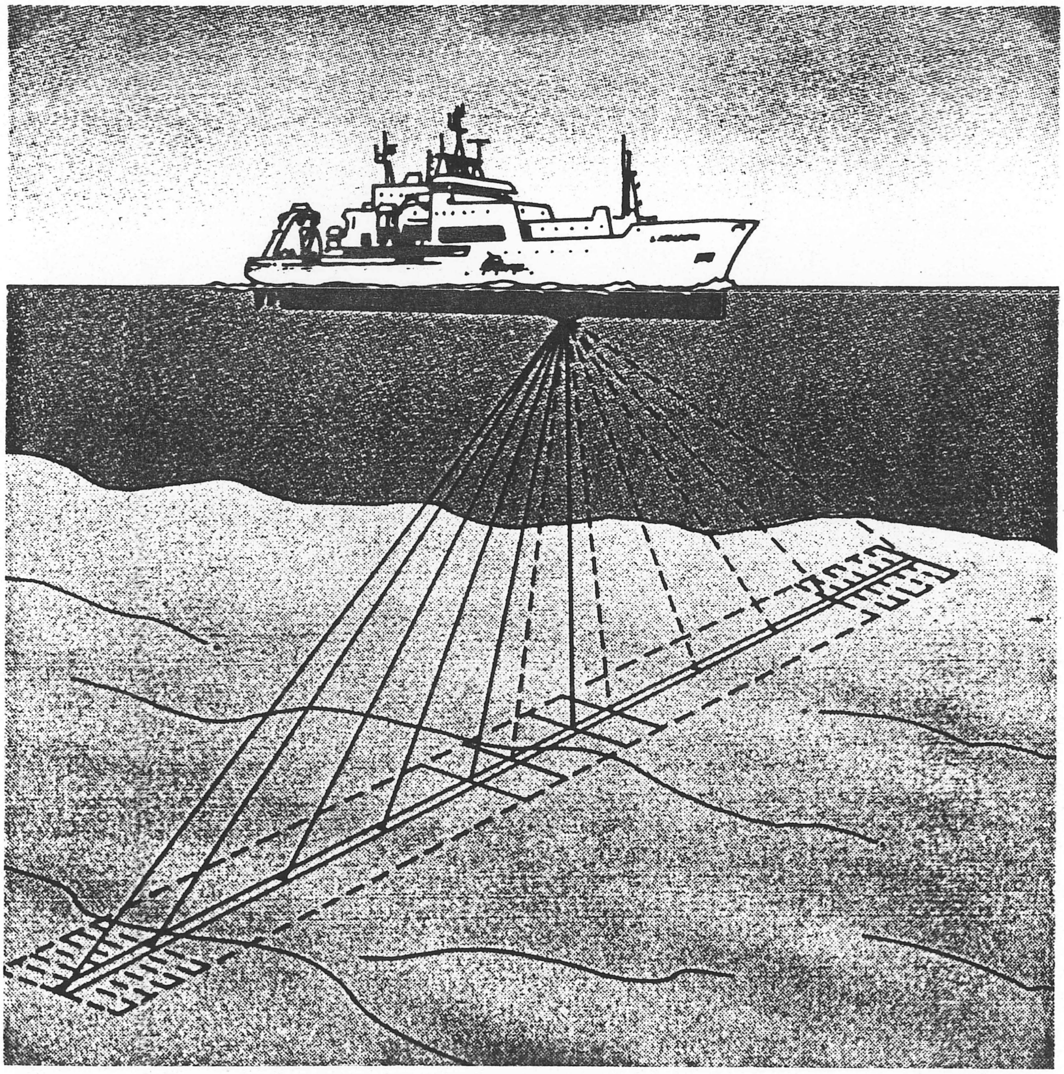


FIGURE 3. N/O *L'Atalante* and the sonar beam configuration of the SIMRAD Dual EM12 swath-mapping system.

(a)

Angular Sector	Maximum Coverage	Depth Range	Horizontal Spacing
150°	7.4 x Depth	50-3000 m	0.047 x Depth
140°	5.5 x Depth	2500-4200 m	0.035 x Depth
128°	4.1 x Depth	3500-6000 m	0.026 x Depth
114°	2.9 x Depth	5000-8000 m	0.019 x Depth
98°	2.3 x Depth	7000-10000 m	0.015 x Depth

(b)

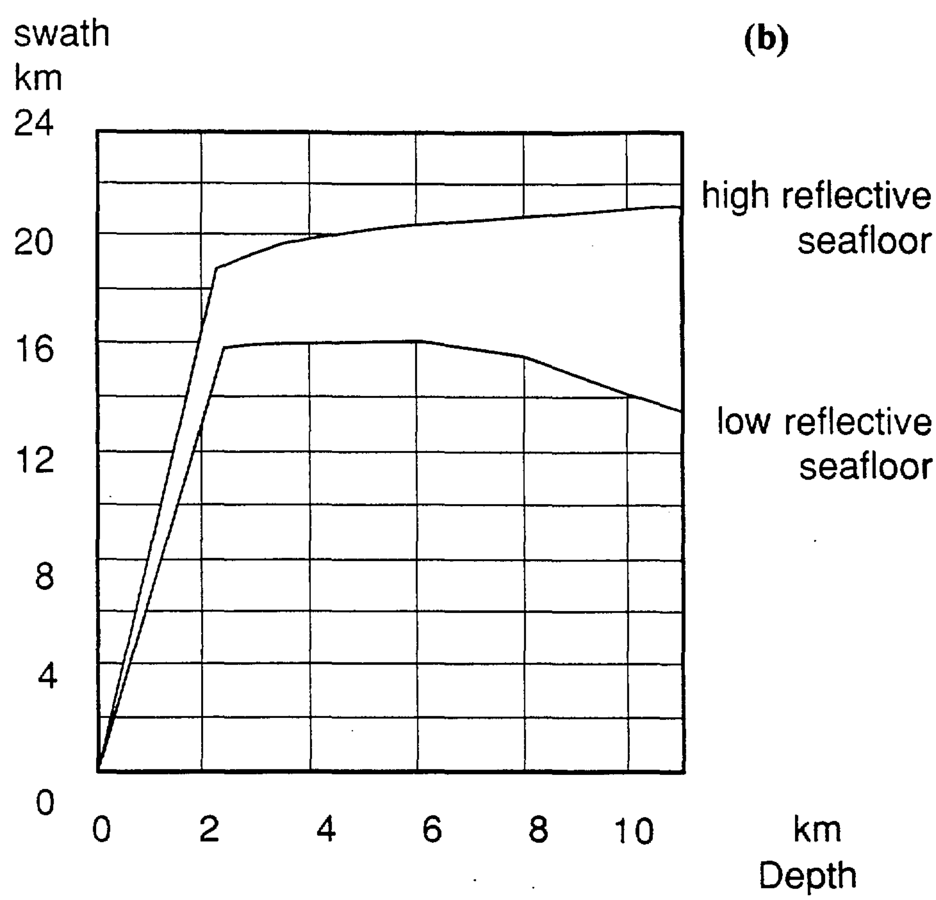


FIGURE 4. EM12D characteristics, (a) deep mode performance for the 5 coverage sectors, and (b) swath coverage versus water depth.

