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CONTINENTAL SHELF DEFINITION IN THE KERGUELEN PLATEAU REGION: LAW OF THE SEA CRUISE PROPOSAL

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EXECUTIVE SUMMARY

The United Nations Convention on the Law of the Sea requires nations to justify claims to Continental Shelf beyond the 200 nautical miles (nM) Exclusive Economic Zone (EEZ), according to formulae set out in Article 76 of that Convention. The southern part of the Kerguelen Plateau lying between the EEZs generated by Heard and McDonald Islands and by the Australian Antarctic Territory is one of the areas where Australia can make such a claim. The subject of this survey proposal is to justify and maximise the Australian claim in the Kerguelen Plateau region.

A program of seismic traverses has been designed which will cross the 2500 m contour (to define its location), the probable foot-of-slope, and areas beyond the foot-of-slope where there is potential for a significant thickness of sediment. These crossings will occur at a sufficient number of sites to allow:

(1) definition of the 100 nM cut-off beyond the 2500 m contour,
(2) definition of the Hedberg Line 60 nM beyond the foot-of-slope, and
(3) determination of the sediment thickness distribution.

The total length of seismic profiling proposed is 3670 km. This is based on the assumption that many traverses will extend beyond the foot-of-slope to around the 100 nM beyond the 2500 m isobath cut-off line, to test the sediment thickness criterion. However, some traverses may be shortened, if the sediment thickness proves to be less significant than expected. Two surveys, each of about 7 weeks duration, are planned for the seismic acquisition in this area. The first survey will focus on surveying the Elan Bank area, where the foot-of-slope is poorly defined, and acquiring a seismic transect line right across the plateau. The second survey will target the eastern side of the plateau including William's Ridge, with lines extending into the Labuan Basin where it is expected that a considerable thickness of sediment may occur, allowing extension of the Australian Continental Shelf claim beyond the Hedberg Line.

INTRODUCTION

The 1982 United Nations Convention on the Law of the Sea (UNCLOS) defines a nation's legal seabed and subsoil jurisdiction as extending throughout its Continental Shelf (Appendix 1). Where the continental margin of a nation extends beyond 200 nM, the outer limit of the 'legal' Continental Shelf is defined by a series of rules contained within Article 76 of UNCLOS. The rules require definition of the foot of the continental slope, knowledge of sediment thickness and good bathymetric information defining the 2500 m water depth contour. The Continental Shelf must be defined at least every 60 nM around the parts of the margin extending beyond 200 nM, and thus in these areas a comprehensive seismic and bathymetric database is essential to maximising Continental Shelf claims.

A preliminary analysis (Symonds & Willcox, 1989) of the extent of Australia's Continental Shelf undei UNCLOS indicated that it could be at least 14.8 million km^2 in area – nearly twice the size of the continent and one of the world's biggest. Eight areas of Continental Shelf, in total about 3.7 million km^2, extend beyond the 200 nM Australian Exclusive Economic Zone (AEEZ). AGSO has been given responsibility by Cabinet to ensure that Australia has the necessary technical information to fully define its Continental Shelf under UNCLOS. AGSO has decided to adopt a 'safe minimum' approach to Continental Shelf definition in which bathymetric and seismic data are acquired on profiles spaced about 30 nM apart over areas of margin extending beyond the AEEZ. Recent AGSO assessments have indicated that further data collection is needed in about six of the eight areas extending beyond the AEEZ. The necessary data collection will also contribute to an improved understanding of the geological framework and resource potential of these generally remote and poorly known areas.

The southern part of the Kerguelen Plateau is one of those areas. The remoteness and the large size of the plateau have resulted in a relatively poor data coverage over some parts of the plateau. The proposed surveys are planned to achieve about 60 nM spacing between lines across the plateau margin, and take into account the application of Article 76 and the actual shape of the margin. Given the often severe weather and ice conditions in the region, the more than 20 days transit to and from the area, and the long transits between lines, only two surveys will be possible in the 1997 summer season. This excludes the application of the 'safe minimum' approach to many parts of the plateau.

PHYSIOGRAPHY AND GEOLOGY

The Kerguelen Plateau (KP) is one of the world's largest oceanic plateaux, extending over 2000 km in a northwest - southeast direction. It is bordered by the Enderby Basin in the west, the Crozet Basin in the northwest and the Australian-Antarctic and Labuan Basins in the northeast (Fig. 1). To the south it is separated from Antarctica by the Princess Elizabeth Trough. The plateau is between 200 and 600 km wide and has a complex shape with two prominent ridges, Elan Bank and William's Ridge, branching off the main body of the plateau in a westerly and southeasterly direction respectively (Fig. 2). The KP is thought to have been created by intense igneous activity in Late Cretaceous time at or near a spreading centre (Royer & Sandwell, 1989). Although most of the plateau formed at that time, the northern part of the plateau has more recent volcanic accumulations and still displays some active volcanism, such as Big Ben volcano which forms Heard Island.

Plate tectonic setting

The KP lies within the Antarctic Plate. The Southeast Indian Ridge (SEIR) which lies to the NE of the KP, separates the Antarctic Plate from the Indo-Australian Plate, and the Southwest Indian Ridge, which lies to the NW, separates it from the African Plate (Fig. 1). Both mid-ocean ridges join at the Rodriguez Triple Junction, which is located about 1200 km to the north of the Kerguelen Islands. The age of the oceanic crust surrounding the KP is variable, ranging from Early Cretaceous in the NW to Oligocene in the east (Fig. 1). The age of the Enderby Basin crust remains unknown.

The KP lies between two oceanic crustal provinces formed by different mid-ocean ridge (MOR) systems. To the northeast of the KP the seafloor was formed by spreading at the SEIR, which followed the breakup between Australia and Antarctica. To the west and south of the KP, in the Crozet and Enderby Basins, the seafloor was formed at the now extinct mid-ocean ridge, which existed in the Indian Ocean in Early-Late Cretaceous time.

The age of the oceanic crust along the eastern margin of the KP varies from about 100 Ma in the Labuan Basin (Rotstein et al., 1991), to 43 Ma (chron 18) in the vicinity of the William's Ridge and to about 32 Ma (chron 11) to the north of 48°S (Fig. 1). These variations reflect the breakup history of the KP. The southern KP and Labuan Basin are thought to have formed at about the same time in the Early Cretaceous (Rotstein et al., 1991), whereas the northern KP was joined to Broken Ridge at that time. Between 46 Ma and 43 Ma, the SEIR propagated westward and separated the southern KP from the Diamantina Zone. The breakup between the northern KP and Broken Ridge occurred between 43.8 and 42.9 Ma (Munschy et al., 1991).

In the Crozet Basin, to the northwest of the plateau, identified magnetic anomalies range from 23 to 34. Further south, in the Enderby Basin, no magnetic anomalies have been identified; however, it has been suggested that the age of the crust here is Mesozoic (Nogi et al., 1991). In most plate tectonic reconstructions it is assumed that the Enderby Basin was formed in Early Cretaceous time (Royer & Coffin, 1992).

Bathymetry and sediment distribution

The KP is a huge, northwest-southeast trending bathymetric high lying between 46° and 64°S. Relatively steep slopes separate the seafloor of the surrounding basins from the high-standing surface of the plateau. Most of the plateau lies 2000-4000 m above the adjacent deep ocean floor, with average depths in the northern part of the plateau ranging between 1000-1500 m, and between 2000-2500 m in the south (Fig. 2). The difference in morphology of the northern and southern parts of the plateau has been recognised for some time (Schlich, 1975; Coffin et al., 1986). The northern sector, usually referred to as the Kerguelen-Heard Plateau, includes two large active volcanic archipelagos (Kerguelen Islands and Heard-McDonald Islands) and a number of bathymetric highs that could represent recent volcanic features. The southern sector of the plateau lies at least 500 m deeper and is characterised by more subdued relief and the absence of young volcanic features. Much of it is covered by about 1000 m of sediment.

The Kerguelen-Heard Plateau and the southern KP are separated by a saddle with average depths ranging from 2500-3000 m. Unusual north-south-trending grabens (77° and 75°E grabens, Fig. 2) have been described in this central part of the plateau (Munschy et al., 1991; Rotstein et al., 1992; Munschy et al., 1993). There are no similar features in the northern part of the plateau, and rift structures of the southern KP are different in morphology and trend. The central part of the plateau, between Banzare Bank and the Kerguelen-Heard Plateau, is considered to be a separate morphological province.

The northeastern flank of the plateau is generally steep and sub-parallel to the SEIR axis, whereas its southwestern flank has a more gentle slope and more complex structure. Characteristic slope morphologies of the KP are shown in Figures 3-5. The morphology of the eastern flank of the plateau is illustrated by profiles H-H', I-I', K-K' and L-L' (Figs. 3, 4). On all these profiles slopes are very steep, particularly in their lower part (eg. profile I-I'). Differences in slope morphology on these profiles are caused by differences in basement structure of the adjoining abyssal plain and the distribution of the overlying sediment. To the north of William's Ridge (profile K-K'), the sea floor lies at about 3600 m water depth. In this area, a narrow zone adjacent to the plateau has a relatively rugged basement surface, which is reflected in the bathymetry. Further to the northeast the basement is characteristic of oceanic crust and the average sediment thickness is about 500 m. In the southern and central parts of the plateau (profiles H-H', I-I', L-L'), the slope faces east towards the Labuan Basin, where the seafloor lies at about 4500 m. Basement here is extremely rugged, with narrow ridges 2000-2500 m high separated by wide, generally sediment-filled troughs (Fig. 4, profile L-L'). Some basement ridges emerge above the level of the seafloor and can be seen on bathymetric profiles (profile I-I'). In other places the ridges are completely covered by sediment, forming a rise at the base of the slope (profiles H-H' and L-L'). In this area the sediment thickness reaches 2000-2500 m.

The most prominent feature of the northeastern margin of the KP is the William's Ridge. It stretches in a southeasterly direction between 53° and 55°S and separates younger oceanic crust of the Australian-Antarctic Basin to the northeast of the ridge from older oceanic crust of the Labuan Basin to the southwest (Fig. 1). The ridge shallows in places to 500 m water depth and is characterised by extremely high-amplitude scarps (up to 3000 m). A bathymetric profile across the William's Ridge is shown in Figure 3, profile J-J'. The ridge is flanked on either side by pronounced bathymetric lows, which are reflected in the gravity image. There is also a deep gravity low located along the central part of the ridge. One of the *Marion Dufresne* tracks (MD47, 1986) intersected this feature, and located a narrow 2500 m-deep trough. Both bathymetric and gravity data suggest that the William's Ridge is a continuation of a basement ridge associated with the northeastern flank of the plateau (profile K-K'; Figs. 3, 4). The William's Ridge is poorly surveyed; however, from the limited data available it seems that it is most likely an integral part of the KP.

The morphology of the southwestern flank of the plateau is dominated by a series of deep gulfs. The two largest gulfs separate the Elan Bank from the rest of the plateau, and another deep gulf is located between the shallow Banzare Bank and the southeastern part of the plateau. In this area, slope morphology alternates between relatively steep slopes on the protruding parts of the plateau, to broad, gentle slopes in the 'gulfs'. Typical slope morphologies are illustrated by profiles B-B', C-C', D-D' and E-E' (Fig. 5). Profile C-C' illustrates the complex morphology of the southwestern slope of Banzare Bank. The lower part of the slope displays a wide terrace lying at about 3600 m. The gravity image and single channel seismic (SCS) data (Fig. 9) suggest that the terrace is structurally part of the KP. Profiles B-B', D-D', and E-E' illustrate the steep slopes on the protruding parts of the plateau. These slopes are generally less steep than those on the northeastern flank of the plateau. The abyssal plain adjoining the southwestern flank is relatively flat, lying at about 4300 m to the south of Elan Bank and rising gently to 3600 m towards the Princess Elizabeth Trough. Data on sediment thickness are very sparse in this area. Two seismic sections over the western slope of the Banzare Bank from *Rig Seismic* cruise 47 (Figs. 6 and 7) demonstrate that the sediment thickness in this part of the Enderby Basin varies from about 500-1000 m. Seismic data acquired on *Eltanin* cruise 47, despite their poor resolution, indicate that sediment thickness increases to the south, reaching at least 1500 m in the Princess Elizabeth Trough.

The major bathymetric feature of the southwestern flank of the plateau is the Elan Bank (Fig. 2). It is 100 to 200 km wide and trends in an east-west direction for about 600 km. The shallowest depths occur in the central part of the bank and rise to about 1000 m below sea level. Elan Bank is bounded by relatively steep slopes to the north and south, but to the west it becomes wider and deeper, and it has more gentle slopes. The bank is poorly surveyed and its bathymetry and sediment thickness are known from only a few profiles. One of the *Eltanin* profiles crossing the northern slope of the bank is shown in Figure 5, profile A-A'. A bathymetry and SCS profile across Elan Bank, recorded on *Marion Dufresne* survey 67 (Fig. 8), reveals the asymmetric morphology of the bank with its southern margin descending to the abyssal plain at about 4700 m, and its northern margin merging with the abyssal plain at about 4000 m. The southern slope displays two distinct 20 km wide terraces at 4500 and 3000 m, whereas the northern slope has a simple form. Seismic data on this profile indicate that the bank is probably composed of layered basaltic complexes, similar to those of the main part of the KP, and that its southern flank is fractured by large faults (Schlich et al., 1991). Gravity data correlate with bathymetry showing a very deep gravity low to the south of the bank. Satellite gravity data also indicate the presence of a number of seamounts to the south of the Elan Bank. Although some of these are probably very large, most have not been mapped. On the latest bathymetry for the area, two of the seamounts have been incorrectly mapped (Figs. 2, 10) as north-south trending basement ridges joining with Elan Bank. Sediment thickness on the top of the Elan Bank is no more than 300 m; in the basin to the north of the bank it is about 1 km, and in the basin to the south it is about 900 m (Schlich, 1991).

The southernmost part of the KP is characterised by very complex morphology. There are several low NW-SE-trending ridges, with average heights ranging from 3000-3500 m below sea level, that are divided by broad depressions. This province gradually merges with the abyssal plain lying at about 3800 m. The bathymetry of this area is illustrated by profiles F-F' and G-G' in Figure 3, and the seismic section for profile G-G' is shown in Figure 9. On some profiles, it seems that highs in the lower part of the slope are natural continuations of the plateau, whereas on others, the highs could be part of the oceanic crust. Seismic data over this province (Fig. 9) indicate that the sediment thickness is highly variable with almost no sediment on the tops of the ridges, and up to 1000 m in the depressions. The widest part of the province lies at about 62°S, where it extends as far as 88°E.

Age of basement and crustal character

Despite pronounced morphological differences between the northern and southern parts of the KP, there is no evidence of any significant difference in the age of their basement rocks. The oldest sediments sampled on the eastern margin of the Kerguelen-Heard Plateau (Wicquart, 1983), and on the southeastern margin of the southern KP (Quilty, 1973; Houtz et al., 1977; Leclaire et al., 1987) are Upper Cretaceous (Cenomanian) chalk oozes and siliceous rocks. These are shallow-water pelagic or shelf deposits.

