# CIRCUM-TASMANIA AND SOUTH TASMAN RISE: CRUISE PROPOSAL FOR DEEP CRUSTAL SEISMIC DATA ACQUISITION, 1995

by

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AUSTRALIAN GEOLOGICAL SURVEY ORGANISATION

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**Marine, Petroleum and Sedimentary Resources Division**

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## SUMMARY

RV *Rig Seismic* will be used to conduct a deep crustal seismic and geophysical acquisition program off Tasmania in early 1995. The program will comprise two components, (i) a circum-Tasmania series of 23 lines that form part of the 'TASGO' National Geoscience Mapping Accord (NGMA) Project, and (ii) several long regional lines over the South Tasman Rise (STR) and adjacent areas, forming part of AGSO's Continental Margins Program.

The TASGO marine seismic sub-program is part of a larger NGMA project which includes onshore reflection seismic, refraction tomography, and aeromagnetic surveys (both onshore and offshore). The main aim of the project is to map, in 3-D, the principal structural and tectonic elements that make up the Tasmanian craton, and to better understand the evolution of this crustal block.

The deep seismic profiles over the STR region are designed to complement recent investigations of this poorly-surveyed region, particularly the 1994 RV *L'Atalante* swath-mapping / moderate-penetration GI-gun seismic survey and February 1995 RV *Rig Seismic* sampling cruise. This part of the southern Australian margin developed in the Jurassic and continued its evolution through the Cretaceous by a poorly-understood sequence of rift phases and wrench movements. The proposed seismic work, integrated with the previous studies, aims to, (i) improve our knowledge of the deep structure and crustal architecture of this complex part of the southern margin, (ii) provide structural data to constrain and help develop kinematic models for the plate tectonic evolution of the region, and (iii) assess the petroleum potential of this frontier area.

Seismic acquisition will be by 192-channel, 4800 m streamer and 50-litre airgun array. Data to be collected will be 48-fold with 16 second record length. Gravity, total-field magnetics and bathymetry data will also be acquired during the survey. During the survey the airguns will act as seismic source for a network of seismic refraction receiver stations set up throughout Tasmania.

The ship will depart ex Hobart and be at sea for up to 31 days. The length of the survey could be reduced due to other survey commitments. About 1900 line-km have been planned for the TASGO survey and 2300 line-km for the STR region. Bad weather, problems with fishing gear (particularly cray-pots) and the possible need to cut the survey short could significantly reduce the achievable seismic production. The TASGO survey has priority over the STR survey.

# INTRODUCTION

The Marine, Petroleum and Sedimentary Resources Division of AGSO plans to conduct a major deep crustal seismic and geophysical program off Tasmania and over the South Tasman Rise in early 1995. The data acquisition will be done using AGSO's research vessel *Rig Seismic* (Appendix 1).

The acquisition program will comprise two parts:-
1. a 'TASGO' component, a series of transects around the coast of Tasmania (Figure 1) which will form part of the Tasmania National Geoscience Mapping Accord (NGMA) Project, and
2. an AGSO Continental Margins Program (CMP) component, consisting of a series of long regional transects over the South Tasman Rise (STR) and adjacent offshore areas (Figures 2 and 3).

The main aim of the marine TASGO study is to map crustal structure at depth around the periphery of Tasmania. Correlation with onshore geology, together with results of other components of the NGMA project, such as aeromagnetics, onshore deep seismic reflection and refraction tomography, will lead to a much better understanding of the 3-D structural and tectonic architecture of Tasmania as a whole, and its geological evolution through time.

The transects over the STR and adjacent areas are designed to investigate the deep structure and tectonic evolution of this part of the southern continental margin of Australia. This work is an integral part of studies of this area currently being undertaken and follows the recent (February/March 1994) AGSO swath-mapping and geophysical survey using the French RV *L'Atalante* (Exon et al., 1994) and the *Rig Seismic* geological sampling program (Exon, 1995) now in progress (February 1995).

Both the TASGO and STR surveys will provide fundamental geological data that will assist in the exploration for, and management of mineral and petroleum resources in the Tasmanian region.