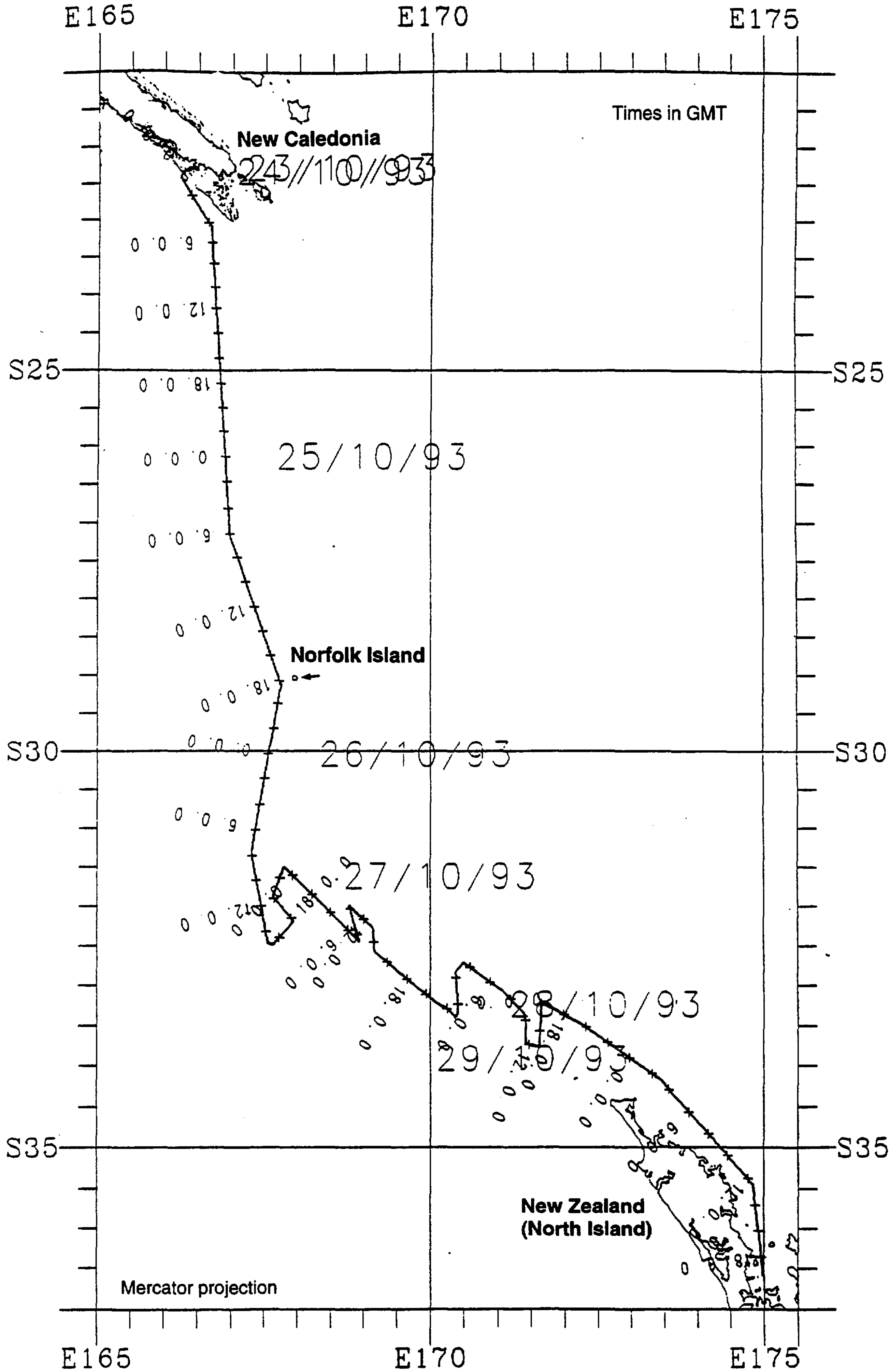


FIGURE 5. *L'Atalante* time-annotated track map, TRANSNOR survey of the Norfolk Ridge and Vening-Meinesz Fracture Zone.

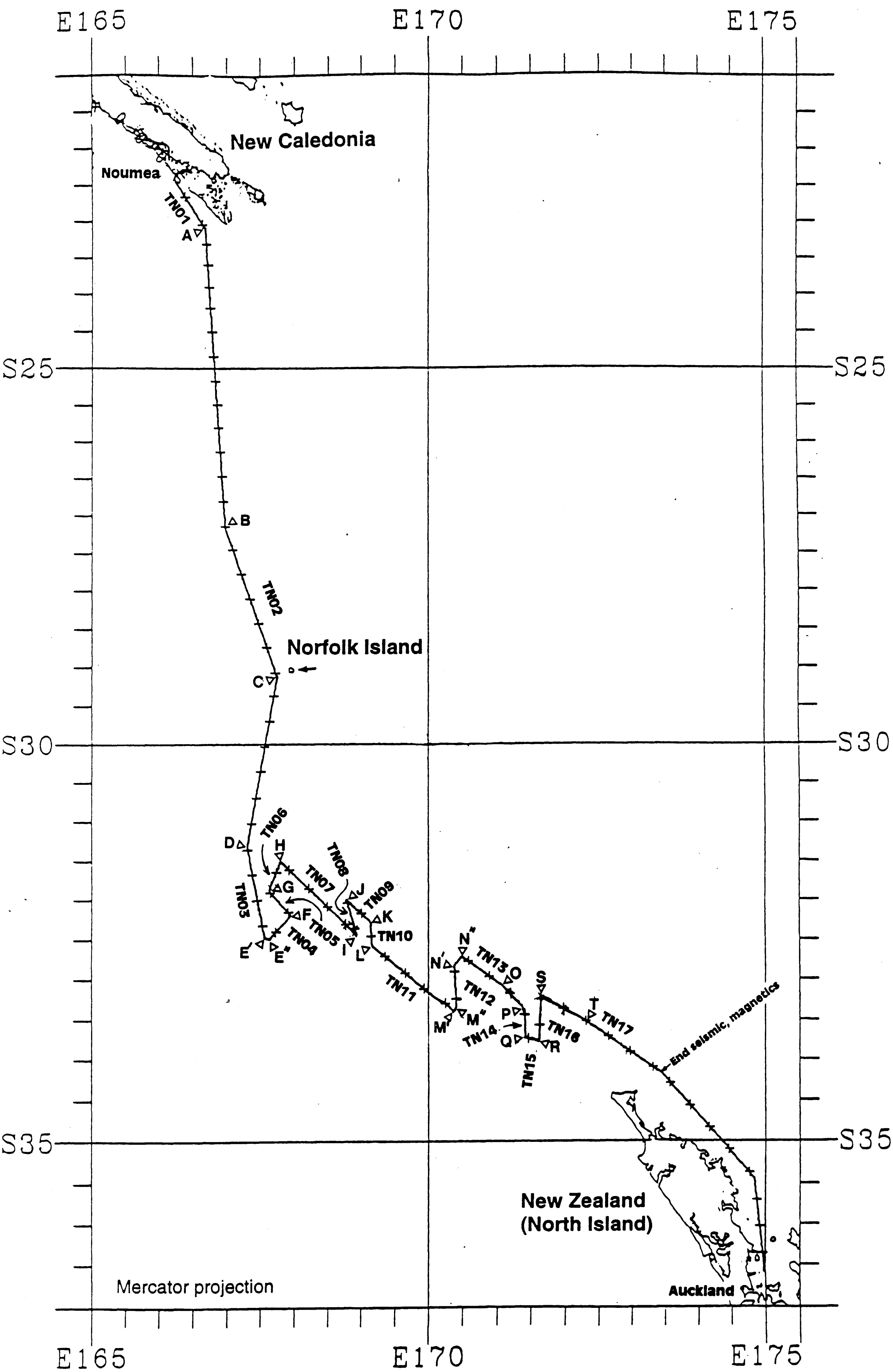


FIGURE 6. Survey lines (TN01-17) and way-point (A-T) location map, TRANSNOR cruise.

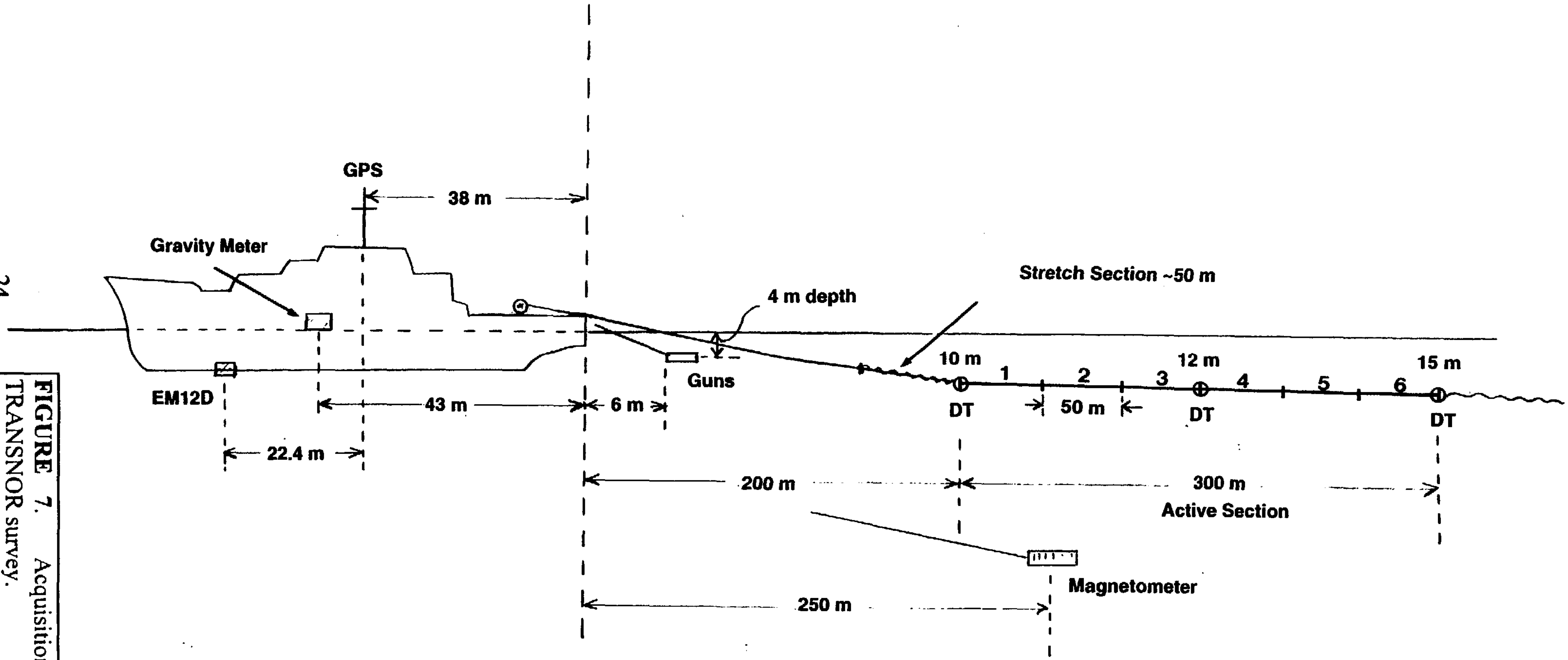


FIGURE 7. Acquisition geometry, *L'Atalante* TRANSNOR survey.