The sampling results are consistent with the ODP drilling results. Locations of the ODP drilling sites are shown in Figure 2. During Legs 119 and 120 (1988), 10 holes were drilled (sites 736-738 and 744-751) on the central and southern parts of the plateau (Schlich & Wise, 1992). Those that reached basement recovered Santonian to Turonian sediments overlying basement, which was silica-saturated transitional tholeiite that erupted above or just below sea level. Early sedimentation records fluvial conditions with wood fragments indicative of soil and vegetation.

In conjunction with the seismic reflection data, the sampling results suggest that extensive Early Cretaceous volcanism was followed by erosion, sedimentation and subsidence throughout the Cretaceous. At the end of the Cretaceous there was a regional uplift followed by further subsidence through the Paleogene and then wide-spread emergence in the mid-Tertiary (Leclaire et al., 1987). Since Neogene time the plateau has been gradually subsiding.

Although the overall geological history of the northern and southern parts of the plateau seem to be similar, there has been considerable debate about their possible different origins. Seismic refraction studies (Recq et al, 1990) indicated that the crust of the Kerguelen-Heard Plateau is 14-21 km thick, with a velocity structure similar to that of oceanic islands. The oceanic origin for the northern part of the plateau indicated by the refraction results is consistent with the chemical and isotopic compositions of basalts from this area and on the Kerguelen Islands (Dosso et al., 1979). Sampling of the Kerguelen-Heard Plateau has recovered volcanic rocks with oceanic island basalt (OIB) rather than mid-ocean ridge basalt (MORB) affinity (Mahoney et al., 1983), and this is consistent with a plume or hotspot-related origin.

According to the authors supporting a hotspot origin for the KP (Luyendyk & Rennick, 1977; Munschy & Schlich, 1987; Davies et al., 1989), the hotspot that underlies the Heard Island volcano today may be the same as that which generated the KP, Broken Ridge, Naturaliste Plateau and Ninetyeast Ridge in Cretaceous-Paleogene time. Since about 40 Ma, the hotspot has remained beneath the KP. The absence of a hotspot track here reflects the extremely slow absolute motion of the Antarctic Plate since that time.

Refraction results for the southern KP are controversial (Houtz et al., 1977; Operto & Charvis, 1995). The crustal thickness of the southern plateau is 21-25 km, and its velocity-depth structure is quite different from typical hotspot-related oceanic plateaux. The crust includes an upper sedimentary layer 2-3 km thick, a 3-6 km thick basaltic layer with velocities ranging from 4.5 to 6.2 km/s, and a 15-17 km thick lower crustal layer with velocities ranging from 6.6 to 6.9 km/s, including a 3-7 km thick transition zone located at the base of the crust with average velocity of 6.7 km/s (Charvis et al., 1993, Operto & Charvis, 1995). This crustal structure is not typical of oceanic plateaux; however, neither can it be considered as clear evidence for a continental origin. Operto & Charvis (1995) suggested that the southern KP might be a fragment of a volcanic passive margin composed of thinned continental crust overlain by basalt flows, rather than a typical oceanic plateau.

The geochemical characteristics of lavas from the southernmost KP are different from typical Indian MORBs (Mahoney et al., 1995). Their isotopic characteristics reflect shallow-level incorporation of continental lithosphere. The most continent-like isotopic and chemical signatures have been found at the plateau sites located closest to continental margins, which may indicate incorporation of continental lithospheric material into the mantle plume (Mahoney et al., 1995). The influence of such material diminished with time, which favours an oceanic origin for the plateau with continental contamination occurring during the plateau-building stage. Neither geophysical nor geochemical evidence rule out the possibility that small blocks of continental crust left from early stages of rifting form part of the southern KP (Coffin & Eldholm, 1992).

The question as to whether all of the KP or only its northern part has an oceanic origin remains unresolved. If the southern KP does prove to be continental in origin, this would significantly improve its petroleum prospectivity.

Structural features

Seismic reflection studies have revealed structural differences between the northern and southern parts of the KP. Kerguelen-Heard Plateau is dominated by recent volcanic features, whereas the basement of the southern KP has been smoothed by subaerial erosion and displays extensional features. The southern part of the KP is tectonically more complex than the northern part. Recent multichannel data (Schaming & Rotstein, 1990) have revealed that the southern KP is underlain by volcanic basement. They show numerous dipping basement reflectors associated with volcanic flows from elevated volcanoes and basement ridges representing extinct volcanic sources. The region is characterised by several large NW-trending basement ridges and it was affected by several stages of normal faulting and graben formation (Rotstein et al., 1992; Royer & Coffin, 1992).

All rift zones mapped in the southeastern part of the KP (Rotstein et al., 1992) are characterised by a NW-SE direction, that is, parallel to axis of the SEIR. However, in the central part of the plateau there are pronounced N-S lineations (Fig. 11). Recent seismic profiling results on the southern KP (Munschy et al., 1991; Rotstein et al., 1992; Munschy et al., 1993) have shown that north-south trending features in the central part of the plateau, and northwest-southeast lineations in the southern part of the plateau, represent extensional rift-type structures. Two known north-south rifts, the 77°E and 75°E grabens, are characterised by 10-30 km wide axial zones within a 100 to 150 km wide uplifted area. Analysis of the seismic refraction data (Munschy et al., 1993) indicated that the 77°E graben consists of six segments, each 50-100 km long, with alternating polarity. The 77°E graben can be clearly seen on the satellite gravity image (Fig. 11); it is particularly pronounced to the south of about 55°S. The 75°E graben is less distinct on the satellite gravity image.

According to Munschy et al. (1993), all rift systems on the KP were formed between 72 and 60 Ma during a major extensional phase associated with the initial stage of spreading at the SEIR. Extension resulted in the formation of NW-SE trending rifts in the eastern and southern parts of the plateau, and N-S oriented rifts in the central part. N-S trending rift zones may have been initiated along preexisting fracture zones. The difference between the strike of the rift and the direction of extension resulted in some strike-slip motion along the N-S trending grabens; however, according to the estimate made by Munschy (1993), such strike-slip motion was quite small.

The KP also displays east-west trending lineations, particularly in its southwestern part. Lineations in this direction define the geometry of the Elan Bank. Very little is known about these E-W or ENE-WSW structural trends. Angoulvant & Schlich (1994) suggested that they may reflect the Late-Cretaceous to Early Tertiary formation and post-emplacement deformation of the Broken Ridge/KP volcanic province.

Origin and tectonic history

This difference between the southern and northern parts of the KP encouraged some scientists (Coffin et al., 1986; Symonds & Willcox, 1989) to believe that the southern part of the plateau may have a different origin from the northern part. However, when multichannel seismic studies indicated a volcanic origin for the southern KP, this reinforced the position of those who believed in an oceanic origin for the whole plateau (Schaming & Rotstein, 1990; Munschy et al., 1993). The presence of a well-evolved rift system on the southern KP has important implications for its origin. Tectonic features observed in these rifts show a strong resemblance to the architecture of the East African and other continental rift systems. There could be two possible explanations for this: either mechanical properties and rifting mechanisms of old oceanic crust are very similar to those of continental crust (Rotstein et al., 1992); or the central and southern part of the KP are at least partly continental. Taken together with the most recent seismic refraction (Operto & Charvis, 1995) and geochemical (Mahoney et al., 1995) results, these extensional rifted structures are more consistent with a volcanic continental margin rather than an oceanic origin.

KP post-emplacement tectonism includes extensional phases, uplift, and differential subsidence. The tectonic history of the plateau based on seismic reflection studies and geological sampling results (Munschy & Schlich, 1987; Rotstein et al., 1992) can be summarised as follows:

1. Formation of the plateau by excessive volcanic activity at the axis of the spreading ridge, which separated India from Antarctica. The enormous volume of volcanic rocks and anomalously thick crust (greater than 20 km) can be explained by the presence of a large and long-lived hotspot. The location of the evolving plateau next to the large continental masses of Australia, Antarctica and India resulted in continental contamination of its lavas.

2. Tectonic activity occurring at about 88 and 75-60 Ma (Munschy et al., 1991), in response to the initial stages of spreading between Australia and Antarctica, caused regional uplift and created large extensional structures in the eastern and southern parts of the plateau.

3. The southern KP was separated from the Diamantina Zone 46 to 43 Ma ago by spreading at the SEIR, and the breakup between the northern KP and Broken Ridge occurred between 43.8 and 42.9 Ma.

Plate tectonic reconstructions

The first attempts at reconstruction between Australia and Antarctica resulted in an overlap between Broken Ridge and the northern KP in Early Eocene time (Houtz et al., 1977; Norton & Molnar, 1977). Reinterpretation of the oldest magnetic anomalies in the Southeast Indian Ocean (Cande & Mutter, 1982) improved the fit, but did not entirely resolve the problem.

Royer & Sandwell (1989) achieved a good fit for anomalies 13 and 18, however at anomaly 20 time the overlap problem emerged again. They suggested that after the breakup of Australia and Antarctica until chron 18, the northern and southern parts of the KP belonged to different plates. The northern part of the plateau remained attached to Broken Ridge (Australian Plate), while the southern part was attached to the Antarctic Plate. Relative motions between the southern and northern parts of the plateau occurred along a transform boundary at the 77°E graben. This hypothesis allowed for the opening of the Labuan Basin and Diamantina Zone, while avoiding large amounts of extension on the Broken/Kerguelen Ridge.

Recent results of seismic surveys on the southern KP have revealed the structure of the 77°E and 75°E grabens (Munschy et al, 1993). The amount of extension observed on the southern KP rift zone (2.5%) did not allow for more than 3-4 km of strike-slip motion. These results were inconsistent with the model of Royer & Sandwell (1989), which required 50 km of extension and 240 km of right-lateral motion along the 77°E graben. On the other hand, seismic studies in the Labuan Basin (Rotstein et al., 1991) showed that megasequences on the KP and in the basin are similar and may have once been contiguous. It was suggested (Rotstein et al., 1991) that the Labuan Basin was created at about the same time as the KP about 110 Ma ago. Munschy suggested that the age of the Diamantina Zone south of Australia is the same as that of the Labuan Basin, which is significantly older than the 95 Ma breakup in Cande & Mutter's (1982) interpretation. If no seafloor spreading occurred between Australia and Antarctica from 96 to 46 Ma, then no strike-slip motion is needed within the KP. However, this latest idea of Rotstein has not been tested for plate tectonic reconstructions.

Sedimentary basins and petroleum potential

Two major sedimentary basins are known to exist on the KP – one, unnamed, in the northern sector between Kerguelen and Heard Islands, and the Raggatt Basin in the southern sector. The structure and sedimentation history of the northern basin are described in Wicquart (1983) and Munschy & Schlich (1987). This basin lies entirely within the French Exclusive Economic Zone. The Raggatt Basin is a large sedimentary basin located between 56° and 59°S, to the east of the 77°E graben. The estimated sedimentary thickness within the basin is up to 3000 m (Ramsay et al., 1986).

The seismic stratigraphy of the Raggatt Basin (Colwell et al., 1988; Coffin et al., 1990) has revealed the following tectonic history: a subaerial or shallow-water environment in the Early Cretaceous; differential subsidence and development of carbonate mounds in Late Cretaceous time, and renewed subsidence near the Cretaceous-Tertiary boundary. The petroleum prospectivity of this basin is unknown. ODP site 748 on the western flank of the Raggatt Basin recovered Late Cretaceous (Turonian) section containing marine siltstone with 0.5% organic content. Symonds & Willcox (1989) suggested that the siltstone could have source potential. They also noted that in other parts of the Raggatt Basin there could be favourable conditions for the formation of petroleum deposits. The petroleum potential of this basin depends largely on whether this part of the plateau is underlain by extended continental or oceanic crust, as well as whether the sedimentary sequence includes rift-related or pre-rift sediments. Both of these factors are unknown at present.

UNCLOS PROGRAM DESIGN

The southern part of the KP to the south of the AEEZ generated by Heard and McDonald Islands is potentially claimable by Australia as Continental Shelf (CS). Its limits have been defined in a preliminary manner by Symonds & Willcox (1989). The aim of the proposed surveys over this part of the plateau is to fill in gaps in data to achieve an adequate definition of the CS and to maximise Australia's CS claim in the region.

North of Heard and McDonald Islands, the AEEZ and Continental Shelf of Australia are defined by a negotiated boundary with France. The portion of this boundary within the limits of the AEEZ was negotiated in 1979; beyond the AEEZ this boundary has yet to be negotiated. To the south of this boundary the outer limit of the CS is defined mainly by the Hedberg Line, and in places by the cut-off lying 100 nM beyond the 2500 m isobath (Fig. 12).

Analysis of existing data

Pre-cruise data evaluation included analysis of all available bathymetric and seismic data for the area (Fig. 10), resulting in identification of preliminary foot-of-slope (FoS) picks (Appendix 3). These data sets and information were compiled and displayed in GIS format using ARC/INFO. A preliminary Hedberg Line based on the identified FoS picks has been computed (Fig. 12). Using the 2500 m contour from the new digital version of the GEBCO bathymetry provided by Scripps Oceanographic Institute, a preliminary 100 nM cut-off boundary was computed by buffering using ARC/INFO (Fig. 12). Comparison of these two lines clearly shows where additional data are required to support and maximise the CS claim. Analysis of the satellite gravity image (Fig. 11), ground-truthed by existing bathymetric profiles, provided a good indication of where the foot-of-slope may lie in poorly surveyed areas. A preliminary analysis of sediment distribution on existing seismic profiles resulted in identification of areas which are likely to satisfy the sediment thickness criterion and thus enable extension of the outer limit of the CS beyond the Hedberg Line.

Surveys used for the analysis are listed in Appendix 2 and shown in Figure 10. Some surveys conducted in the study area (identified by searching either the AGSO seismic database or in GEODAS) are not present in this list. There are several reasons for this: the absence of bathymetric (and seismic) data along the lines crossing the margin – e.g. *Aurora Australis*, 1995; duplication of data sets within the AGSO database – surveys 86 and 1704; and the unavailability of data, particularly in digital form – most of the French surveys. There are two surveys recently conducted by Ecole et Observatoire de Physique du Globe, Strasbourg, in the KP region, *Marion Dufresne* surveys 66 and 67, that are not available through international databases. Our attempts to obtain the digital data directly from the source did not succeed in time for inclusion in this analysis. There are also at least fourteen old French surveys by *Gallieni* and *Marion Dufresne*, mostly covering the northern part of the plateau, that are also unavailable through AGSO or international databases.

Careful analysis of existing bathymetric lines showed that there are two major areas with insufficient data to locate the FoS – the Elan Bank and William's Ridge areas. Available geological data suggest that both features form integral parts (natural prolongations) of the plateau, and therefore may be claimable as part of the CS. Known sediment distribution and the shape of the plateau suggest that the sediment thickness criterion may be applicable in the area to the southwest of Elan Bank.