The seismic acquisition will be by 4800 m streamer and 50 litre airgun source, collecting 48-fold data and 16 second records. Appendix 2 provides the main seismic acquisition parameters. Gravity, magnetics and bathymetry data will also be collected. A full list of survey and equipment specifications is shown in Appendix 3. The ship will have a complement of 32 (Appendix 4), comprising 17 AGSO personnel, 14 AMSA crew and a fisherman from Tasmania who will facilitate operations in the main fishing grounds.

The survey has been planned assuming that 31 days of ship time are available. If less time is available, a sub-set of the full program will be completed. The cruise, AGSO Survey 148, will depart from Hobart after completion of the Tasmanian geological cruise (Survey 147; Exon, 1995).

The acquisition program mapped out amounts to a total of 4200 line-km of seismic, comprising about 1900 km in the TASGO sub-program and 2300 km in the STR sub-program. This is achievable, but only under very good weather conditions and minimal down-time due to equipment and other problems. Some reduction or modification of the optimum program may be required as the survey progresses.

## GEOLOGICAL BACKGROUND

### Plate Tectonic Setting Of The Tasmania / South Tasman Rise Region
(after Royer and Rollet in Exon et al., 1994)

The STR is known from deep sea drilling and dredging to be of continental origin, and as such was part of the former East Gondwana continent. Reconstructions of Gondwana show that the STR was contiguous to several continental fragments that are now thousands of kilometres apart. Going counterclockwise, the STR was bounded by Victoria Land, Antarctica, to the west, by the Ross Sea shelf to the south, by the Campbell Plateau to the southeast, by the Challenger Plateau and Lord Howe Rise to the east, and by Tasmania and Australia to the north. The STR is the smallest of these Gondwana fragments, and because of its central location in the plate boundary framework that developed within East Gondwana, it underwent all the major tectonic events that led to the dispersal of the Gondwanan fragments. These tectonic events span from the Late Jurassic to the Late Oligocene, after which the STR drifted passively northward along with the Australian plate.

Early extension between Australia and Antarctica started in the Late Jurassic along a NW-SE direction (relative to a fixed Australian plate; Willcox and Stagg, 1990). Extension in the Bass Strait, between Tasmania and the mainland, is contemporaneous and, in large part, in the same direction (Willcox et al., 1992). This extension phase lasted until the Late Cretaceous when seafloor spreading started in the Great Australian Bight (Cande and Mutter, 1982). The continent-ocean boundary is dated as 95 Ma old (Cenomanian; Veevers, 1986). Subsidence studies along the southern Australian margin, as well as the conjugate pattern of seafloor magnetic anomalies off Australia and Antarctica, suggest that the breakup between Australia and Antarctica propagated from the Great Australian Bight towards Tasmania (Mutter et al., 1985). Seafloor spreading started at a very slow spreading rate (< 1 cm/yr, full rate) until the Early Eocene, increasing somewhat to a slow rate (~ 2 cm/yr) until the Middle Eocene. The western margins of Tasmania and STR paralleled the north-south seafloor spreading direction and therefore behaved as a transform margin. It is possible that north-south extension was initiated at this time between Tasmania and the STR (Veevers et al., 1991), as the STR might have still been attached to Antarctica.

Seafloor spreading between Australia and Antarctica accelerated drastically (up to 4-5 cm/yr) in the Middle Eocene (~chron 18; 45 Ma). This event coincided with major reorganisation of the plate boundaries in the Indian and Pacific Oceans. During this second stage, the STR remained attached to the Australian plate; but this does not preclude any further extension, if not early oceanisation, between the STR and Tasmania. At chron 13 (36 Ma; late Oligocene), the large transform offset of the Tasmanian and STR margins (~750 km long) was still preventing any deep water circulation between the Australian-Antarctic Basin and the Pacific Ocean. The Southeast Indian ridge axis remained in contact with the STR western margin until about chron 8 (28 Ma). As seafloor spreading continued, the transform margin of the STR gave birth to the large-offset Tasman and Balleny oceanic fracture zones. The outstanding signatures of these fracture zones on the satellite gravity data provide major constraints to reconstruction of the relative motions of Australia and Antarctica (Royer and Sandwell, 1989).