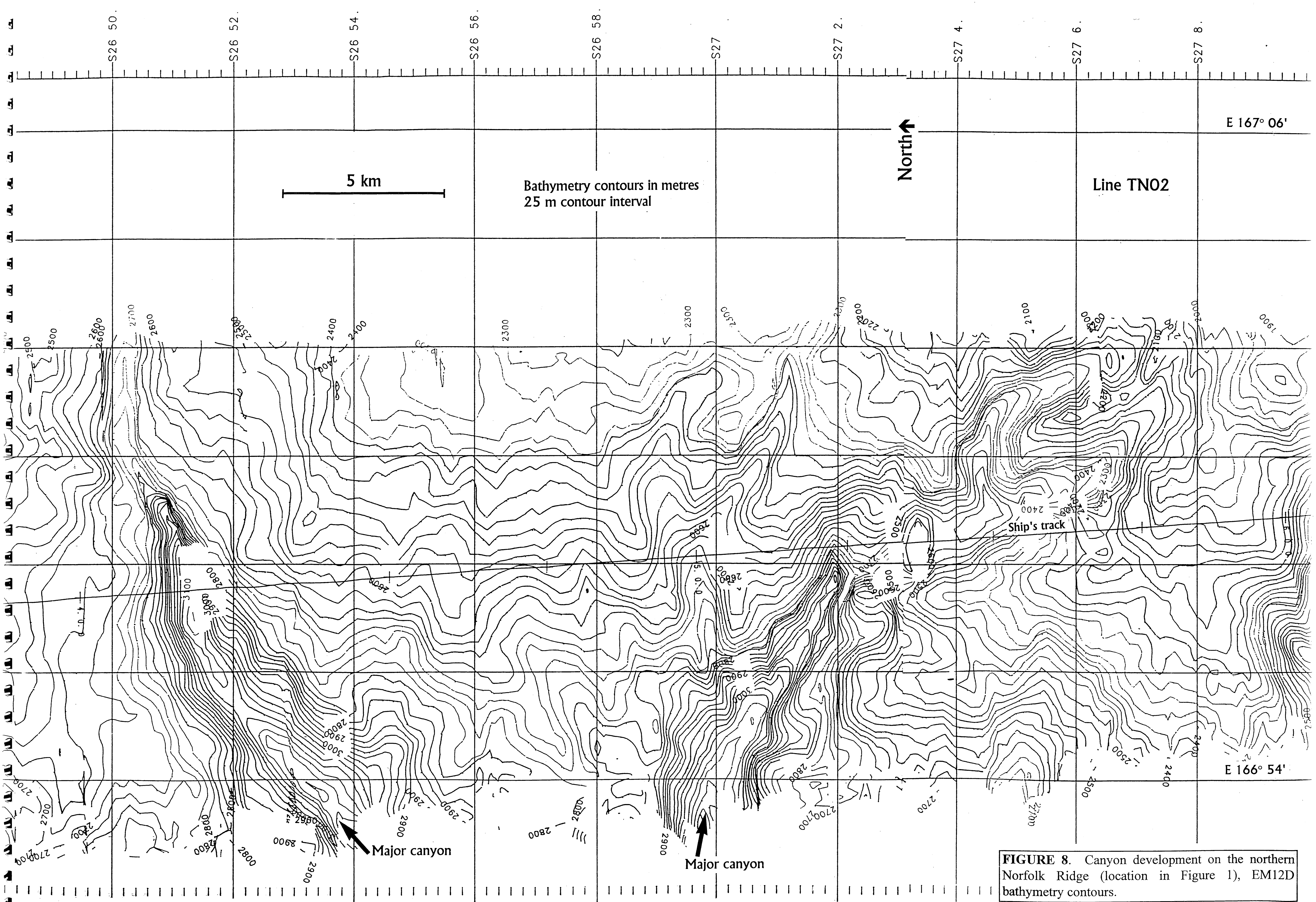


FIGURE 8. Canyon development on the northern Norfolk Ridge (location in Figure 1), EM12D bathymetry contours.

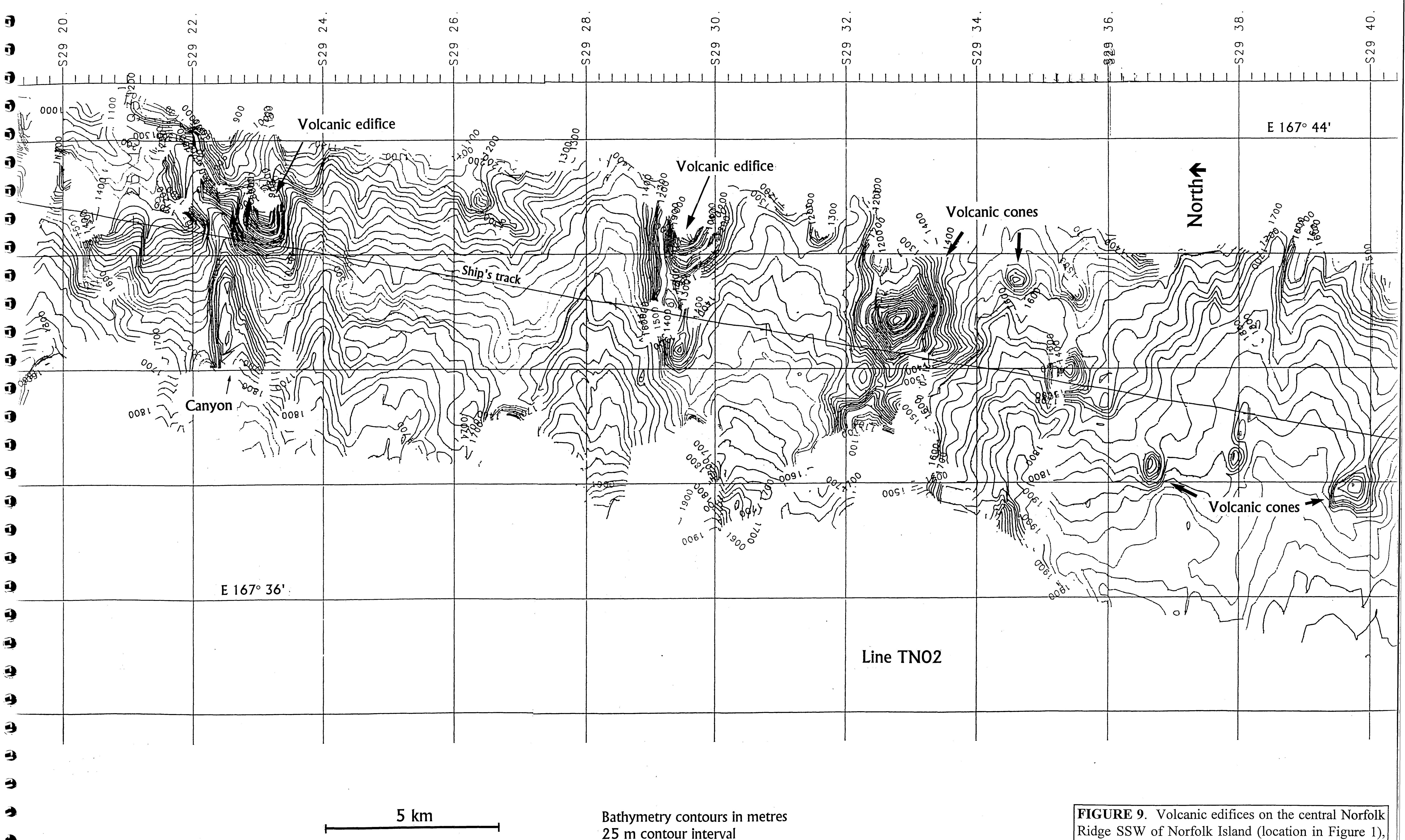


FIGURE 9. Volcanic edifices on the central Norfolk Ridge SSW of Norfolk Island (location in Figure 1), EM12D bathymetry contours.