The southern part of the KP generally has sufficient survey data to determine the position of the Hedberg Line, although there is rarely enough data to satisfy the 30 nM spacing of AGSO's 'safe minimum' approach. In several areas the Hedberg Line lies well inside the 100 nM cut-off beyond the 2500 m isobath. These areas are hachured in Figure 12. These areas could potentially be claimed provided sediment thickness beyond the Hedberg Line exceeds 1% of the distance from the FoS. Existing data indicate appropriate thicknesses of sediment in the area, and thus there is a good chance to extend the CS claim in all of these areas.

Proposed lines

Nineteen survey lines are proposed to justify and extend Australia's claim for CS in the KP region. The total length of the seismic lines is 3670 km and the way points for the lines are given in Appendix 5. Because of the remoteness of the plateau and uncertainties in weather conditions, it may not be possible to acquire seismic on all the lines, therefore 4 of the proposed lines have been marked as optional or lower priority. The total length of these lines is 690 km. It will require 2 survey episodes of more than

40 days duration each to complete the proposed lines. This includes transits to and from the survey area, between lines and an allowance for bad weather conditions.

Elan Bank

Figure 12 indicates a big gap in data determining the position of the Hedberg Line (FoS picks) in the southwestern area of the Elan Bank. At least 4 lines are required to determine the position of the FoS in this area. The satellite gravity data indicate that Elan Bank may have a southwestward extension as far south as 59.5°S (see predicted FoS line, Fig. 12). If this turns out to be the case, then Australia would be able to claim most of the area within the 100 nM cut-off on the basis of bathymetric data (Hedberg Line) alone. If the FoS lies further to the north, at about 57°S, then the Hedberg Line would lie approximately 30 nM to the north of the cut-off line. There are no reliable data on sediment thickness in this area, however, *Eltanin* seismic data about 200 nM to the south show a considerable thickness of sediment, probably in excess of 1 km. Two seismic lines are proposed in the southwestern part of the Elan Bank to substantiate a possible claim based on the sediment thickness criterion.

Line KP-A tests the accuracy of the 2500 m isobath on the new GEBCO bathymetric map. According to the compilation track chart provided by the Scripps Oceanographic Institution there are very few ship tracks in this area. The satellite gravity image suggests that there is a high in the area similar to that in the central part of the plateau. The shallowest point on a bathymetric profile along the line lying about 30 nM to the north of the identified area (*Robert Conrad,* survey 1351) is 2611 m, which implies the possibility of even shallower depths to the south. If line KP-A confirms the presence of a bathymetric high rising above 2500 m, then the 100 nM cut-off boundary may extend considerably to the northwest. At present the Hedberg Line lies about 30 nM beyond the cut-off line. If the cut-off line is moved farther westward, it would allow extension of the CS claim to the limit of the Hedberg Line.

Line KP-B is an optional line. It lies on the continuation of line KP-A and will define the position of the FoS. The spacing of FoS points 2,3, and 4 (Appendix 3) is sufficient for defining the Hedberg Line – however, bathymetric profiles used for establishing these points were from relatively old surveys. Point 3 was picked on a profile from survey 1351 (*Robert Conrad*, 1964), which did not have satellite navigation, and points 2 and 4 were picked on a profile from survey 1416 (*Robert Conrad*, 1974), which crossed only the northernmost part of the Elan Bank. As this is a very important area for extending the CS claim it would be very useful to obtain new data with high precision navigation to support the original FoS picks.

Line KP-C will determine the position of the FoS on the western slope of Elan Bank. There are no data on FoS along the western and southern slopes of the bank.

The bathymetric map and the satellite gravity image indicate that the southwestern prolongation of the bank consists of the two basement ridges. Lines KP-D and KP-H have been positioned to test the maximum extension of these ridges. At this stage it is not clear whether the FoS is located at about 57-58°S, or further to the south, along the southwestern prolongation of the bank.

Line KP-D is another optional line and tests the southwestern prolongation of Elan Bank running along the axis of a basement ridge identified from the bathymetric map and the satellite gravity image. Depending on the position of the FoS on this line, the southernmost part of the line (the last 30 nM) may be used to test the sediment thickness criterion in the area. If the FoS on this line is found to the south of 57°45'S, then the Hedberg Line produced by this point would coincide with or go beyond the cut-off boundary. In this case there would be no need to test for sediment thickness and the line could be cut short.

Line KP-E will define the position of the FoS and test for sediment thickness in the southern part of the line. The satellite gravity image suggests that the position of the FoS here would line up with FoS point 5. This means that there would be a 30 nM gap between the Hedberg Line and the cut-off boundary. Testing for sediment thickness in the southern part of the line may help extend the CS claim in this area.

Line KP-F will establish the position of the FoS and test for sediment thickness. The gravity image shows a deep gravity low to the south of Elan Bank, which may be associated with sediment accumulations. There are currently no seismic data available with which to predict sediment thickness and distribution in this area. If sufficient sediment thickness is found, the CS claim could be extended by about 30 nM.

Line KP-G is aimed at defining the position of the FoS over this part of the bank. The new FoS point would not extend the maximum envelope of the Hedberg Line, but it would positively join the Hedberg Line around Elan Bank to the Hedberg Line around the southwestern part of the plateau.

Line KP-H is a regional transect, from the Enderby Basin across the whole plateau and the northern end of the Labuan Basin to the Australian-Antarctic Basin. This line has considerable scientific interest, because it crosses all major crustal provinces in the region. The transect will cross the northernmost part of the southern Kerguelen province with the pronounced extensional features, the 75°E graben and the 77°E graben.

Line KP-I is an optional line, and will establish the position of the FoS and test for sediment thickness to the north of Elan Bank. There is a large gap between FoS picks here, resulting in a poorly defined Hedberg Line (Fig. 12). Because the AEEZ boundary is situated closer than 60 nM from the Hedberg Line, it is possible to connect the westernmost point on the negotiated Australia-French boundary to the Hedberg Line produced by FoS points 2 and 3. This will maximise our claim without any additional work. However, with FoS point 3 being picked on a very old line (S1351) with pre-satellite navigation, there is a need for additional data in this area. If it is not possible to record the whole line, a shortened version of the line, defining the position of the FoS only, would probably be sufficient to justify the claim.

Eastern slope of the southern KP

On the eastern flank of the plateau between 55°S and 62°S, the Hedberg Line lies about 30 nM to the west of (inside) the 100 nM cut-off line. Individual seismic lines available for this region (*Rig Seismic,* 1985; *Eltanin,* 1971-72) indicate sediment thickness up to 2-2.5 km in the vicinity of the Hedberg Line. To substantiate a claim based on sediment thickness, additional surveying will be required in this area.

Line KP-J tests a protrusion of the 2500 m contour seen on the bathymetric map, and sediment thickness beyond the Hedberg Line.

Line KP-K tests the position of the 2500 m contour and the applicability of the sediment thickness criterion. It is located 60 nM to the north of line KP-J at the cut-off boundary.

Line KP-L is located about 60 nM to the north of the intersection between the cut-off boundary and an *Eltanin* line (survey 1101) which indicates the presence of up to 2 kilometres of sediment in this area. This line also tests the location of the 2500 m contour and the sediment thickness between the Hedberg Line and the cut-off boundary. It will also identify the position of the FoS between points 49 and 54 which are about 60 nM apart. The large distance between lines KP-K and KP-L is related to the presence of two multichannel (*Marion Dufresne,* survey 59) and 2 single channel (*Eltanin*, survey 1101) lines, which can be used for defining the outer limit of the CS based on the sediment thickness criterion.

Line KP-M will establish the position of the FoS and the sediment thickness distribution between the Hedberg Line and the cut-off boundary. It is located about 60 nM to the north of seismic line 33 shot by *Rig Seismic* (survey 47), which shows considerable sediment thickness.

Line KP-N is located 60 nM to the north of line KP-M. It will provide the position of the FoS and the sediment thickness distribution between the Hedberg Line and the cut-off boundary.

William's Ridge

Another large gap in data occurs on the northeastern flank of William's Ridge (Fig. 12). Satellite gravity data indicate that the eastern flank of William's Ridge is very steep and straight. Four lines are required to identify the minimum number of FoS picks required for CS definition. To the north, William's Ridge is bordered by relatively young (Eocene) oceanic crust with a sediment blanket of insignificant thickness, and thus seismic lines here can be relatively short (Fig. 12). In between William's Ridge and the main body of the plateau, sediment thickness is considerable (up to at least 1.5 km); however, because of the configuration of the 100 nM cut-off line, claims based on the sediment thickness criterion will not be applicable here.

Line KP-O will define the position of the FoS on both flanks of William's Ridge and verify the position of the 2500 m contour in the southeastern part of the ridge.

Line KP-P will further verify the position of the 2500 m contour in the southeastern part of the ridge and define the position of the FoS .

Lines KP-Q and KP-R will test the position of the FoS and the 2500 m contour in the central part of the ridge.

Line KP-S is optional. It will provide the FoS position in the 90 nM gap between FoS points 89 and 91.

All of these proposed lines will be surveyed using the acquisition parameters specified in Appendix 4. There will undoubtedly be further changes to the proposed line locations and lengths during 'fine-tuning' prior to the survey and during the survey itself.

Conclusion

In comparison to other surveys planned for LOS purposes, where the 'safe minimum' approach has been implemented, AGSO has had to adopt different standards for the KP survey planning. The weather window will only permit the completion of two cruises in any year, during the summer period. The remoteness of the plateau and the severe weather conditions likely to be experienced imply that up to 50% of the total time could be spent on transits and 'down time'. Within the framework of the two cruises planned for 1997 it was impossible to implement the 'safe minimum' approach in all instances. The lines have therefore been positioned to justify and maximise the CS claim taking into account the shape of the plateau and the gaps in existing data. It is possible that if much worse than usual weather conditions are encountered, all of the required data may not be collected. In this case, a decision will have to be made to either make the best claim possible with the available data, or to plan a further survey at a later time.

REFERENCES

Angoulvant-Coulon, M.-P. and Schlich, R., 1994 - Mise en evidence d'une nouvelle direction tectonique sur le plateau de Kerguelen. *Comptes Rendus de l'Academie des Sciences, Paris, 319, serie II, 929-935.*

Barron, J., Larsen, B., et al, 1989 - *Proceedings of the Ocean Drilling Program, Initial Reports, vol. 119,* College Station, Tex.

Colwell, J.B., Coffin, M.F., Pigram, C.J., Davies, H.L., Stagg, H.M.J. and Hill, P.J., 1988 - Seismic stratigraphy and evolution of the Raggatt basin, southern Kerguelen Plateau. *Marine and Petroleum Geology, 5, 75-81.*

Cande, S.C. and Mutter, J.C., 1982 - A revised identification of the oldest sea-floor spreading anomalies between Australia and Antarctica. *Earth and Planetary Science Letters, 58, 151-160.*

Charvis, P., Operto, S., Konnecke, L.K., et al., 1993 - Structure profonde du domaine nord du plateau de Kerguelen (Ocean Indien austral): resultats preliminaires de la campagne MD66/KeOBS - C.R. Acad. Sci. Paris, 316, serie II, 341-347.

Coffin, M.F., Davies H.L., Haxby W.F., 1986 - Structure of the Kerguelen Plateau province from SEASAT altimetry and seismic reflection data. *Nature, 324, 134-136.*

Coffin, M.F., Munschy, M., Colwell, J.B., Schlich, R., Davies, H.L., and Li, Z.G., 1990 - Seismic stratigraphy of the Raggatt Basin, southern Kerguelen Plateau: Tectonic and palaeogeographic implications. *Geological Society of America Bulletin, 102,* 563-579.

Coffin, M.F. and Eldholm O., 1994 - Large igneous provinces: crustal structure, dimensions, and external consequences, *Reviews of Geophysics, 32, 1-36.*

Davies, H.L., Sun, S.-S., Frey, F.A., et al.,1989 - Basalt basement from the Kerguelen Plateau and the trail of a Dupal plume. *Contributions to Mineralogy and Petrology, 103, 457-469.*

Dosso, L., Vidal, P., Cantagrel, J.M., Lameyre, J., Marot A., and Zimine, S., 1979 - "Kerguelen: continental fragment or oceanic island?": Petrology and isotopic geochemistry evidence. *Earth and Planetary Science Letters, 43, 46-60.*

Houtz, R.E., Hayes, D.E. and Markl, R.G., 1977 - Kerguelen Plateau bathymetry, sediment distribution and crustal structure. *Marine Geology, 25, 95-130.*

Leclaire, L., Bassias, Y., Denis-Clocchiatti, M., Davies, H., et al., 1987 - Lower Cretaceous basalt and sediments from the Kerguelen Plateau. *Geo-Marine Letters, 7, 169-176.*

Luyendyk, B.P. and Rennick, W., 1977 - Tectonic history of aseismic ridges in the eastern Indian Ocean. *Geological Society of America Bulletin, 88, 1347-1356.*

Mahoney, J. J.. Macdougall, J.D., Lugmair, G.W. and Gopalan, K., 1983 - Kerguelen hotspot source for Rajmahal Traps and Ninetyeast Ridge? *Nature (London), 303, 385-389.*

Mahoney, J., Jones, W., Frey, F.A., Salters, V., Pyle, D. and Davies, H., 1995 - Geochemical characteristics of lavas from Broken Ridge, the Naturaliste Plateau and southernmost KP: Early volcanism of the Kerguelen hotspot. *Chemical Geology, 120, 315-345.*

Munschy, M. and Schlich, R., 1987 - Structure and evolution of the Kerguelen-Heard Plateau (Indian Ocean) deduced from seismic stratigraphy studies. *Marine Geology 76, 131-152.*

Munschy, M., Rotstein, Y., Fritsch, B. and Schlich, R., 1991 - Rifting of the Kerguelen Plateau, Indian Ocean. *TERRA Abstracts, 3, 273-274.*

Munschy, M., Rotstein, Y., Schlich, R. and Coffin, M.F., 1993 - Structure and tectonic setting of the 77° and 75°E grabens, Kerguelen Plateau, south Indian Ocean. *Journal of Geophysical Research, 98-B, 6367-6382*

Nogi, Y., Seama, N., Hayashi, T., Funaki, M. and Kaminuma, K., 1991 - Geomagnetic anomaly lineation and fracture zones on the basin west of the Kerguelen Plateau, *EOS, Transactions of American Geophysical Union, 72, 445.*

Norton, I.O. and Molnar, P., 1977 - Implications of a revised fit between Australia and Antarctica for the evolution of the eastern Indian Ocean. *Nature, 267, 338-339.*

Operto, S. and Charvis, P., 1995 - Kerguelen Plateau: A volcanic passive margin fragment?. *Geology, 23, 137-140.*

Quilty, P.G., 1973 - Cenomanian-Turonian and Neogene sediments from the northeast of Kerguelen Ridge, Indian Ocean. *Journal of Geological Society of Australia, 20, 361-371.*