Rifting along the eastern margin of Australia, Tasmania and the STR, probably began in the mid Cretaceous. The opening of the Tasman Sea, between Lord Howe Rise/Challenger Plateau and Australia, started in the Late Cretaceous (~chron 33; 80 Ma), along an ENE-WSW direction (Hayes and Ringis, 1973; Weissel and Hayes, 1977). Seafloor spreading propagated from south to north along the eastern Australian margin. The oldest magnetic anomalies (chron 33) identified in the Tasman Sea are located just east of the East Tasman Plateau. Further south, lack of magnetic anomaly profiles prevents any exact dating of the oceanic crust lying east of the STR. However, plate reconstructions at chron 33 bring the western slopes of Challenger Plateau next to the STR (e.g. Molnar et al., 1975). Seafloor spreading in the Tasman Sea stopped abruptly in the early Eocene (chron 24/23, 55 Ma), probably when the Australian-Antarctic and Pacific-Antarctic spreading systems connected south of the STR.

Seafloor spreading resumed south of the Tasman Sea almost at right angles to the former spreading ridge, leaving a prominent scar on the seafloor, extending from the southeastern tip of the STR to the South Island of New Zealand. The oldest magnetic anomalies, south of this boundary, roughly oriented east-west, are of Middle Eocene age (chron 21-22; 50 Ma) and record the relative motion between the Antarctic and Australian plates. South of the STR, early-mid Eocene basal sediments were recovered at DSDP site 280, suggesting that seafloor spreading between Antarctica and the STR started during this plate boundary reorganisation in the Tasman Sea. The large time difference between of initiation of seafloor spreading west (Late Cretaceous) and east (early/mid Eocene) of the Tasman transform margin suggests major extension, if not oceanisation, took place between the STR and Tasmania.

The plate reconstruction of East Gondwana brings the southern boundary of the STR along the Ross Sea shelf and the western Campbell Plateau (e.g. Molnar et al., 1975; Weissel et al., 1977). The breakup of these continental fragments seems to have occurred in the Late Cretaceous with a triple junction developed in the vicinity of the STR. The three branches of this system being: (i) to the north, the Tasman spreading ridge between Tasmania-Australia and the Challenger Plateau-Lord Howe Rise, (ii) to the south, the early Pacific-Antarctic Ridge separating the Ross Sea shelf from the Campbell Plateau, and (iii) to the east, a transform boundary splitting the Challenger Plateau from the Campbell Plateau. An additional plate boundary is hypothesized between East and West Antarctica, across the Ross Sea.

## STR / Offshore West Tasmania: Morphology And Seafloor Character Based On 1994 *L'Atalante* Survey

The summit area of the STR is dome-shaped and gently sloping. Down to the 1400 m isobath, it is about 150 km across. The summit is fairly flat at about 800 m depth, though several hillocks are as shallow as 725 m. The acoustic imagery suggests that the summit area is mostly covered by pelagic sediment; rocky outcrop comprises about 40%. Canyons, typically about 50 m deep, run down the northern and northeastern flanks of the Rise from about the 1500 m isobath. A number of conical hills on the northern flank are probably volcanoes. They are 200-300 m high, 3-4 km across and show high backscatter (and are therefore rocky). The northern flank is crossed by a NW-trending basement ridge and escarpment that are largely bare of sediment cover.

The deep ocean basin between the ETR and the STR has a flat, sedimented floor. The floor of the basin lies at water depths of 3950-4150 m and is about 120 km wide.

The western and northwestern STR is an region of diverse and spectacular topographic relief. The most prominent structural feature is the NNW-striking lineament of the Tasman Fracture Zone, separating the high-standing continental rocks of the STR from Paleogene oceanic crust at abyssal depths (4000-4800 m) to the west. The lineament is 600 km long and consists of a narrow (20 km wide) zone of high-relief ridges, troughs and escarpments. The scarps are 2-2.7 km high in places. Another transform escarpment, 1500 m high, is located at the extreme southwest corner of the STR. It parallels the Tasman Fracture Zone but is offset 50 km to the east. Its mapped length is 100 km. The abyssal plains (4000-4600 m depth) adjacent to the southeastern part of the STR are relatively flat-lying and appear to be mostly sediment covered, yet they produce fairly high acoustic backscatter and appear quite dark in the acoustic imagery. This suggests that either they may be covered by a pavement of manganese nodules and/or crust or that deep-sea currents have scoured the seafloor, perhaps leaving coarse lag deposits.