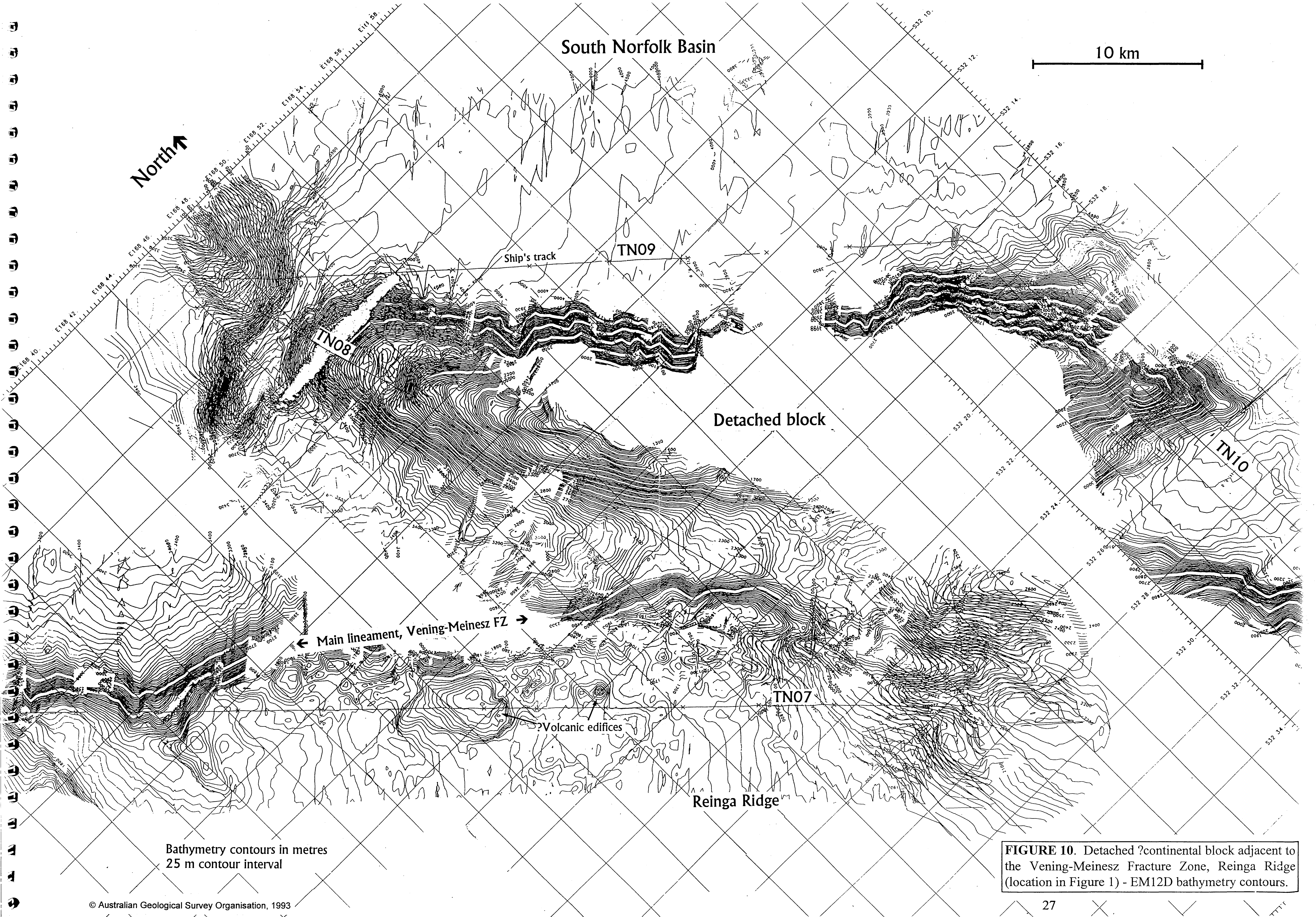


FIGURE 10. Detached ?continental block adjacent to the Vening-Meinesz Fracture Zone, Reinga Ridge (location in Figure 1) - EM12D bathymetry contours.

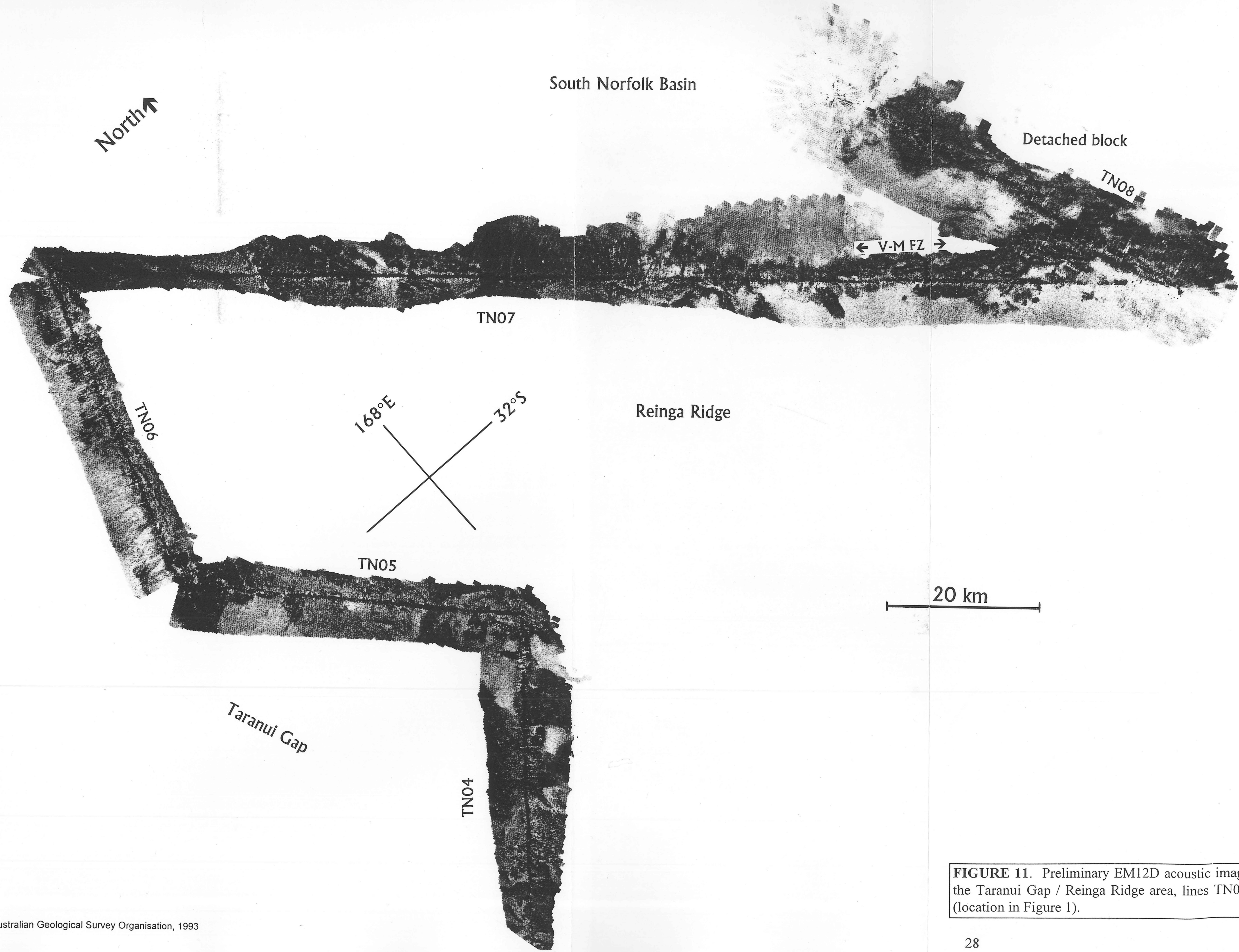


FIGURE 11. Preliminary EM12D acoustic image of the Taranui Gap / Reinga Ridge area, lines TN04-08 (location in Figure 1).