Ramsay, D.C., Colwell, J.B., Coffin M.F., Davies H.L., Hill, P.J., Johnston N.A., Pigram, C.J., Stagg, H.M.J, 1986 - Rig Seismic research cruise 2: Kerguelen Plateau, initial report. *BMR, Australia, Report 270, 41 pp.*

Recq, M., Brefort, D., Malod, J. and Veinante, J.-L., 1990 - The Kerguelen Isles (southern Indian Ocean) new results on deep structure from refraction profiles. *Tectonophysics, 182, 227-248.*

Rotstein, Y., Munschy, M., Schlich, R. and Hill, P.J., 1991 - Structure and early history of the Labuan Basin, south Indian Ocean. *Journal of Geophysical Research, 96, 3887-3904.*

Rotstein, Y., Schlich, R., Munschy, M. and Coffin, M.F., 1992 - Structure and tectonic history of the southern Kerguelen Plateau (Indian Ocean) deduced from seismic reflection data. *Tectonics, 11, 1332-1347.*

Royer, J-Y. and Coffin, M.F., 1992 - Jurassic and Eocene plate tectonic reconstructions in the Kerguelen Plateau region. *Proceeding of the ODP, Scientific Results, 120, 917-928.*

Royer, J-Y. and Sandwell, T., 1989 - Evolution of the eastern Indian Ocean since the Late Cretaceous: constraints from GEOSAT altimetry. *Journal of Geophysical Research, 94-B, 13,755-13,782.*

Schaming, M. and Rotstein, Y., 1990 - Basement reflectors in the Kerguelen Plateau, south Indian Ocean: Implications for the structure and early history of the plateau. *Geological Society of America Bulletin, 102, 580-592.*

Schlich, R., 1975 - Structure et age de Ocean Indien occidental. *Memoires Hors.-Ser. Societe Geologique Francaise, 6, 1-103.*

Schlich, R., Munschy, M., Whitechurch, H., et al., 1989 - Resultats preliminaires de la campagne de forages du Joides Resolution sur le plateau de Kerguelen (ODP, Leg. 120). *Comptes-Rendus de l'Academie de Sciences, Paris, 308, 1597-1603.*

Schlich, R., 1991 - Campagne MD67/ KERSIMAG. *Les rapports de campagnes a la mer a bord du Marion-Dufresne. L'ecole et Observatoire Physique du Globe, Laboratoire de Geophysique Marine, 24 pp.*

Schlich, R. and Wise, S.W., 1992 - The geologic and tectonic evolution of the Kerguelen Plateau: An introduction to the scientific results of Leg 120. *Proceedings of the ODP, Scientific Results, 120, 5-30.*

Symonds & Willcox, 1989 - Australia's petroleum potential in areas beyond an Exclusive Economic Zone. *BMR Journal of Australian Geology and Geophysics, 11, 11-36.*

USNS Eltanin, Cruises 46-50, Preliminary report of volume 25, 1977 - *Lamont-Doherty Geological Observatory of Columbia University, Technical report CU-1-77.*

USNS Eltanin, Cruises 51-55A, Preliminary report of volume 26, 1978 - *Lamont-Doherty Geological Observatory of Columbia University, Technical report CU-1-78.*

Wicquart, E., 1983 - Modele lithostratigraphique de plateau de Kerguelen-Heard, Ocean Indien (Ph.D. thesis), Paris, France, Universite Curie, 135 pp.

APPENDICES

Appendix 1

United Nations Convention on the Law of the Sea

Article 76
Definition of the continental shelf

1. The continental shelf of a coastal State comprises the seabed and subsoil of the submarine areas that extend beyond its territorial sea throughout the natural prolongation of its land territory to the outer edge of the continental margin, or to a distance of 200 nautical miles from the baselines from which the breadth of the territorial sea is measured where the outer edge of the continental margin does not extend up to that distance.

2. The continental shelf of a coastal State shall not extend beyond the limits provided for in paragraphs 4 to 6.

3. The continental margin comprises the submerged prolongation of the land mass of the coastal State, and consists of the seabed and subsoil of the shelf, the slope and the rise. It does not include the deep ocean floor with its oceanic ridges or the subsoil thereof.

4. (a) For the purposes of this Convention, the coastal State shall establish the outer edge of the continental margin wherever the margin extends beyond 200 nautical miles from the baselines from which the breadth of the territorial sea is measured, by either:

   (i) a line delineated in accordance with paragraph 7 by reference to the outermost fixed points at each of which the thickness of sedimentary rocks is at least 1 per cent of the shortest distance from such point to the foot of the continental slope; or

   (ii) a line delineated in accordance with paragraph 7 by reference to fixed points not more than 60 nautical miles from the foot of the continental slope.

   (b) In the absence of evidence to the contrary, the foot of the continental slope shall be determined as the point of maximum change in the gradient at its base.

5. The fixed points comprising the line of the outer limits of the continental shelf on the seabed, drawn in accordance with paragraph 4 (a) (i) and (ii), either shall not exceed 350 nautical miles from the baselines from which the breadth of the territorial

sea is measured or shall not exceed 100 nautical miles from the 2,500 metre isobath, which is a line connecting the depth of 2,500 metres.

6. Notwithstanding the provisions of paragraph 5, on submarine ridges, the outer limit of the continental shelf shall not exceed 350 nautical miles from the baselines from which the breadth of the territorial sea is measured. This paragraph does not apply to submarine elevations that are natural components of the continental margin, such as its plateaux, rises, caps, banks and spurs.

7. The coastal State shall delineate the outer limits of its continental shelf, where that shelf extends beyond 200 nautical miles from the baselines from which the breadth of the territorial sea is measured, by straight lines not exceeding 60 nautical miles in length, connecting fixed points, defined by coordinates of latitude and longitude.

8. Information on the limits of the continental shelf beyond 200 nautical miles from the baselines from which the breadth of the territorial sea is measured shall be submitted by the coastal State to the Commission on the Limits of the Continental Shelf set up under Annex II on the basis of equitable geographical representation. The Commission shall make recommendations to coastal States on matters related to the establishment of the outer limits of their continental shelf. The limits of the shelf established by a coastal State on the basis of these recommendations shall be final and binding.

9. The coastal State shall deposit with the Secretary-General of the United Nations charts and relevant information, including geodetic data, permanently describing the outer limits of its continental shelf. The Secretary-General shall give due publicity thereto.

10. The provisions of this article are without prejudice to the question of delimitation of the continental shelf between States with opposite or adjacent coasts.

Appendix 2

Summary of surveys used for planning

Survey -id	Name	Institution	Ship	Year	Data Spacing (minutes)	Navigation Type	Data Type
1101	elt71/72	LDGO	Eltanin	1971	10	T	B/SCS
1351	C0802	LDGO	R. Conrad	1964	6	A	B/SCS
1416	C1704	LDGO	R. Conrad	1974	6	T	B/SCS
1569	INMD05MV	SIO	Melville	1978	5	T	B
1677	UM66-C	UTOKYO	Umitaka Maru	1967	10	T	B
1691	ANTAC26	JODC	Shirase	1985	15	T	B
1695	C1104	LDGO	R. Conrad	1967	6	T	B/SCS
1697	ELT46	LDGO	Eltanin	1971	5-10	T	B
1701	LUSI6BAR	SIO	ARGO	1962	10	A	B
1703	ODP119JR	TEXAS A&MU	Joides Resolution	1988	5	T	B
1704	ODP120JR	TEXAS A&MU	Joides Resolution	1988	5-10	T	B
1725	ANTAC29	JODC	Shirase	1987	20	T	B
31	S OCEAN 1	AGSO	Nella Dan	1981	1	T	B
32	S OCEAN 2	AGSO	Nella Dan	1981	1	T	B
33	S OCEAN 3	AGSO	Nella Dan	1980	1	T	B/SCS
36	HEARD ISLAND	NATMAP	Cape Pillar	1980	1	T	B
47	KERGUELEN 1	AGSO	Rig Seismic	1985	1	T	B/MCS
59	KERGUELEN 2	FRANCE	Marion Dufresne	1986	1	T	B/MCS
60	KERGUELEN 3	FRANCE	Marion Dufresne	1986	5	T	B/DWG

Data type:
- B - bathymetry
- SCS - single-channel seismic
- MCS - multi-channel seismic
- DWG - digital water gun

Navigation type:
- T - transit satellite fixes
- A - astronomical

Appendix 3

TABLE OF PRELIMINARY FOOT-OF-SLOPE PICKS

Kerguelen Plateau foot of slope picks

	A	B	C	D	E	F	G	H	I	J	K	L
1	Longitude	Latitude	Depth	Line	Dec Hour	FOS type	Fos_id	Survey Name	Institution	Ship	Year	Data_spacing(min)
2	85.96258	-61.0438	-4063	1101/067	300	FOS	40	elt71/72	LDGO	Eltanin	1971	10
3	87.19219	-60.3116	-4498	1101/067	1633	EAP	41	elt71/72	LDGO	Eltanin	1971	10
4	86.05189	-59.1021	-4572	1101/069	117	EAP	50	elt71/72	LDGO	Eltanin	1971	10
5	84.93389	-58.9698	-4385	1101/069	467	FOS	49	elt71/72	LDGO	Eltanin	1971	10
6	73.03151	-61.0592	-4115	1101/072	83	FOS?	14	elt71/72	LDGO	Eltanin	1971	10
7	72.01528	-60.3865	-4374	1101/073	300	LFOS/EAP	11	elt71/72	LDGO	Eltanin	1971	10
8	72.33439	-60.3425	-4261	1101/073	517	FOS	12	elt71/72	LDGO	Eltanin	1971	10
9	81.14292	-55.7745	-4668	1101/075	1950	FOS/EAP	69	elt71/72	LDGO	Eltanin	1971	10
10	81.27931	-55.9101	-4703	1101/561	250	FOS/EAP	68	elt71/72	LDGO	Eltanin	1971	10
11	81.24117	-56.7356	-4458	1101/561	1067	EAP	63	elt71/72	LDGO	Eltanin	1971	10
12	81.15031	-56.8208	-4455	1101/561	1133	FOS	62	elt71/72	LDGO	Eltanin	1971	10
13	81.19951	-56.9116	-4325	1101/561	1592	UFOS	61	elt71/72	LDGO	Eltanin	1971	10
14	81.09839	-56.6486	-4500	1101/564	283	FOS/EAP	65	elt71/72	LDGO	Eltanin	1971	10
15	64.11671	-54.4935	-4639	1351/019	600	FOS	3	C0802	LDGO	R. Conrad	1964	6
16	89.34282	-61.2991	-4269	1569/046	342	PFOS	39	INMD05MV	SIO	Melville	1978	5
17	87.39666	-59.5633	-4588	1691/345	2000	EAP	44	ANTAC26	JODC	Shirase	1985	15
18	85.63333	-59.8967	-4379	1691/345	2400	FOS	43	ELT46	LDGO	Eltanin	1971	5 to 10
19	75.37251	-61.2567	-4039	1697/360	283	FOS/EAP	18	ELT46	LDGO	Eltanin	1971	5 to 10
20	75.25992	-61.2515	-4070	1697/002	2297	EAP	17	ELT46	LDGO	Eltanin	1971	5 to 10
21	75.11901	-60.7306	-3611	1697/003	280	FOS	16	ELT46	LDGO	Eltanin	1971	5 to 10
22	85.45876	-59.7261	-4449	1703/039	742	FOS	52	ODP119JR	TEXAS A&MU	Joides Resolution	1988	5
23	86.73123	-58.8937	-4641	1703/044	92	EAP	51	ODP119JR	TEXAS A&MU	Joides Resolution	1988	5
24	86.56739	-59.5275	-4609	0032/334	1237	EAP	45	S OCEAN 2	AGSO	Nella Dan	1980	1
25	78.19227	-62.0372	-3927	0032/355	1637	FOS/EAP	19	S OCEAN 2	AGSO	Nella Dan	1980	1
26	71.82672	-59.9909	-4463	0033/070	2225	FOS/EAP	8	S OCEAN 3	AGSO	Nella Dan	1981	1
27	86.25256	-59.2869	-4631	0033/072	1225	EAP	48	S OCEAN 3	AGSO	Nella Dan	1981	1
28	78.31642	-62.1172	-3890	0033/341	517	FOS/EAP	20	S OCEAN 3	AGSO	Nella Dan	1981	1
29	87.42723	-60.6131	-4400	0033/342	1630	EAP	42	S OCEAN 3	AGSO	Nella Dan	1981	1
30	78.48239	-62.5013	-3870	0034/063	2140	FOS/EAP	21	S OCEAN 3	AGSO	Nella Dan	1981	1
31	88.18686	-62.2522	-3943	0034/065	643	EAP	38	S OCEAN 3	AGSO	Nella Dan	1981	1
32	76.00385	-50.4622	-3195	0036/069	992	FOS/EAP	94	HEARD ISLAND	NATMAP	Cape Pillar	1980	1
33	80.98011	-55.7301	-4592	0047/090	1333	FOS/EAP	70	KERGUELEN 1	AGSO	Rig Seismic	1985	1
34	81.30121	-56.1701	-4622	0047/091	2160	FOS	67	KERGUELEN 1	AGSO	Rig Seismic	1985	1
35	81.10112	-56.1802	-4517	0047/091	2270	UFOS	66	KERGUELEN 1	AGSO	Rig Seismic	1985	1
36	81.06011	-56.7011	-4454	0047/094	1217	FOS/EAP	64	KERGUELEN 1	AGSO	Rig Seismic	1985	1
37	72.61012	-59.4301	-4504	0047/102	1325	FOS/EAP	7	KERGUELEN 1	AGSO	Rig Seismic	1985	1
38	71.80112	-60.0402	-4404	0047/103	1267	LFOS/EAP	10	KERGUELEN 1	AGSO	Rig Seismic	1985	1
39	72.01011	-60.0101	-4199	0047/103	1383	FOS?	9	KERGUELEN 1	AGSO	Rig Seismic	1985	1
40	85.20231	-61.9313	-3903	0059/020	1733	FOS?	96	KERGUELEN 2	FRANCE	Marion Dufresne	1986	1