The swath data over the oceanic crust west of the Tasman Fracture Zone clearly display the E-W oriented spreading fabric. The acoustic imagery shows that the sediment cover is moderate to thin in the north and only a veneer or absent in the south. The repeated series of horst and grabens are produced by normal faults generally spaced 2-8 km apart. The fault scarps are typically 100-300 m high. The most pronounced spreading fabric terminates against a well-defined oceanic transform fault that lies just west of the Tasman Fracture Zone. This transform meets the Tasman Fracture Zone at a slight angle (6°).

The more elevated (3500 m depth or less) central and southern parts of the western STR are of moderate to gentle relief and mostly sedimented by pelagic cover. Some patches of bedrock outcrop are present at escarpments. A line of such outcrop trends NNE through this area. The northwestern part of the STR is a jumble of large basement blocks probably produced by wrench movements. Relief is high, often 500-1000 m, and about 40% of the seafloor appears to be exposed bedrock. A large, 1500 m high seamount at 45° 10'S 146° 00'E has little sediment cover and may be a volcano.

The continental slope immediately south of Tasmania, from ~700 m depth (upslope limit of mapping) to more than 3200 m in the saddle between Tasmania and the STR, is of rugged topography. Extensive rock exposures are present on the upper part of the slope, which is also cut by a number of jagged canyons up to several hundred metres deep. The most remarkable feature of the slope is a large field of volcanic cones in water depths of 900-2300 m. Most cones are clustered in the one field, but other more isolated cones are also present. More than 70 cones have been mapped. The cones are typically 400 m high and several km across. The larger ones are about 600 m high. Some of the cones have flat tops which could be summit craters (?now filled with pelagic sediment) or perhaps these cones were planated by subaerial erosion prior to submergence as the margin sagged.

Off western and southwestern Tasmania, the continental slope is mostly blanketed by an extensive sheet of sediment. The slope is incised by an extensive system of linear to curvilinear, 100m-deep canyons that extend 60 km or more from the shelf edge to depths of several thousand metres. A 50 km wide and 300 m deep depression on the upper slope off southwest Tasmania (centred at about 43° 10' S 145° 00' E) is probably the scar of a massive submarine landslide. Several local highs were mapped on the southwestern mid-slope. Strong acoustic backscatter from parts of these (particularly their down-slope sides), suggests exposed bedrock. A series of local highs and NW-trending ridges rise above the relatively gently inclined lower slope and flat abyssal plain in water depths of 3500-5000 m. Many of the highs are partially covered by sediment. However, most of these features are of high relief and as a result the steeper slopes have remained sediment-free. The largest of these highs is a 160 km long ridge on the lower southwest continental slope. It stands up to 2.5 km above the surrounding seafloor and the slope of its southwest side (~24°) is considerably steeper than that on the northeast (~6°).

## Structure And Sediment Distribution West And South Of Tasmania Based On 1994 *L'Atalante* Survey Results

A preliminary map of sediment time-thickness and basement structure (Figure 4) has been produced for the entire Tasmanian/STR survey area. This map is based on the *Tasmante* monitor seismic records, but also includes data from earlier surveys (Figure 5). The earlier data sources include *Sonne* survey SO36B (Hinz et al., 1985; Hinz et al., 1986), AGSO *Rig Seismic* survey 78 (Exon et al., 1989) and interpretations based on oil company surveys on the west Tasmanian continental shelf (Moore, 1991; Moore et al., 1992). Features mapped in Figure 4 have been constrained or guided by structural information from the *Tasmante* swath-bathymetry and acoustic imagery, as well as lineations seen in GEOSAT satellite gravity data. The sediment thickness shown in Figure 4 is that visible in the seismic profiles, and so represents minimum sediment thickness. Processing of the *Tasmante* data (to 6-fold stacks), which is now in progress, should improve the data quality of the profiles and could reveal greater sediment thickness over some parts of the survey area.

The structural pattern over the area is generally complex, though two main structural trends stand out. These trends are NW at about 325°, and NNW at about 350°. The 350° structures exist mainly along the western margin of the STR and are clearly related to Eocene crustal extension and Southern Ocean seafloor spreading (roughly in a N-S direction). A slightly more northerly (~356°) trend is also present in the southwest part of the survey area, where a major, relatively young transform fault within oceanic crust has this orientation. The 356° trend may represent the local Oligocene (?and younger) seafloor spreading direction. The 325° trend predominates off west and southwest Tasmania. This structural trend is less well-developed directly south of Tasmania and over the STR. Over the STR, a subsidiary and more westerly trend (~310°) is evident. It may have resulted from rotation of structures originally trending 325°.