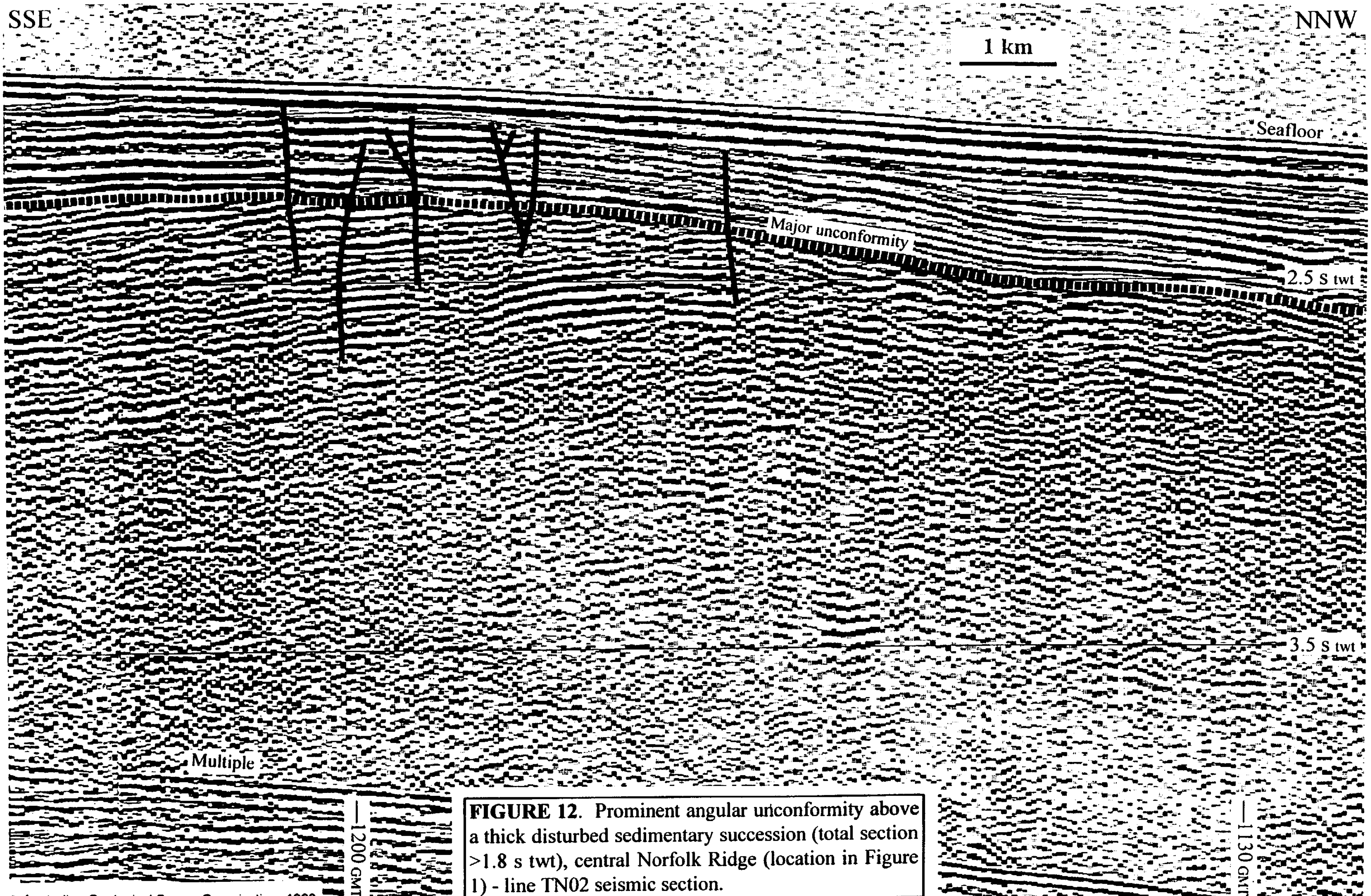


FIGURE 12. Prominent angular unconformity above a thick disturbed sedimentary succession (total section >1.8 s twt), central Norfolk Ridge (location in Figure 1) - line TN02 seismic section.

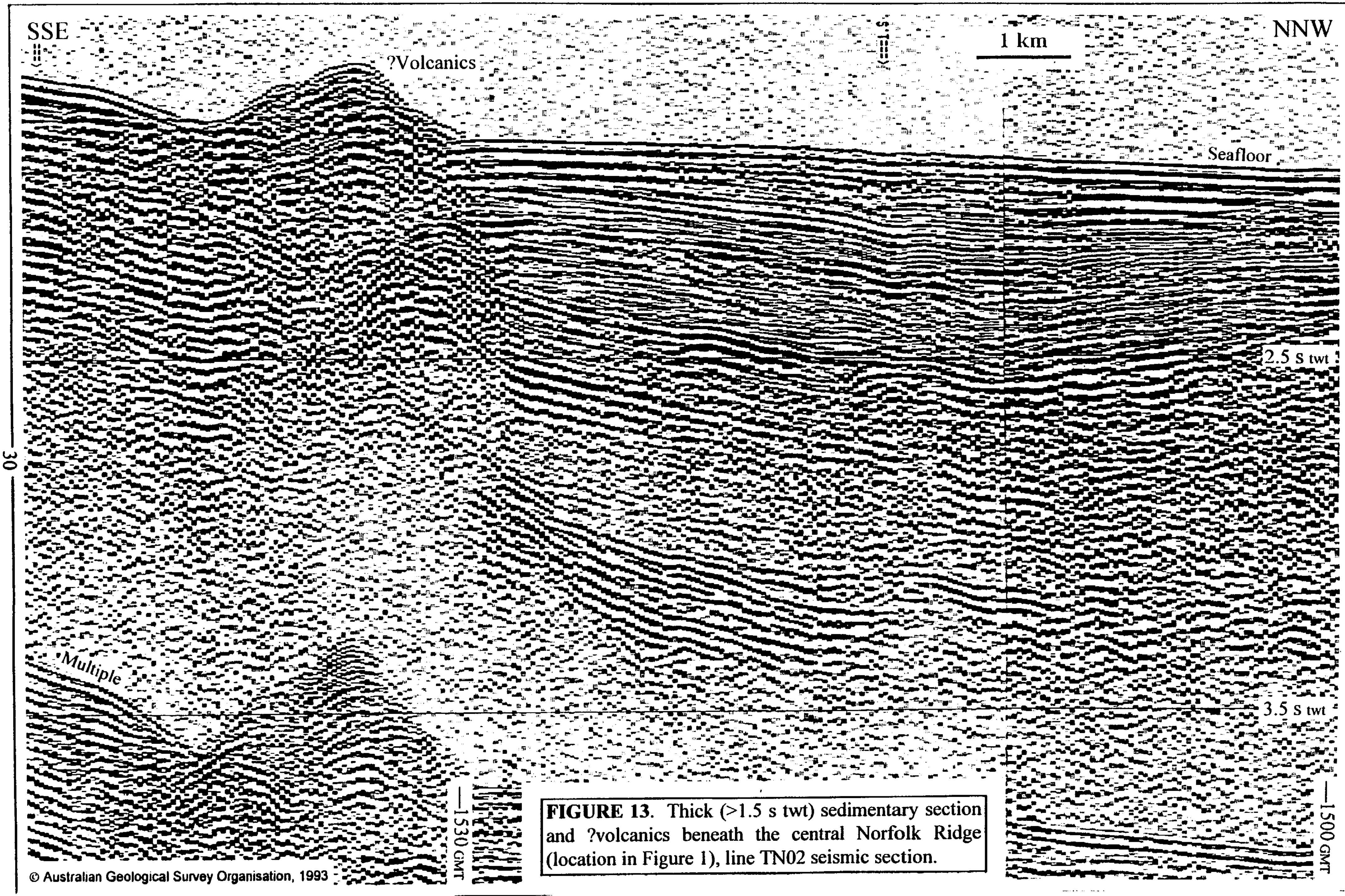


FIGURE 13. Thick (>1.5 s twt) sedimentary section and ?volcanics beneath the central Norfolk Ridge (location in Figure 1), line TN02 seismic section.

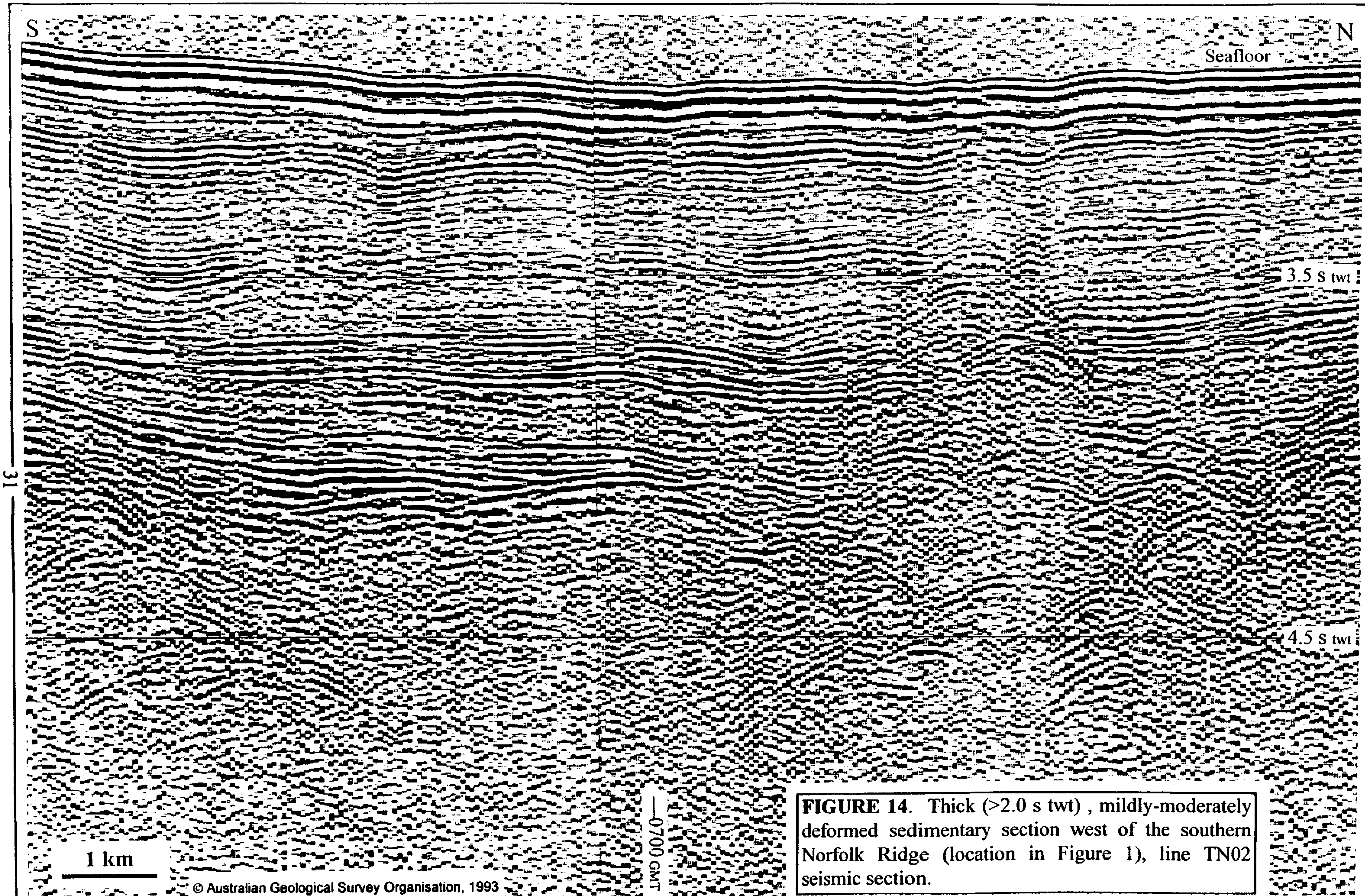


FIGURE 14. Thick (>2.0 s twt) , mildly-moderately deformed sedimentary section west of the southern Norfolk Ridge (location in Figure 1), line TN02 seismic section.