Kerguelen Plateau foot of slope picks

	A	B	C	D	E	F	G	H	I	J	K	L
41	85.71852	-61.7151	-3997	0059/020	2050	FOS?	97	KERGUELEN 2	FRANCE	Marion Dufresne	1986	1
42	86.65931	-61.3427	-3900	0059/021	225	FOS	98	KERGUELEN 2	FRANCE	Marion Dufresne	1986	1
43	86.45732	-59.4374	-4563	0059/025	1942	EAP	46	KERGUELEN 2	FRANCE	Marion Dufresne	1986	1
44	85.25221	-59.5851	-4470	0059/026	208	FOS	47	KERGUELEN 2	FRANCE	Marion Dufresne	1986	1
45	81.82882	-54.1823	-4155	0059/033	1242	FOS	75	KERGUELEN 2	FRANCE	Marion Dufresne	1986	1
46	64.55641	-54.4202	-4652	1416/021	1870	FOS	2	C1704	LDGO	R. Conrad	1974	6
47	63.86471	-55.3525	-4501	1416/022	420	FOS	4	C1704	LDGO	R. Conrad	1974	6
48	67.55631	-55.2986	-4362	1351/019	2300	FOS	1	C0802	LDGO	R. Conrad	1964	6
49	68.05082	-57.3543	-4672	1416/024	1950	FOS	5	C1704	LDGO	R. Conrad	1974	6
50	69.27391	-57.8864	-4653	1416/025	680	FOS	6	C1704	LDGO	R. Conrad	1974	6
51	72.33431	-60.3424	-3801	1101/073	850	PFOS	13	elt71/72	LDGO	Eltanin	1971	10
52	74.46862	-60.8784	-3924	1101/071	1867	PFOS	15	elt71/72	LDGO	Eltanin	1971	10
53	85.54721	-60.6772	-4253	0033/342	1188	FOS?	100	S OCEAN 3	AGSO	Nella Dan	1981	1
54	80.08599	-63.1691	-3816	0033/046	2200	FOS/EAP	22	S OCEAN 3	AGSO	Nella Dan	1981	1
55	80.54984	-63.3538	-3666	1703/007	933	FOS	23	ODP119JR	TEXAS A&MU	Joides Resolution	1988	5
56	80.51861	-63.3758	-3711	1101/056	117	FOS?	24	elt71/72	LDGO	Eltanin	1971	10
57	81.83897	-63.6628	-3699	1101/064	933	FOS/EAP	26	elt71/72	LDGO	Eltanin	1971	10
58	81.43901	-63.5211	-3659	1703/035	1892	FOS/EAP	25	ODP119JR	TEXAS A&MU	Joides Resolution	1988	5
59	82.20986	-63.8448	-3692	0034/014	2135	FOS/EAP	27	S OCEAN 3	AGSO	Nella Dan	1981	1
60	84.11567	-63.6628	-3725	1101/065	1717	FOS/EAP	30	elt71/72	LDGO	Eltanin	1971	10
61	85.35671	-63.0626	-3809	1697/355	2287	FOS/EAP	33	ELT46	LDGO	Eltanin	1971	5 to 10
62	84.95296	-63.2526	-3789	0033/047	2073	FOS/EAP	31	S OCEAN 3	AGSO	Nella Dan	1981	1
63	85.12842	-63.1647	-3744	0034/014	1070	FOS/EAP	32	S OCEAN 3	AGSO	Nella Dan	1981	1
64	87.62417	-62.0306	-3834	1101/063	1100	PFOS	36	elt71/72	LDGO	Eltanin	1971	10
65	85.94419	-62.4661	-3763	1101/063	1817	LFOS	35	elt71/72	LDGO	Eltanin	1971	10
66	85.61069	-62.5576	-3756	1101/063	1983	FOS	34	elt71/72	LDGO	Eltanin	1971	10
67	85.98395	-62.5078	-3760	0034/065	118	FOS?	37	S OCEAN 3	AGSO	Nella Dan	1981	1
68	87.12012	-62.4784	-3789	1569/045	1717	PFOS	99	INMD05MV	SIO	Melville	1978	5
69	82.18719	-57.1936	-4517	1101/554	890	FOS?	58	elt71/72	LDGO	Eltanin	1971	10
70	82.95219	-57.6333	-4301	1101/554	2375	FOS	56	elt71/72	LDGO	Eltanin	1971	10
71	81.93128	-57.0939	-4509	1101/562	1733	FOS	59	elt71/72	LDGO	Eltanin	1971	10
72	83.86865	-57.4071	-4531	0033/322	1728	EAP	55	S OCEAN 3	AGSO	Nella Dan	1981	1
73	81.45011	-57.0301	-4470	0047/095	1395	FOS	60	KERGUELEN 1	AGSO	Rig Seismic	1985	1
74	82.39012	-57.4012	-4544	0047/098	382	FOS	57	KERGUELEN 1	AGSO	Rig Seismic	1985	1
75	83.99011	-58.0711	-4509	0047/108	1330	FOS	54	KERGUELEN 1	AGSO	Rig Seismic	1985	1
76	80.80578	-54.863	-4262	1101/077	1250	FOS/EAP	72	elt71/72	LDGO	Eltanin	1971	10
77	79.67869	-54.8501	-3994	1101/077	1750	FOS	71	elt71/72	LDGO	Eltanin	1971	10
78	79.65576	-54.8297	-3915	0060/062	1645	FOS	76	KERGUELEN 3	FRANCE	Marion Dufresne	1986	5
79	79.48381	-54.5452	-4158	0059/033	208	FOS?	74	KERGUELEN 2	FRANCE	Marion Dufresne	1986	1
80	80.15194	-52.5829	-4155	0060/062	250	FOS	79	KERGUELEN 3	FRANCE	Marion Dufresne	1986	5

Kerguelen Plateau foot of slope picks

	A	B	C	D	E	F	G	H	I	J	K	L
81	79.97243	-53.6293	-4230	0060/062	875	FOS	**78**	KERGUELEN 3	FRANCE	Marion Dufresne	1986	5
82	78.27433	-52.0703	-3578	1101/051	567	EAP	**85**	elt71/72	LDGO	Eltanin	1971	10
83	78.17814	-52.1568	-3460	1101/051	633	FOS	**84**	elt71/72	LDGO	Eltanin	1971	10
84	78.90741	-52.3379	-3789	1351/022	175	FOS/EAP	**95**	C0802	LDGO	R. Conrad	1964	6
85	77.61671	-51.8011	-3456	1677/035	2167	FOS	**89**	UM66-C	UTOKYO	Umitaka Maru	1967	10
86	78.16511	-51.5667	-3557	1677/035	2400	EAP	**90**	UM66-C	UTOKYO	Umitaka Maru	1967	10
87	79.14353	-52.3523	-3922	0036/073	1550	LFOS	**83**	HEARD ISLAND	NATMAP	Cape Pillar	1980	1
88	78.92414	-52.3874	-3853	0036/073	1630	FOS	**82**	HEARD ISLAND	NATMAP	Cape Pillar	1980	1
89	77.82923	-51.9432	-3225	0060/061	1550	FOS?	**86**	KERGUELEN 3	FRANCE	Marion Dufresne	1986	5
90	76.05441	-50.7489	-3147	1697/009	2273	FOS/EAP	**93**	ELT46	LDGO	Eltanin	1971	5 to 10
91	76.17681	-50.8074	-3217	0036/084	1215	FOS/EAP	**91**	HEARD ISLAND	NATMAP	Cape Pillar	1980	1

Appendix 4

Acquisition Parameters

Navigation

Continuous dGPS.

Echo sounding

Continuous 12 kHz and 3.5 kHz.

Magnetics

Continuous gradiometer (preferred) or single detector magnetometer; required for spreading anomalies.

Gravity

Continuous; required for scientific (deep) targets.

Seismic

Source : 1 or 2 arrays of 10 x Sleeve guns (150 in^3 each) @ 1800 psi.
or 1 or 2 arrays of 6 x G.I. guns (variable volume) @ 1800 psi.
Source Depth : 10 m nominal.

Receiver, Reflection	Streamer : minimum 3000 m, 25 m groups.
	Streamer Depth : minimum 10 m nominal.
	Shot Frequency : 19.4 sec. at 5 knots.
	Shot interval : 50 m.
	Data : Record length 16 sec.
	Sample rate 4 msec.
	Filter settings 4/180 Hz.
Receiver, Refraction	Sonobuoys

Appendix 5

Way point listing of proposed lines

LINE NAME	COMMENTS	SP	LATITUDE DD MM SS	LONGITUDE DDD MM SS	LOS PURPOSE	DISTANCE (KM) IN PART	TOTAL
KP-A	SOL	1.0	55 55 04.7S	65 32 48.7E	2500 m - extend the		
KP-A	EOL	2.0	55 20 30.5S	65 10 35.5E	cut-off boundary		68.3
KP-B	SOL	1.0	55 20 30.5S	65 10 35.5E	FOS		
KP-B	EOL	2.0	54 41 34.1S	63 39 29.4E	(optional)		121.0
KP-C	SOL	1.0	56 21 08.0S	63 07 49.6E	FOS		
KP-C	EOL	2.0	56 25 26.8S	65 16 08.8E			132.3
KP-D	SOL	1.0	56 35 53.4S	65 12 15.5E	FOS - extend		
KP-D	EOL	2.0	57 21 41.3S	62 02 50.1E	the Hedberg Line (optional)		209.9
KP-E	SOL	1.0	57 041 4.0S	65 28 55.4E	FOS - extend the		
KP-E	TURN	2.0	57 37 50.3S	64 29 29.1E	Hedberg Line,	86.3	
KP-E	EOL	3.0	58 42 07.2S	63 31 42.8E	SED	132.1	218.4
KP-F	SOL	1.0	58 53 21.8S	65 56 08.5E	FOS, SED		
KP-F	EOL	2.0	57 01 10.8S	66 26 08.3E			210.3
KP-G	SOL	1.0	57 11 45.6S	71 10 33.1E	FOS		
KP-G	EOL	2.0	58 05 04.8S	70 54 26.5E			100.3
KP-H	SOL	1.0	58 15 03.6S	70 54 59.9E	TRANSECT		
KP-H	TURN	2.0	57 06 55.8S	75 08 51.5E	2 FOS, SED in the	282.2	
KP-H	TURN	3.0	56 05 39.6S	80 02 42.9E	northern Labuan	321.5	
KP-H	EOL	4.0	54 46 23.5S	84 49 54.3E	Basin	336.7	940.4
KP-I	SOL	1.0	55 51 09.8S	65 40 53.4E	FOS, SED		
KP-I	EOL	2.0	53 25 30.2S	66 47 17.3E	(optional)		279.5
KP-J	SOL	1.0	61 56 27.1S	89 01 39.9E	FOS, SED		
KP-J	TURN	2.0	61 40 34.5S	86 54 14.2E		115.8	
KP-J	EOL	3.0	61 15 24.6S	85 32 36.6E		86.3	202.1
KP-K	SOL	1.0	61 12 20.9S	85 33 31.0E	FOS, SED		
KP-K	EOL	2.0	61 01 16.1S	89 11 31.7E			197.0
KP-L	SOL	1.0	58 23 14.8S	87 26 39.6E	FOS, SED		
KP-L	EOL	2.0	58 36 53.7S	83 21 12.8E			239.0
KP-M	SOL	1.0	58 01 50.0S	83 07 58.1E	FOS, SED		
KP-M	EOL	2.0	56 59 52.3S	85 13 13.3E			169.9
KP-N	SOL	1.0	56 15 06.0S	84 03 43.6E	FOS, SED		
KP-N	EOL	2.0	57 21 33.8S	82 09 38.8E			169.4

KP-O	SOL	1.0	54 44 36.7S	83 31 08.0E	2 FOS, 2500 m		
KP-O	TURN	2.0	54 17 24.3S	82 41 32.0E		73.6	
KP-O	EOL	3.0	53 10 36.5S	82 50 44.7E		124.3	197.9
KP-P	SOL	1.0	53 47 46.9S	82 25 43.3E	FOS, 2500 m		
KP-P	EOL	2.0	53 45 16.7S	83 48 08.3E			90.7
KP-Q	SOL	1.0	52 49 39.8S	82 39 24.5E	FOS, 2500 m		
KP-Q	EOL	2.0	53 19 31.9S	80 47 27.2E			136.8
KP-R	SOL	1.0	52 13 47.8S	81 13 40.2E	FOS, 2500 m		
KP-R	EOL	2.0	53 19 31.9S	80 47 27.2E			125.4
KP-S	SOL	1.0	51 13 31.0S	77 20 33.2E	FOS		
KP-S	EOL	2.0	51 50 11.8S	76 45 07.5E	(optional)		79.4
					Total		**3755.9**
					Optional lines		**689.8**

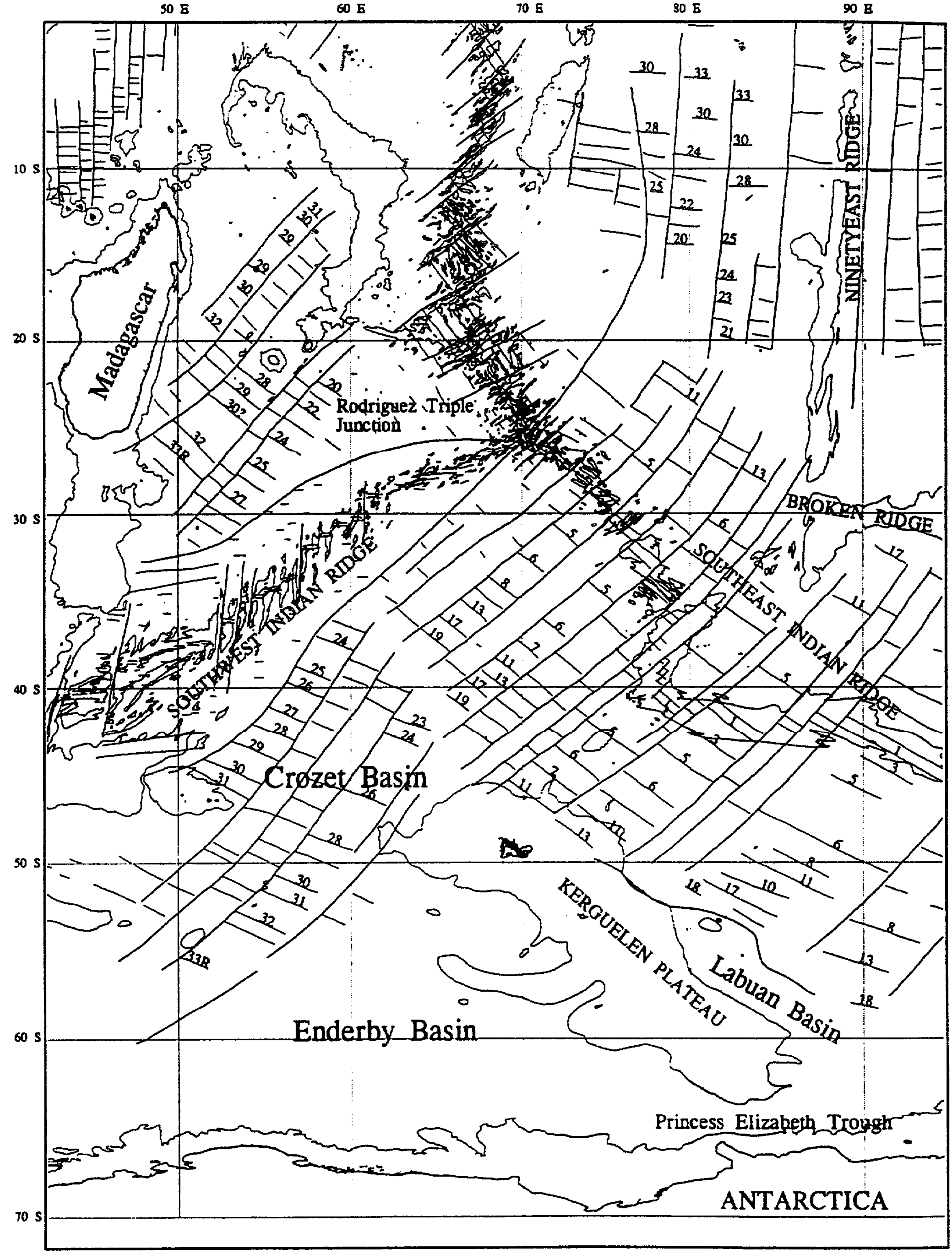

Fig. 1. Plate tectonic setting of the Kerguelen Plateau. Shows magnetic lineations and major transform faults. Outline of the plateau is shown by 3000 m contour.