The most sedimented part of the survey area is the continental slope off west and southwest Tasmania. The section includes both syn-rift (mainly Cretaceous) and Cainozoic post-breakup deposits. Sediment thickness from the shelf to abyssal depths (as much as 5000 m) is 1.5 s twt or more almost everywhere in this region; extensive areas have more than 2.0 s of section. The adjacent continental shelf is underlain by the wrench sub-basins of the Sorell Basin (Moore et al., 1992). All of these sub-basins (King Island, Sandy Cape, Strahan and Port Davey Sub-basins) contain more than 3 km of section, but the intervening and adjoining shelfal areas have less and very variable sediment thickness. Many of the basement highs beneath the shelf have less than a few hundred metres of cover.

The area immediately south of Tasmania has several small, though fairly deep (> 1.5 s twt), fault-bounded depocentres. In general, however, this area of high relief has little sediment cover. Some of the shallow basement here may be similar to the Precambrian and early Palaeozoic terrain onshore. However, it is likely that much of seismic basement may be volcanic as suggested by the presence in the swath imagery of numerous ?Tertiary volcanic cones and other edifices in this area.

The summit area of the STR, where water depths range from about 800 to 1200 m, is poorly sedimented with either basement outcrop or a cover of less than several hundred metres of late Cainozoic sediment.

The western margin of the STR is a very complex structural province. Basement faults are generally closely highly spaced and vary greatly in orientation. Much of the structure was imparted by wrench movements and crustal extension during the Late Cretaceous (?) and early Tertiary as the Australian and Antarctic plates separated. Many of the numerous transtensional rift graben in this area are relatively narrow, but often very deep, and contain sedimentary sequences commonly 2.0 s twt or more in total thickness. The largest sub-basin in this area is located on the northwest STR in water depths of ~2000-2600 m. It is about 140 km long and 70 km wide.

Pre-late Oligocene deformation of the sedimentary section is almost ubiquitous throughout the survey area. This deformation, believed to be largely wrench related, is commonly relatively mild - with small-scale faulting in flower structures and gentle local folding of the section. However, along the western margin of the STR the wrench deformation is often considerably more severe. Transpressional forces acting on the narrow, once-transtensional basins have, in many places, strongly faulted and folded the basin-fill. Uplift of parts of the basins has often led to subaerial/wave-base erosion and truncation of the section, particularly at the Oligocene unconformity.

The continent-ocean boundary (COB), here defined as the 'landward' limit of pure oceanic crust, is indicated in Figure 4. It has been mapped mainly on the basis of seismic character and depth of basement. Evidence of stratification in fault blocks, as well as considerations such as structural fabric and magnetic expression were also taken into account in differentiating 'oceanic' from 'continental' crust.

West of Tasmania, the COB lies well out (about 200 km) from the coast and in very deep water, 4600-5000 m depths. The oldest magnetic anomaly identified with a fair degree of confidence adjacent to the COB is 19, suggesting that full-scale spreading did not start here until the mid Eocene. Though modified by ?transform offsets, the trend of the COB is approximately 325°, parallel to continental rift structures on the adjacent slope. The COB is marked by a series of 'basement' highs, some of which appear to be volcanic and others continental in origin. A second ridge or series of 'basement' highs lies 30-70 km landward of the COB. This 'base-of-slope high' consists predominantly of elevated continental fault blocks. The 30-70 km wide zone is believed to be a continental/oceanic transition zone underlain by a mixture of highly thinned continental crust and oceanic/rift volcanics. The mid Eocene pillow basalt drilled at DSDP Site 282 (Kennett, Houtz et al., 1975A) located on the 'base-of-slope high' was probably extruded at the time of maximum extension of the continental crust, i.e. at the onset of seafloor spreading.