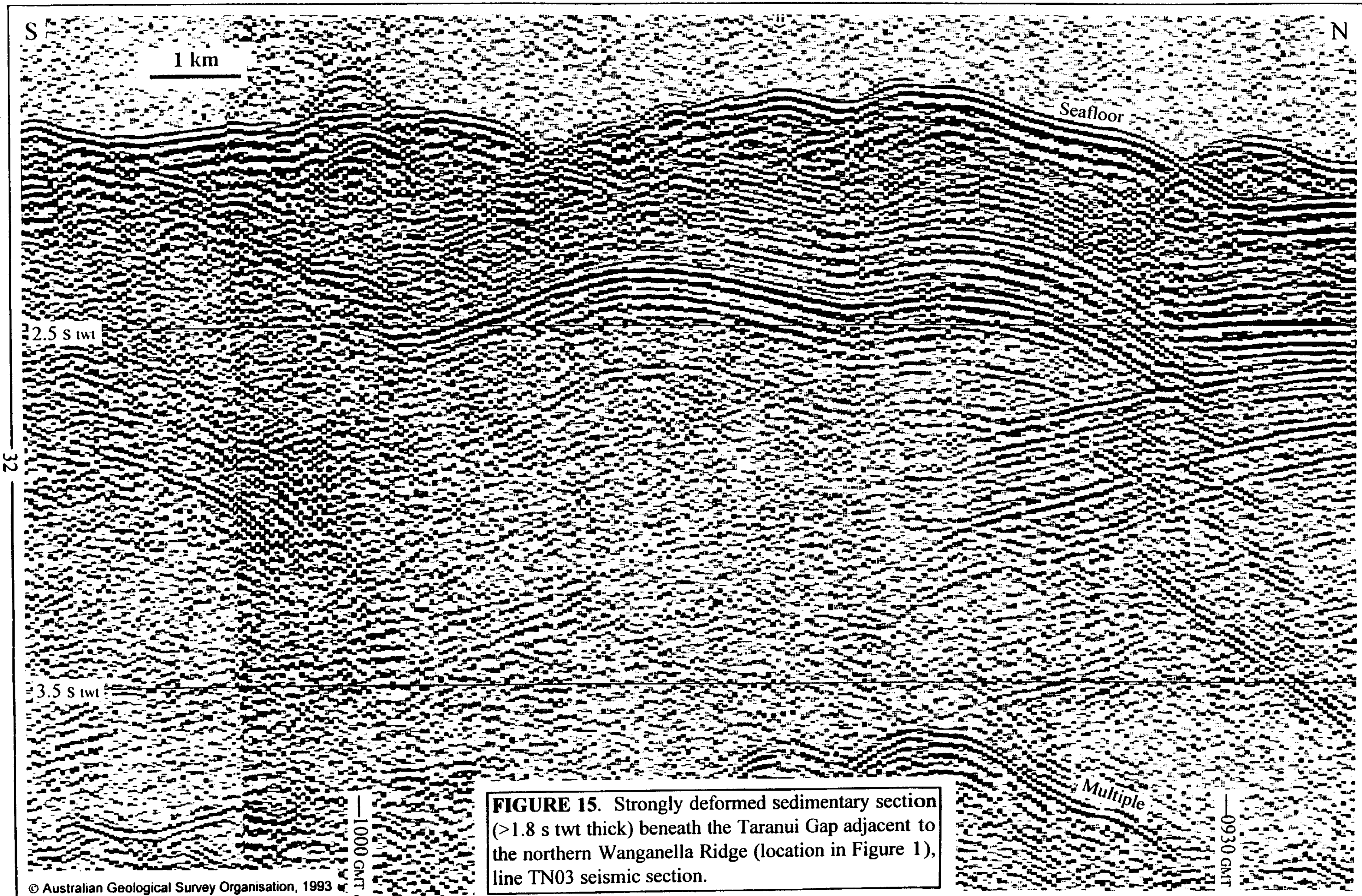


FIGURE 15. Strongly deformed sedimentary section (>1.8 s twt thick) beneath the Taranui Gap adjacent to the northern Wanganella Ridge (location in Figure 1), line TN03 seismic section.

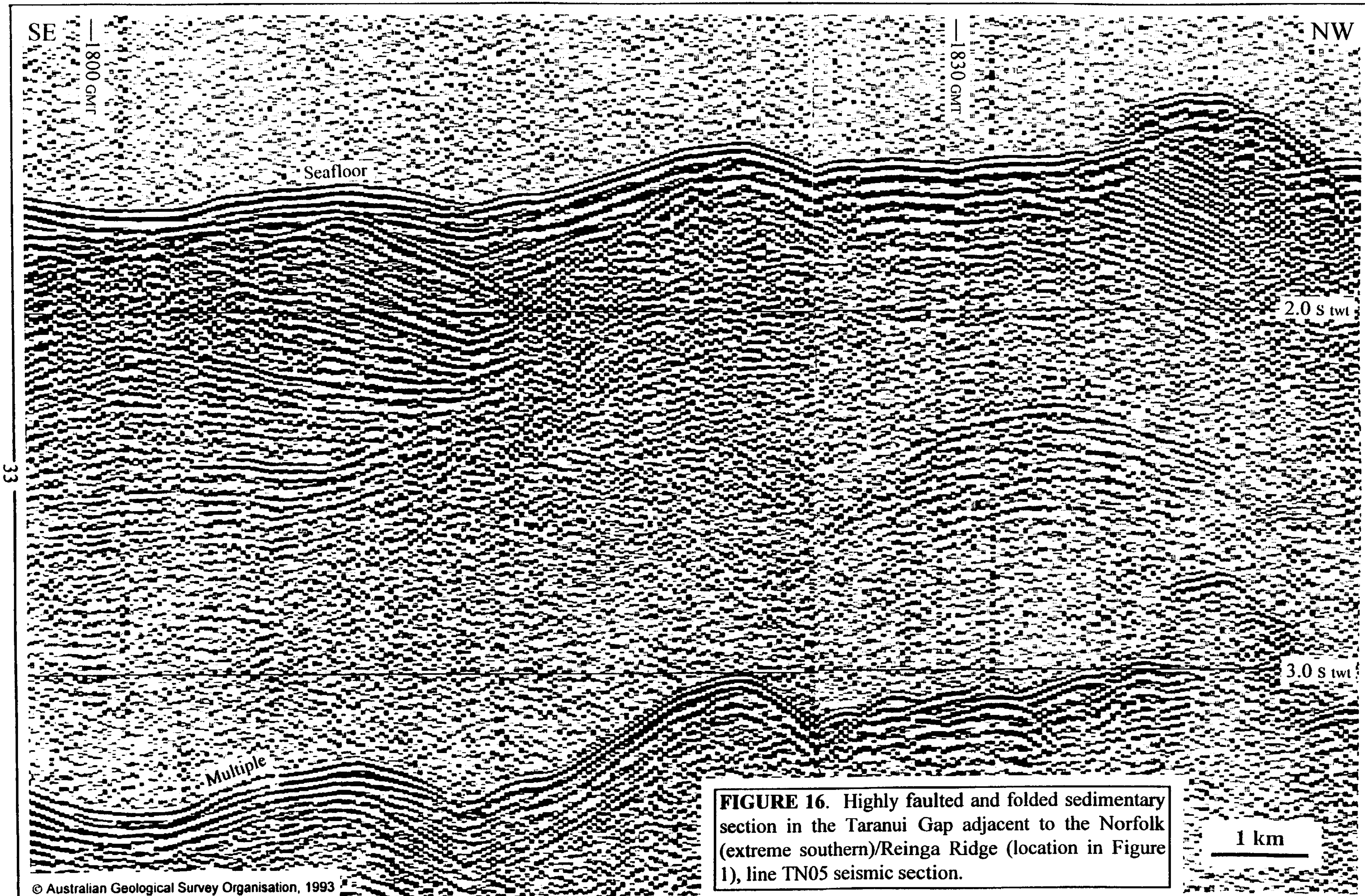


FIGURE 16. Highly faulted and folded sedimentary section in the Taranui Gap adjacent to the Norfolk (extreme southern)/Reinga Ridge (location in Figure 1), line TN05 seismic section.