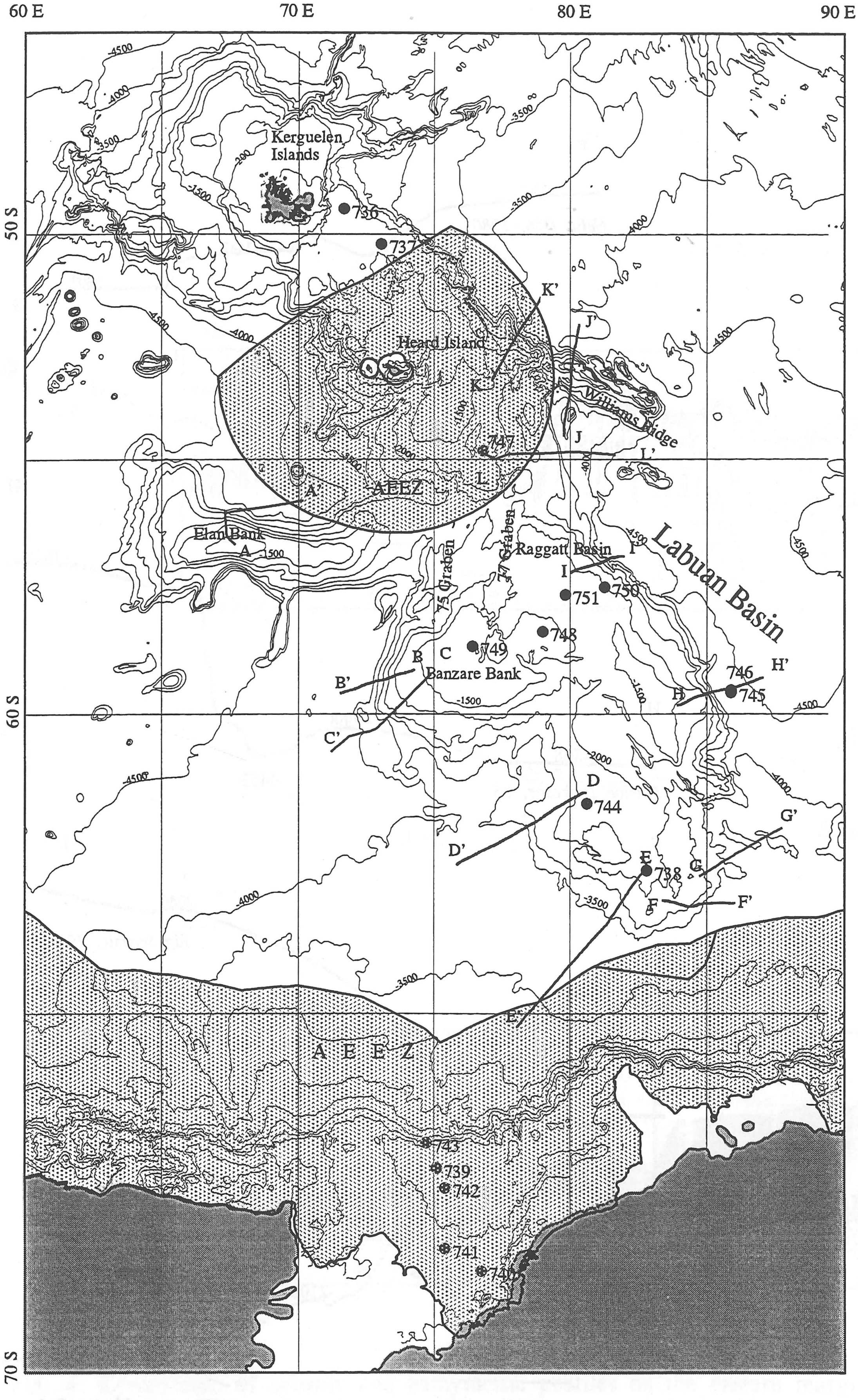

Fig. 2. Bathymetric map of the Kerguelen Plateau (new GEBCO version).
Shows locations of profiles in Figures 3-5. Also shows locations of ODP drilling sites and boundaries of Australian EEZ around Heard/MacDonald Islands and the Australian Antarctic Territory.

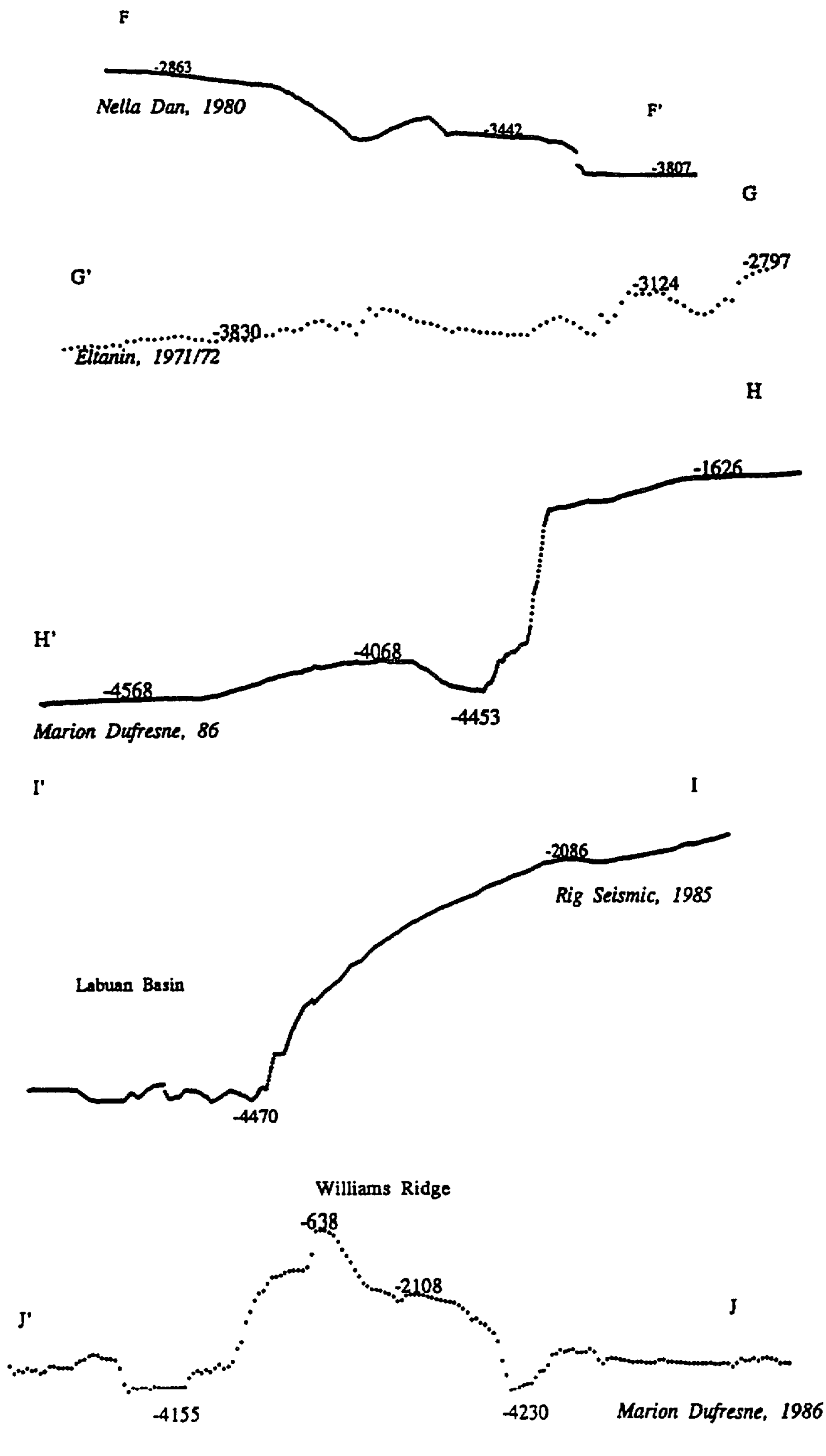

Fig. 3. Examples of bathymetric profiles across the eastern margin of the plateau. Location of the profiles is shown in Fig. 2.

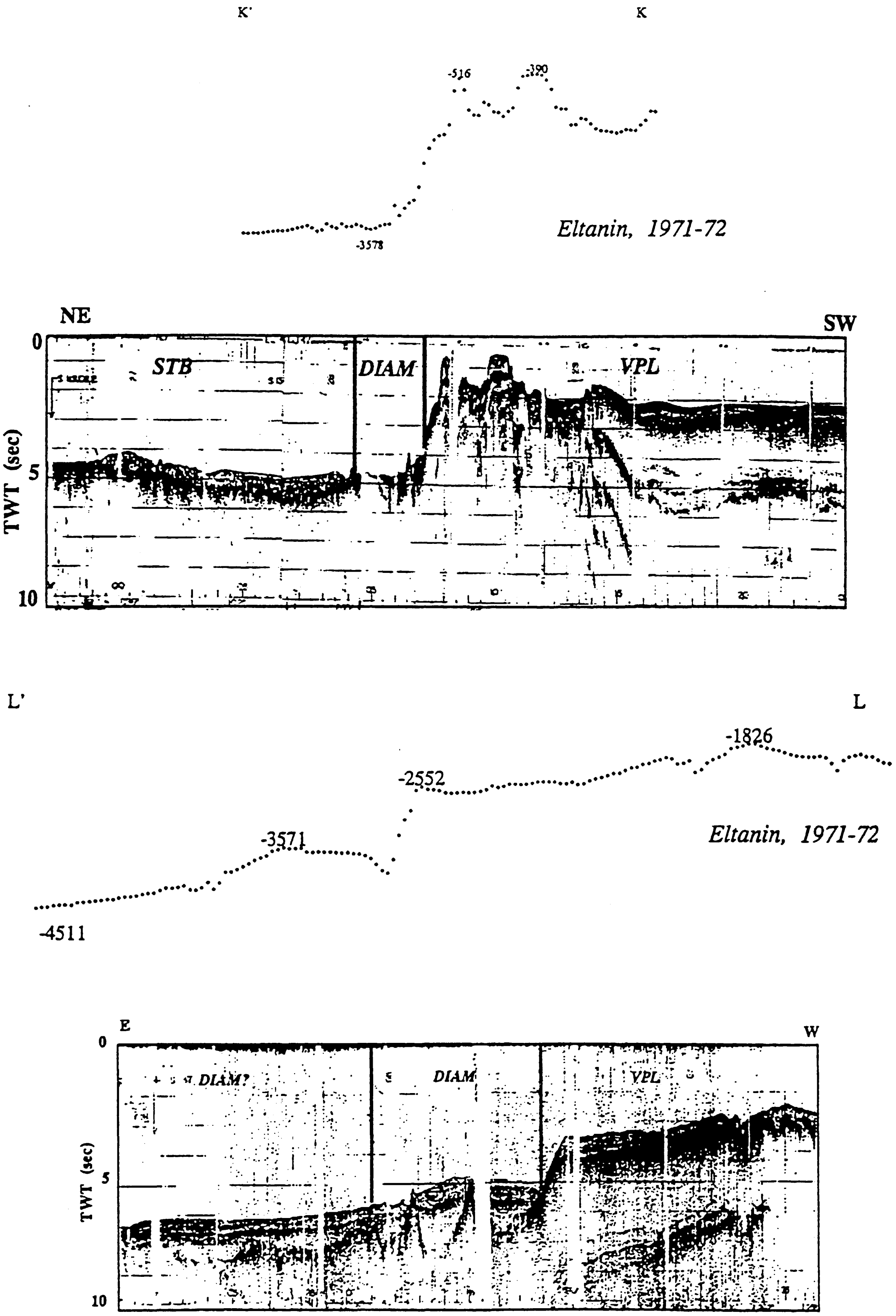

Fig. 4. Comparison of seismic and bathymetric profiles on the eastern margin showing complex basement structure in the adjacent ocean basin - Eltanin, survey 47 (USNS Reports, Cruises 46-50, 1977). Location of the profiles is shown in Fig. 2.

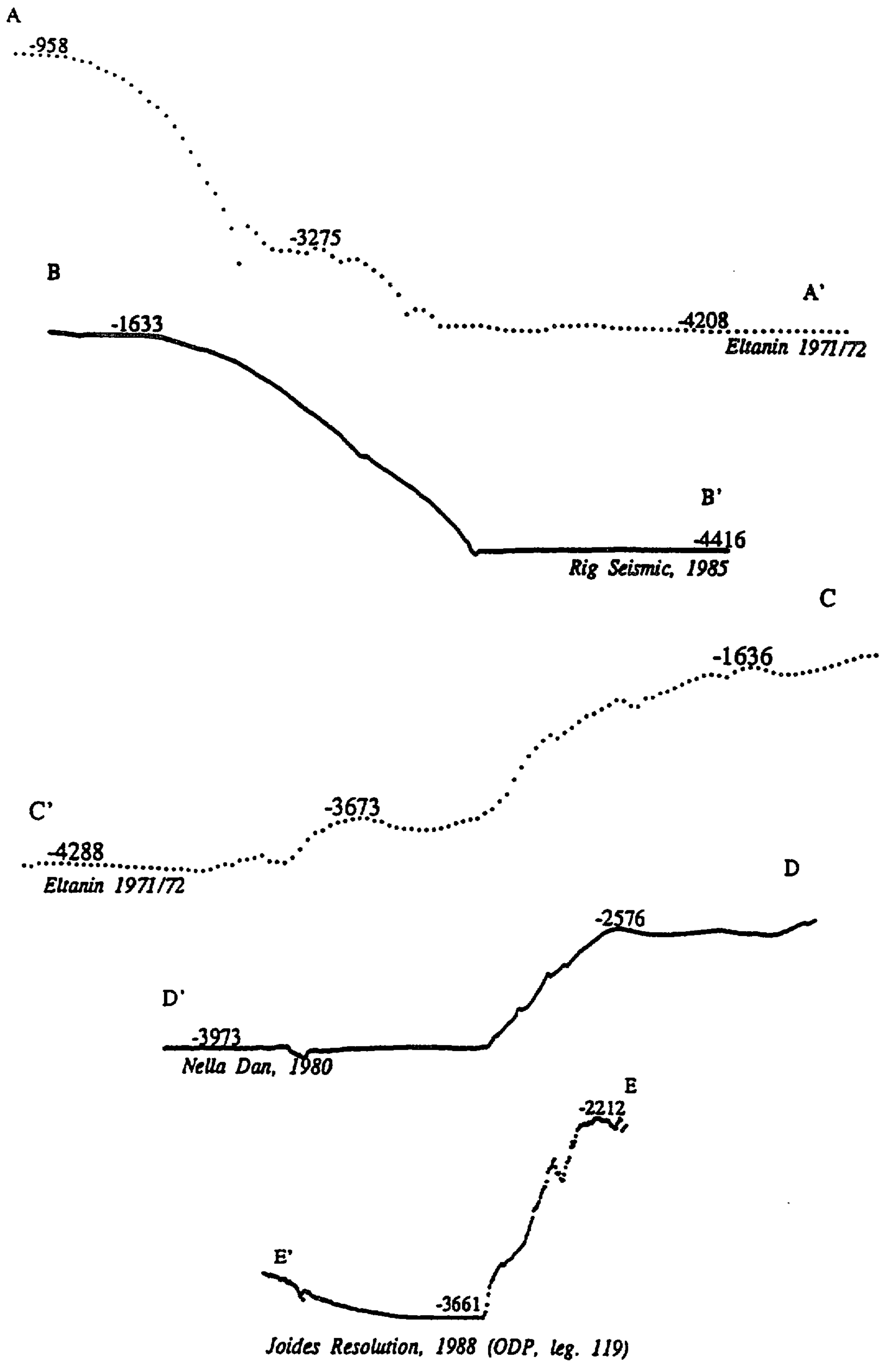

Fig. 5. Examples of bathymetric profiles across the western margin of the plateau. Location of the profiles is shown in Fig. 2.

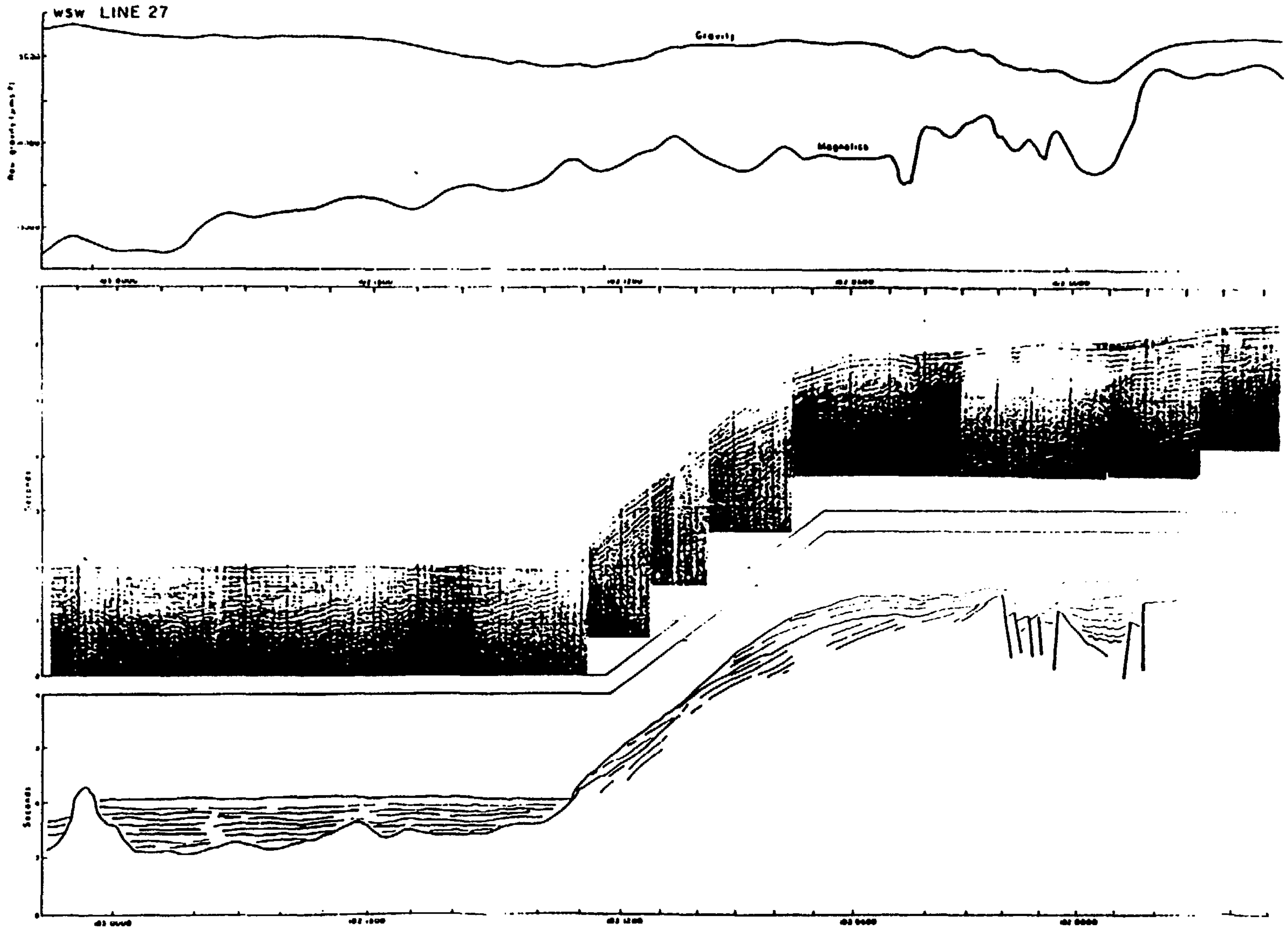

Fig. 6. Single-channel seismic profile, line drawing, and gravity and magnetic profiles for line 27 - *Rig Seismic*, survey 47 (after Ramsay et al., 1986).

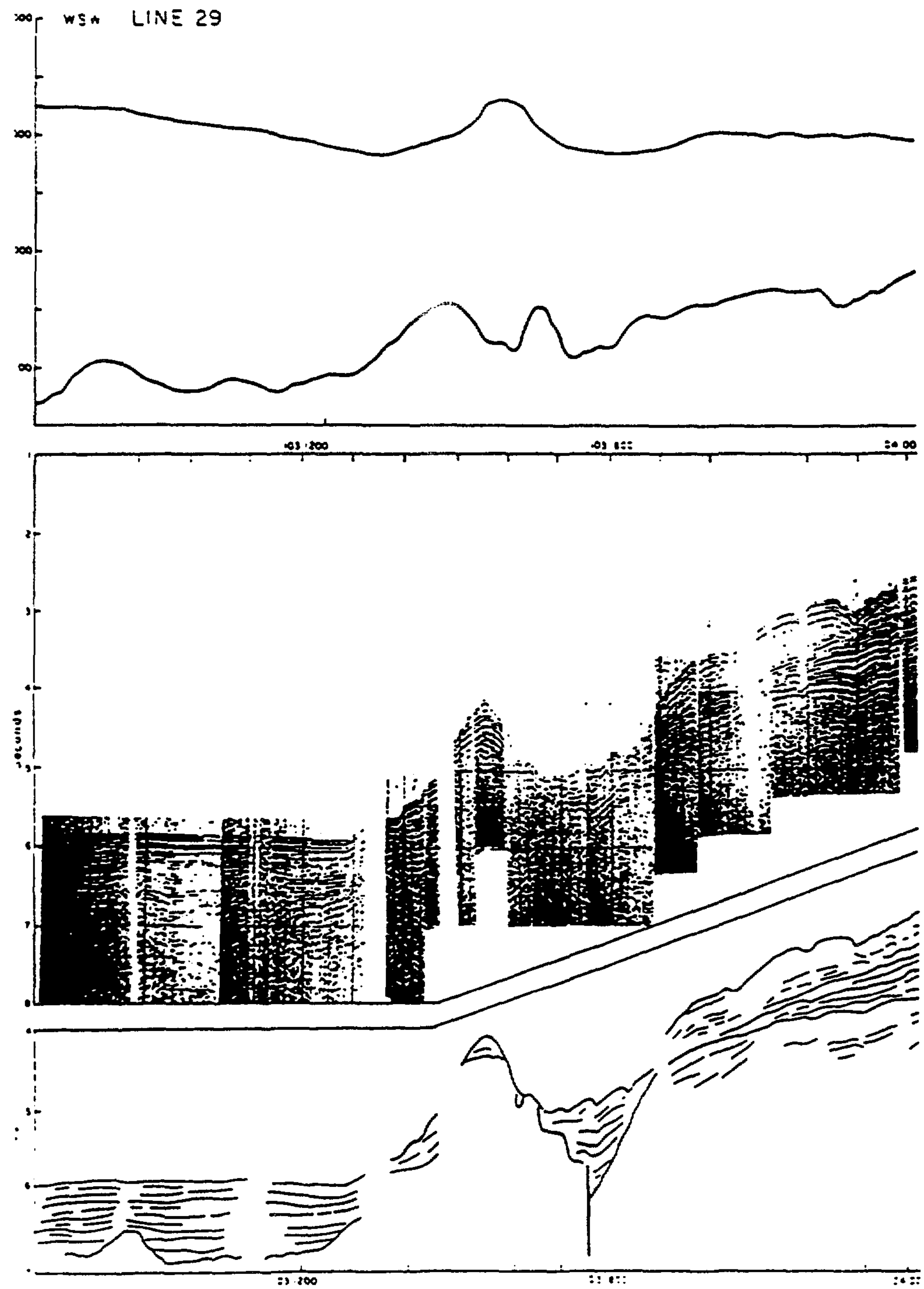

Fig. 7. Single-channel seismic profile, line drawing, and gravity and magnetic profiles for line 29 - *Rig Seismic*, survey 47 (after Ramsay et al., 1986).

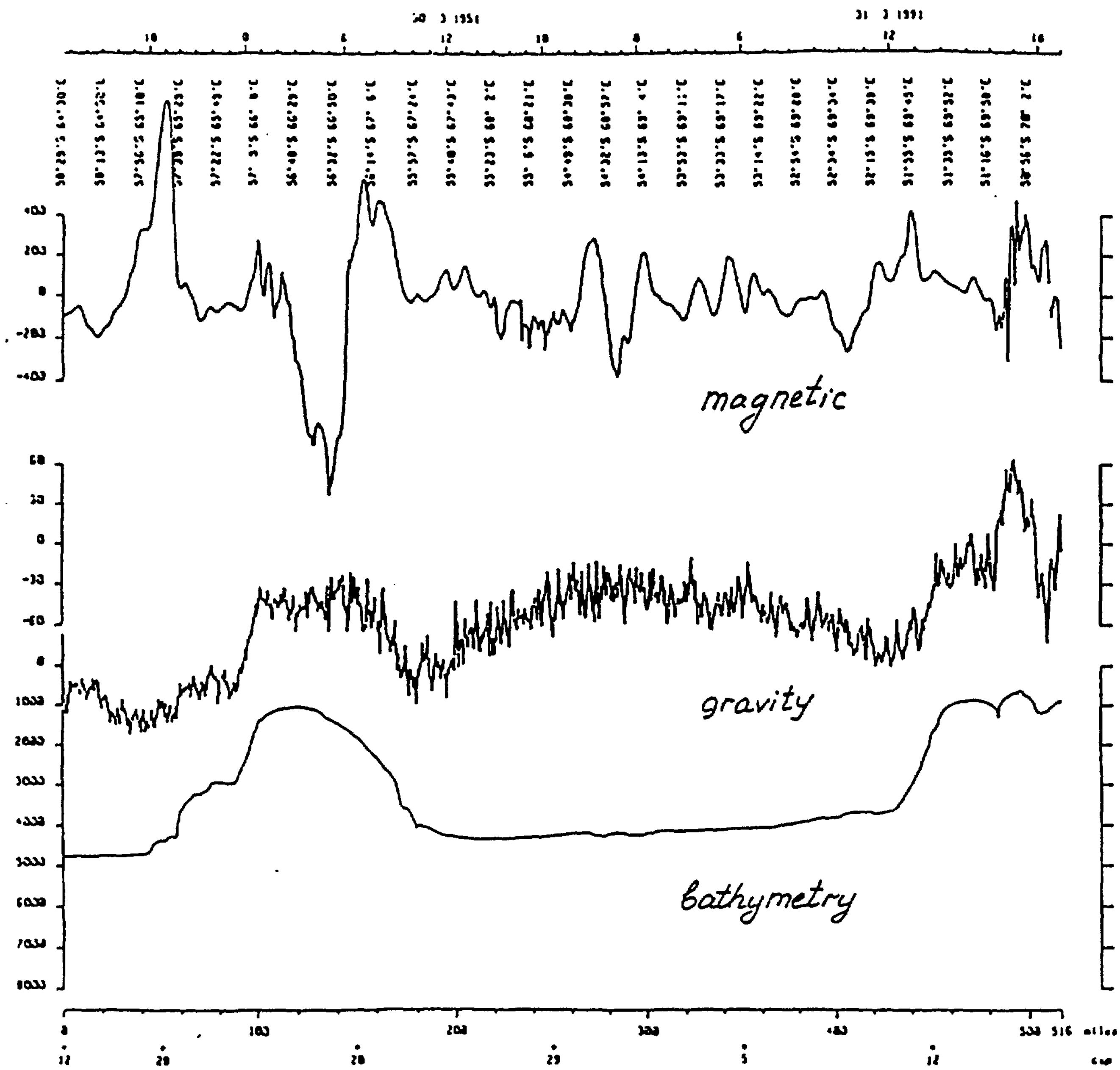

Fig. 8. Bathymetric, gravity and magnetic profiles across the Elan Bank - *Marion Dufresne*, survey 67 (after Schlich, 1991).