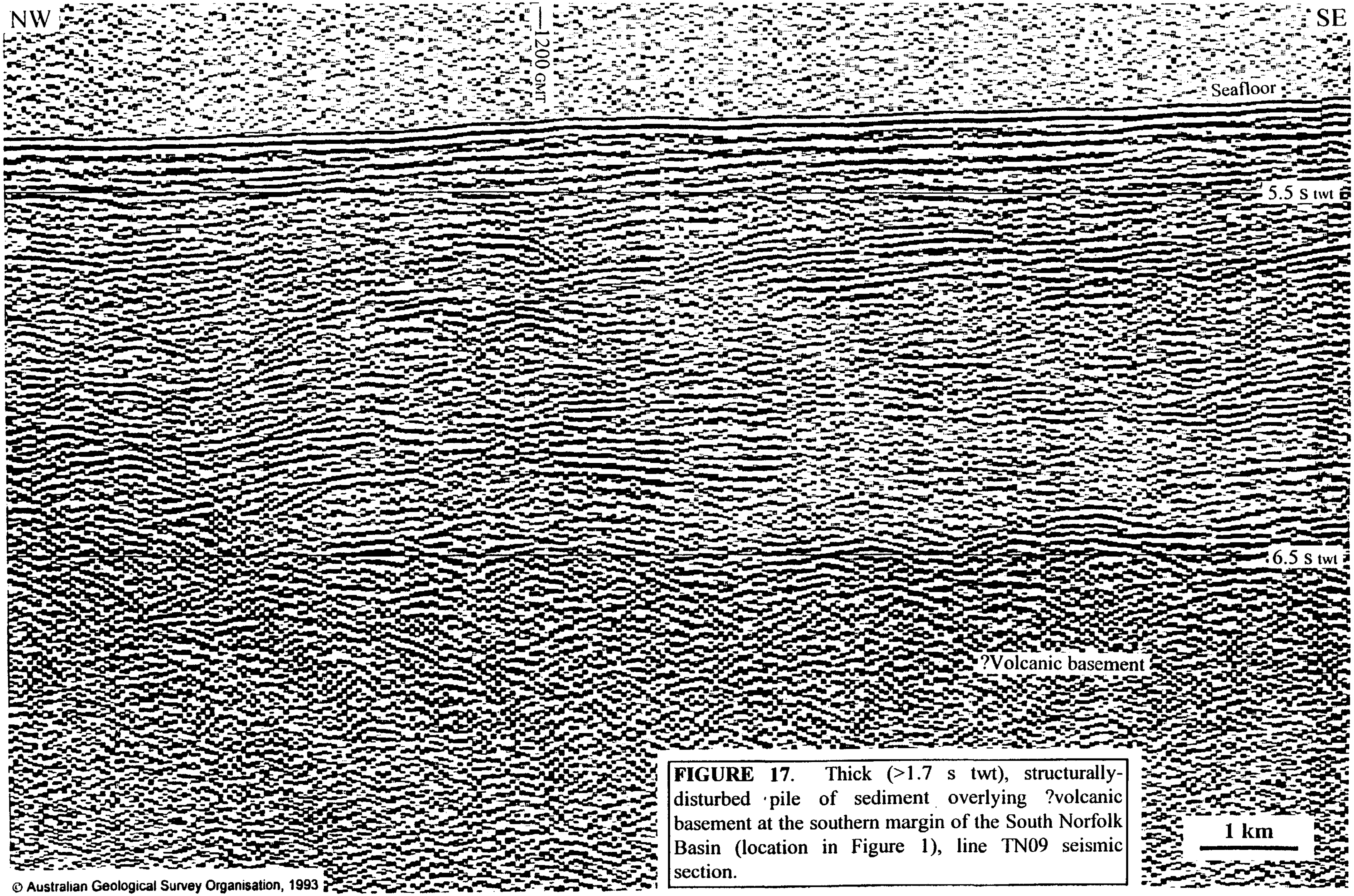


FIGURE 17. Thick (>1.7 s twt), structurally-disturbed pile of sediment overlying ?volcanic basement at the southern margin of the South Norfolk Basin (location in Figure 1), line TN09 seismic section.

APPENDIX 1
Shipboard Personnel

Scientists

Jean Mascle	Cruise leader and Directeur, Laboratoire de Géodynamique Sous-marine, Villefranche-sur-Mer, France
Richard Herzer	Senior Geoscientist, Institute of Geological and Nuclear Sciences (IGNS), Wellington, New Zealand
Peter Hill	Research Scientist, Australian Geological Survey Organisation (AGSO), Canberra
Christophe Basile	Associate Professor, University of Grenoble, France

Captain
Jean Claude Gourmelon

In addition, the shipboard personnel comprised 34 officers and crew, including engineers and technicians of GENAVIR (the company that operates the ship).

APPENDIX 2
Information on *L'Atalante*

Length overall	84.60 m
Beam overall	15.85 m
Draught (zero trim)	5.05 m
Gross tonnage	2355 tons
Net tonnage	435 tons
Cruising speed	13 knots
Maximum speed	14.5 knots
Endurance at 12 knots	60 days
Port of registry	Brest, France

Propulsion:

Diesel-electric, twin screw

- 3 diesel alternators, each 1570 kVA
- 2 main electric engines DC, each 1000 kW
- 1 directional retractable bow thruster, 370 kW DC

Deck Equipment:

22 ton rotating stern A-frame

12 ton deep-sea winch (2 x 8000 m storage capacity)

Accommodation:

Total complement of 59 in single/double berth cabins

Officers and crew, 17-30

Scientists and technicians, 25-29

Operating company:

GENAVIR

APPENDIX 3
SIMRAD EM12D Multibeam Echo-sounder, Technical Details and Characteristics

The EM12D consists of two EM12 13 kHz multibeam echo-sounders (one on each side of the ship), each generating 81 stabilized beams. The transducer arrays of each individual system are mounted in a cross-shaped configuration with one array for transmission (longitudinal relative to the ship) and one array for reception (transverse). The two sets of arrays are tilted 40° to each side from the horizontal. There are 11 common central beams, thus 151 points on the seafloor across-track are sampled with each ping.

The beam spacing of the EM12D, rather than being equiangular, is equidistant in horizontal spacing thus providing regular sampling of the seafloor. Unless manually overridden, the EM12D automatically selects the coverage sector (Figure 3) according to depth, bottom conditions, and the number of beams with valid bottom detections. In deep mode, the 150° sector is usually operative in water depths to several kilometres. The swath width is 7.4 times water depth (in shallow to moderately deep water); typical cross-track coverage from about 2500 m depth to full ocean depth is about 20 km (Figure 3).

The transmission sector is stabilized both for roll (±15°) and pitch (±10°). The reception beams are roll stabilized and the sampling interval in each beam is 240 cm in range (deep mode). The transmission beam-width is 1.8° and the reception beam-width is 3.5°.

Acoustic frequencies: 12.66/13.00/13.33 kHz
Transmission transducer dimensions: 4.8 m long, 555 mm wide, 262 mm deep
Reception transducer dimensions: 2.4 m long, 555 mm wide, 262 mm deep
Pulse length: 5 x 10ms (deep water mode)
Typical ping rate (deep water): 15 seconds
Relative precision on beams: ~0.2 %
Seabed image resolution (deep mode): ~7 m cross-track, 60-200 m in track direction

<u>Operatonal considerations</u>

Cross-track coverage determines the survey line spacing. Coverage is a function of seafloor topography, reflectivity (bottom backscattering strength) and weather conditions. Usually 10% overlap between lines is adequate, but if large variations in reflectivity and/or topography are expected it may be necessary to increase the overlap.

In areas of steep seabed, lines should be run along slope and not up or down the slopes. This is because coverage is then kept reasonably constant (making survey planning easier and lines more efficient). In addition, echo-sounder performance is better when running along slope since relatively more acoustic energy is reflected back to the transducers, reducing bottom detection loss or the possibility of false detections in sidelobes.

Rough seas and possibly ship speed may increase noise levels. Cavitation or aeration at the transducers will further degrade the data and could cause detection loss. Cavitation/aeration problems are greatest with the ship heading at a small angle into oncoming seas; the problem is reduced with the ship heading directly into the seas. The EM12D performs well in following seas. Performance is generally satisfactory with seas abeam, though excessive roll of the ship could be a problem since electonic roll compensation is effective only to ±15°. The vessel is susceptible to excessive roll because of its relatively large superstructure which presents a large area to winds blowing across the vessel.

A hull-mounted sound velocity sensor provides near-surface data to control beam direction. In addition, temperature profiles are measured daily (or more frequently if required) to a depth of about 2000 m using expendable probes with the SIPPICAN profiler (0.2°C accuracy). Standard salinity tables are used to convert the temperature data to sound velocity data.