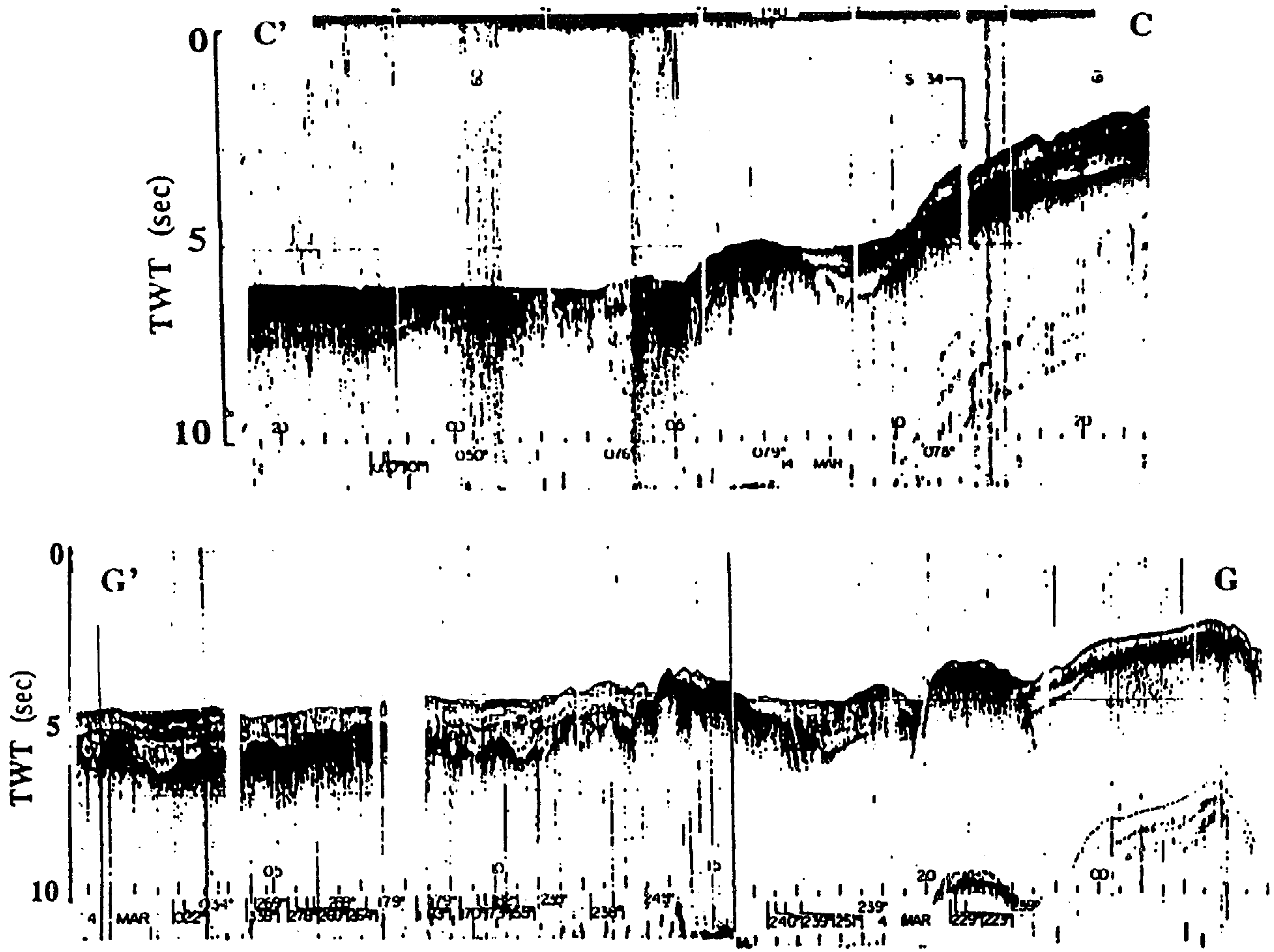

Fig. 9. Single-channel seismic profiles corresponding to bathymetric profiles C-C' and G-G' - *Eltanin*, survey 47 (USNS Reports, Cruises 46-50, 1977). Location of the profiles is shown in Fig. 2.

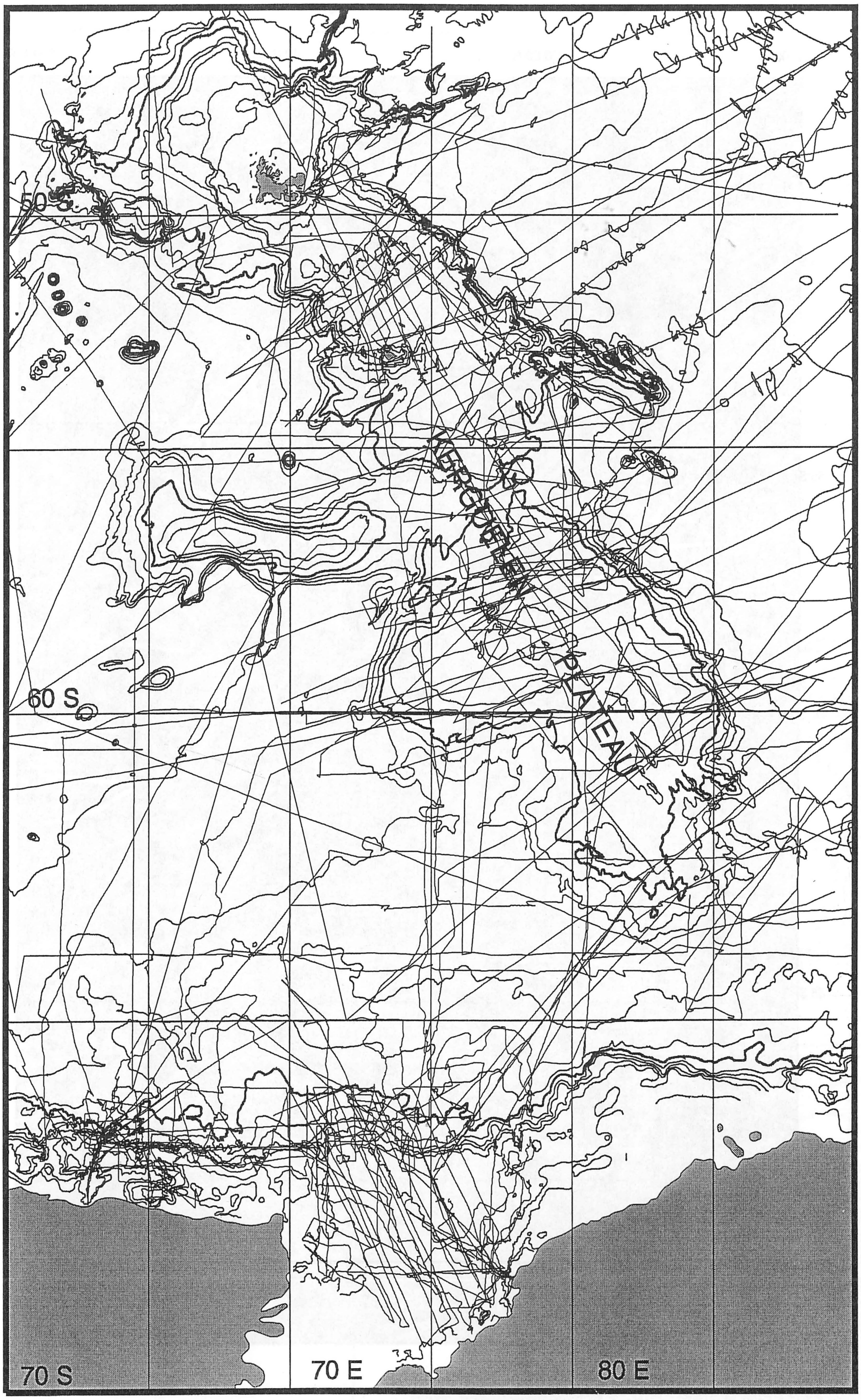

Fig. 10. Existing survey track chart for the Kerguelen Plateau region. Shows track lines used for definition of the foot-of-slope picks (surveys are listed in Appendix 2)

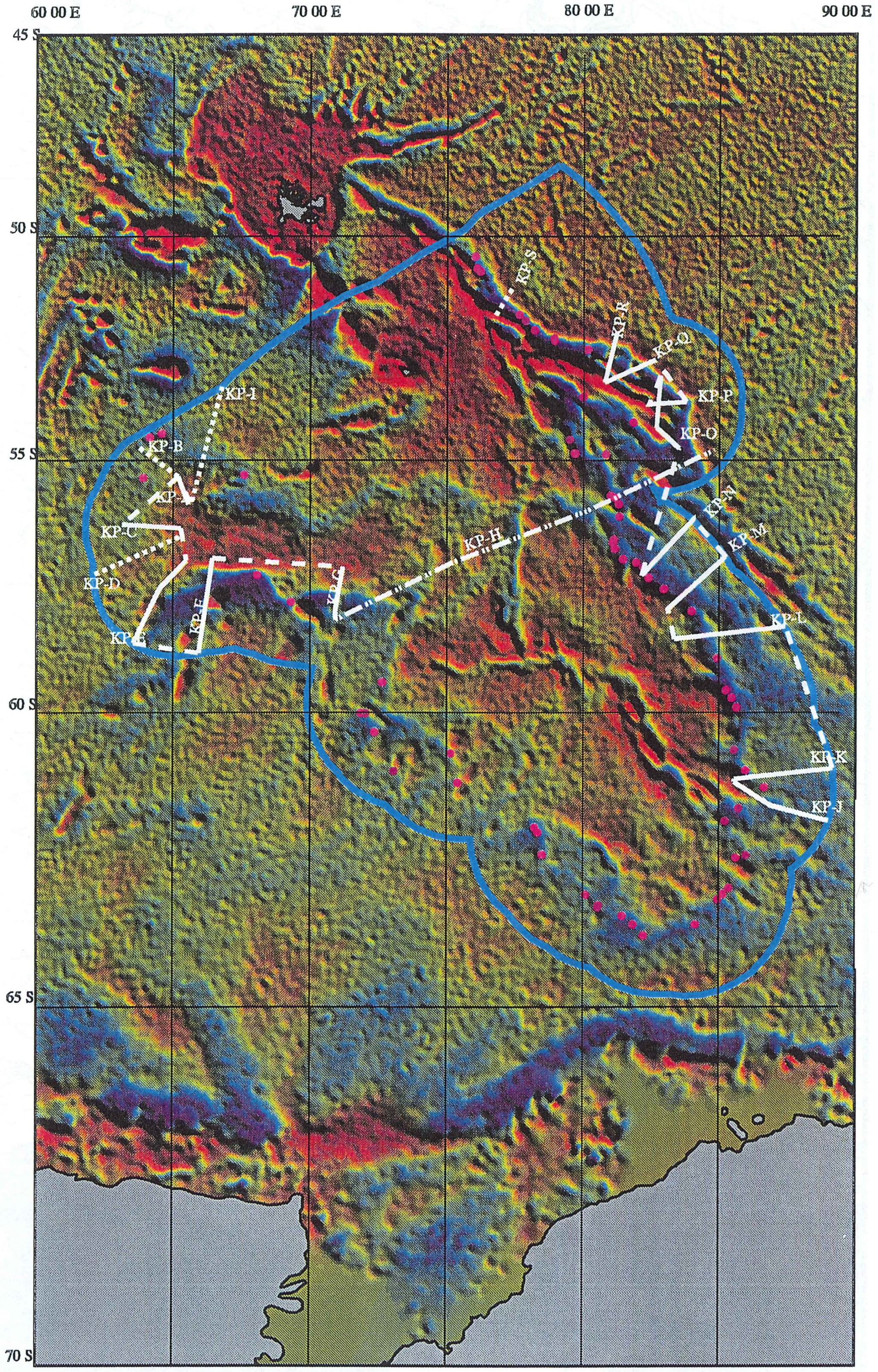

Fig. 11. Satellite gravity image of the Kerguelen Plateau. The location of foot-of-slope picks are shown by the red dots. Also shows the proposed lines for both surveys.

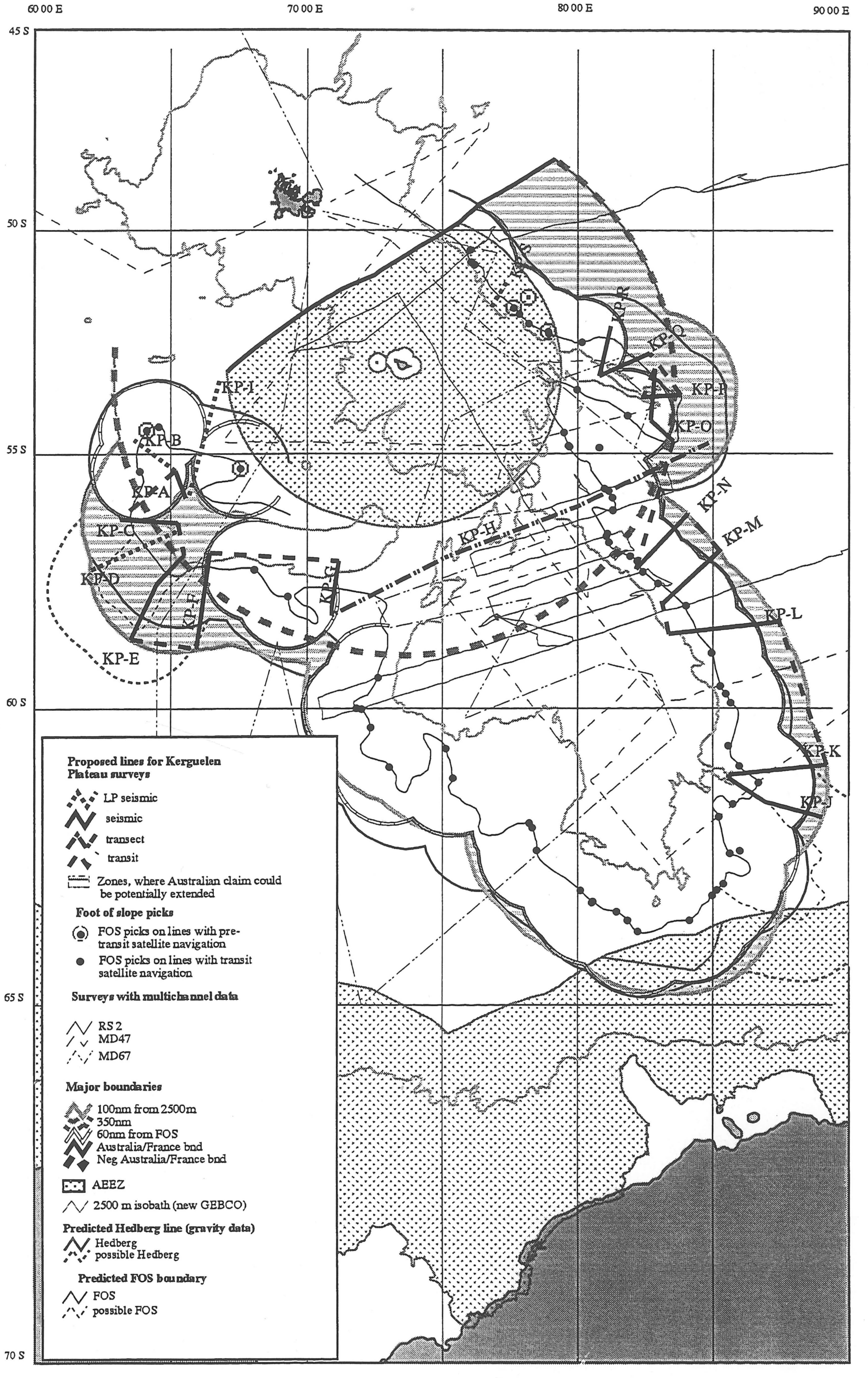

Fig. 12. Proposed seismic lines for Kerguelen Plateau surveys. Shows foot-of-slope picks, Hedberg Line based on the existing data, 2500 m isobath and cut-off boundaries (maximum claimable area).