APPENDIX 4
Line Designations and Approximate Lengths

LINE	START / END (way-points)	APPROX. LENGTH (nm)
TN01	Off Noumea ⇒ A	48
TN02	A ⇒ B ⇒ C ⇒ D	501
TN03	D ⇒ E'	70
TN04	E" ⇒ F	24
TN05	F ⇒ G	24
TN06	G ⇒ H	24
TN07	H ⇒ I	80
TN08	I ⇒ J	27
TN09	J ⇒ K	24
TN10	K ⇒ L	18
TN11	L ⇒ M'	79
TN12	M' ⇒ M" ⇒ N' ⇒ N"	44
TN13	N" ⇒ O ⇒ P	60
TN14	P ⇒ Q	21
TN15	Q ⇒ R	10
TN16	R ⇒ S	33
TN17	S ⇒ T ⇒ towards Auckland	100+

APPENDIX 5
Survey Way-points

WAY-POINT	LATITUDE (S)	LONGITUDE (E)
Off reef, Noumea	22° 24.4'	166° 13.0'
A	23° 05.0'	166° 41.0'
B	27° 10.0'	166° 59.0'
C	29° 08.0'	167° 45.0'
D	31° 19.2'	167° 18.6'
E'	32° 27.9'	167° 33.6'
E"	32° 29.3'	167° 38.3'
F	32° 11.4'	167° 57.0'
G	31° 52.8'	167° 37.8'
H	31° 30.0'	167° 48.0'
I	32° 26.4'	168° 55.8'
J	32° 00.0'	168° 46.8'
K	32° 16.2'	169° 08.4'
L	32° 34.8'	169° 09.6'
M'	33° 24.0'	170° 22.8'
M"	33° 19.8'	170° 25.2'
N'	32° 49.2'	170° 22.8'
N"	32° 42.6'	170° 29.4'
O	33° 04.8'	171° 04.8'
P	33° 21.6'	171° 24.0'
Q	33° 43.2'	171° 24.0'
R	33° 46.2'	171° 37.2'
S	33° 13.2'	171° 39.0'
T	33° 30.0'	172° 16.8'

APPENDIX 6
Scientific and Navigation Equipment

Swath-mapping

SIMRAD Dual EM12 multibeam bathymetric / acoustic imagery system

Geophysical

6-channel seismic reflection system, digital acquisition (Aquisition Sismique Rapide, Version AMUL_D_02)

Digi-Data 9-track tape drive

DOWTY Model 3710 thermal linescan recorder (fast monitor, channel 1)

DOWTY Thermaline Hard Copy Recorder Series 195 (slow monitor, channel 3)

AMG 37-43 streamer (6 active sections, each 50 m long containing 48 hydrophones and 1¾ inch in diameter)

2 GI 90 airguns, each 2 x 45 cu. inch (i.e. total capacity 180 cu. inch)

Raytheon 3.5 kHz echo-sounder / high resolution sediment profiler, 2 kW power (typical penetration ~50 m)

BODENSEEWERK KSS30 gravity meter (accuracy ~1 mGal)

BARRINGER M244 magnetometer (~1 nT accuracy)

Navigation

GPS SERCEL NR103 receiver - primary navigator (operated in non-differential mode, giving position accuracy of ~100 m).

Standby receivers: Transit MAGNAVOX MX 1107 and Loran-C MLR LRX22P

Vessel heading: 2 BROWN SGB 1000 gyrocompasses

Relative fore-and-aft & athwarship speeds: THOMPSON SINTRA Doppler log & electromagnetic ALMA log

APPENDIX 7
Geophysical Acquisition Parameters

Seismic
Streamer length (active) 300 m [6 groups, each 50 m]
Offset, stern to front of group 1 = 200 m
Depth of streamer: ~10 m at front, ~12 m in middle, ~15 m at rear
Gun depths 4 m
Gun offset from stern 6 m
Operating air pressure to guns 160 b (2300 psi)
Shot rate 10 seconds
Record length 5 seconds
Sampling interval 2 ms
25-125 Hz passband
Ship's speed during acquisition: 10 knots nominal

Magnetics
Magnetometer sensor towed 250 m astern

APPENDIX 8
File Structures, (a) Navigation and (b) Non-seismic (including gravity and magnetics) Data

(a) Navigation

FORMAT D'UN ENREGISTREMENT : $CASTM, date, TYPNA, POINT, PARAM, [CR][LF]

CARACTERISTIQUES : Taille :
NACOU --> 112 octets
NAGP1 --> 68 octets
NAGP2 --> 68 octets
NALO1 --> 68 octets
NAEXT -->72 octets

Récurrence des enregistrements :
NACOU --> 10 secondes
NAGP1 --> 10 secondes
NAGP2 --> 10 secondes
NALO1 --> 20 secondes
NAEXT --> 10 secondes

DESCRIPTION :

EN-TETE				
Début de message		$	ASCII	1 octet
Type du talker (Centrale cinnA)		CA	ASCII	2 octets
Type de la donnée (STockage)		STM,	ASCII	4 octets
DATE	Date du message			
Date		JJ/MM/AA,	ASCII	9 octets
Heure		HH:MM:SS.DDD,	ASCII	13 octets
TYPNA	Type de navigation			
	NAvigation COUrante intégrée	NACOU,		
	NAvigation GPs 1	NAGP1,		
	NAvigation GPs 2	NAGP2,		
	NAvigation LOran-c 1	NALO1,		
	NAvigation EXTerne	NAEXT,	ASCII	6 octets
POINT	Position courante (latitude / longitude)			
Latitude		s,dd,mm.mmmmm,	ASCII	14 octets
Longitude		s,ddd,mm.mmmmm,	ASCII	15 octets
PARAM	Paramètres spécifiques au type de message			
NACOU :				
Loch doppler longitudinal	(noeuds)	+nnn.nn,	ASCII	8 octets
Loch doppler transversal	(noeuds)	+nnn.nn,	ASCII	8 octets
Loch électro. longitudinal	(noeuds)	+nnn.nn,	ASCII	8 octets
Loch électro. transversal	(noeuds)	+nnn.nn,	ASCII	8 octets
Cap scientifique	(deg)	ccc.cc,	ASCII	7 octets
Cap passerelle	(deg)	ccc.cc	ASCII	6 octets
NAGP1, NAGP2, NALO1 :				
Réservé		espace	ASCII	1 octet
NAEXT :				
Type de navigation		XXX,	ASCII	4 octets
Réservé		espace	ASCII	1 octet
FIN	Fin du message	[CR] [LF]	ASCII	3 octets

(b) Non-seismic

$ PAMES, date, GRA, MAG, CVE, TQP, THE, MET [CR] [LF]

CARACTERISTIQUES :

Nom : PAMES
Taille : 356 octets
Fréquence : 2 à 60 secondes
Protocole : UDP - Broadcast
NÅ de port : 6001
Station d'émission : TERMESV

DESCRIPTION :

EN-TETE					
Début de message		$		ASCII	1 octet
Type du talker (station L'ATALANTE)		PA		ASCII	2 octets
Type de la donnée (données scientifiques TERMES)		MES,		ASCII	4 octets
DATE	Date du message				
Date		JJ/MM/AA,		ASCII	9 octets
Heure		HH:MM:SS.D,		ASCII	11 octets
GRA	Gravimétrie	VTGRA,		ASCII	6 octets
Date		JJ/MM/AA,		ASCII	9 octets
Heure		HH:MM:SS.D,		ASCII	11 octets
Etat	(0 = bon) (-1 = défaut appareil) (-2 = défaut communication) (-3 = défaut centrale horaire)	±X,		ASCII	3 octets
Gravité		±XXXXX.XX,	mgal	ASCII	10 octets
Acx		±X.XXXX,	m/s2	ASCII	8 octets
Acy		XX.XXXX,	m/s2	ASCII	8 octets
Eotvos		±XXXX.X,	mgal	ASCII	8 octets
Anomalie à l'air libre		±XXXX.X,	mgal	ASCII	8 octets
Bouguer		XXXX.X,	mgal	ASCII	7 octets
MAG	Magnétisme	VTMAG,		ASCII	6 octets
Date		JJ/MM/AA,		ASCII	9 octets
Heure		HH:MM:SS.D,		ASCII	11 octets
Etat	(voir gravimétrie)	±X,		ASCII	3 octets
Magnétisme		XXXXXX,	1/10 Gamma	ASCII	7 octets
CVE	Centrale de vent	VTCVE,		ASCII	6 octets
Date		JJ/MM/AA,		ASCII	9 octets
Heure		HH:MM:SS.D,		ASCII	11 octets
Etat	(voir gravimétrie)	±X,		ASCII	3 octets
Amplitude		XX.XXX,	m/s	ASCII	7 octets
Direction		XXX.XX,	degrés	ASCII	7 octets
TQP	Thermomètre à quart	VTTQP,		ASCII	6 octets
Date		JJ/MM/AA,		ASCII	9 octets
Heure		HH:MM:SS.D,		ASCII	11 octets
Etat	(voir gravimétrie)	±X,		ASCII	3 octets
Température		±XX.XX,	degrés C	ASCII	7 octets
THE	Thermosalinomètre	VTTHE,		ASCII	6 octets
Date		JJ/MM/AA,		ASCII	9 octets
Heure		HH:MM:SS.D,		ASCII	11 octets
Etat	(voir gravimétrie)	±X,		ASCII	3 octets
Pression		XXXX.X,	dbar	ASCII	7 octets
Conductivité		XX.XXX,	ms/cm	ASCII	7 octets
Température		±XX.XXX,	degrés C	ASCII	8 octets
Salinité		XX.XXX,	ppt	ASCII	7 octets
Masse volumique		XX.XXX,	kg/m^3	ASCII	7 octets
Vitesse du son		XXXX.X,	m/s	ASCII	7 octets
MET	Centrale Météo	VTMET,		ASCII	6 octets
Date		JJ/MM/AA,		ASCII	9 octets
Heure		HH:MM:SS.D,		ASCII	11 octets
Etat	(voir gravimétrie)	±X,		ASCII	3 octets
Température de l'air		±XX.XX,	degrés C	ASCII	7 octets
Humidité relative		XX.XX,	%	ASCII	6 octets
Pression atmosphérique		XXXX.XX,	mbar	ASCII	8 octets
Radiation		XXXX.XX,	mw/m2	ASCII	8 octets
Pluviomètre		XXX,	mm	ASCII	4 octets
FIN	Fin du message	[CR] [LF]		ASCII	2 octets
	Soit au total				356 octets