South from 43° 50' S the COB changes direction to ~350° and coincides with the Tasman Fracture Zone, a dramatic topographic lineament with over 2 km relief that separates continental rocks of the STR from Eocene-Oligocene oceanic crust. Slivers of continental crust, apparently detached during transform motion along the Tasman Fracture Zone, lie adjacent to the transform COB. The oceanic terrain west of the STR is characterised by a distinct spreading fabric comprising E-W oriented volcanic ridges and troughs with little or no sediment cover. Sediment thickness over the oceanic crust generally increases northward to the 325°-trending COB, where the thickness is mainly about 0.5-1 km. Some pockets adjacent to the COB may be up to 1.5 km thick. The thickness is greater in the north, because of a terrigenous influx from Tasmania and because the crust is older and so has accumulated more pelagic cover.

Oceanic crust immediately south of the central STR was probably emplaced at the same time that spreading occurred adjacent to the 325°-trending COB southwest of Tasmania. At DSDP Site 280, about 40 km south of the mapped COB, sediment immediately above basalt basement was dated as early to mid Eocene (Kennett, Houtz et al., 1975A). Though poorly constrained by the limited available data, the spreading fabric appears to trend roughly E-W. Sediment cover over oceanic basement is much the same as at the 325°-trending COB southwest of Tasmania, and the same southward-thinning pattern is seen here. Local thick sediment accumulations (~2 s twt) at the COB may have been sourced from a then-emergent STR, and channelled south via south and southwest-trending graben.

The age of the oceanic basin southeast of Tasmania, between the East Tasman Plateau (ETP) and the STR, is uncertain. It was probably created sometime between mid Cretaceous and Eocene, in conjunction with either Southern Ocean or Tasman opening. The direction in which it opened still needs to be established. Existing data coverage is too sparse to permit mapping of magnetic lineations and their orientations. The basin is thickly sedimented, with more than 2 s twt commonly adjacent to the COB. The thick section suggests that the basin is relatively old (mid/Late Cretaceous rather than Eocene). However, the substantial thickness of the sediment pile could be explained by a plentiful sediment supply originating from the elevated and adjacent ETP, STR and southeast Tasmania.

**East Tasman Plateau**
(after Exon et al., 1994)

Little has been written about the East Tasman Plateau, whose known character was summarised by Willcox (1982). The crest of the rise has an average depth of about 2800 m, but it is topped by a central peak, the Soela Seamount, that rises to less than 1000 m. Its eastern flank falls very steeply from 3000 m to 4000 m. Seismic coverage is poor, but basement appears to be rugged, and the overlying sediments appear to be 500-1500 m thick. The Soela Seamount has been sampled at three locations and yielded mixed rocks containing marine biogenic carbonate and volcanic debris (Quilty and Jenkins, in prep.). The biogenic carbonates include late Eocene shallow water material, deeper water Miocene material, and Quaternary deep water material. I. McDougall has dated a volcanic clast by the K/Ar technique, and it has yielded an age of 31.6 Ma (early Oligocene). The Soela

Seamount is clearly a Palaeogene volcanic edifice, but whether the remainder of the rise is of continental or volcanic origin remains to be determined.

The ETP was crossed by a single transit line during the recent *L'Atalante* survey, adding to our knowledge of is geological makeup. The eastern side of the plateau is marked by a very steep and straight scarp, trending north-south and rising abruptly from 4200 m to 2900 m. This scarp is onlapped by the sediments on oceanic crust, and consists of unbedded basement rocks. Basement is downfaulted west of the scarp, and slopes down westward to allow accumulation of 1 second of fairly flat-lying younger sediments. Soela Seamount is a guyot about 1200 m high and 10 km across, and culminates 650 m below sea level. There is a maximum of 0.7 seconds of poorly bedded and disturbed sediment beneath the surface of the western East Tasman Rise, probably derived largely as debris flows from the seamount. The southwestern scarp falls from 2800 m to 3200 m.

## PRE-1994 GEOLOGICAL AND GEOPHYSICAL STUDIES

(condensed from Exon et al., 1994)

### Early Cruises

The first regional seismic survey that included the Tasmanian region was the 1970-73 BMR Continental Margins Survey (Figure 5). This survey used a 120 kilojoule sparker source, and extended from the shelf to the abyssal plain, with a line spacing of about 50 km, and was the basis of a report on the Australian southern margin by Willcox (1978).

In 1973, BMR recorded about 1000 km of low-energy sparker reflection profiles over the west Tasmanian shelf from M.V. *Sprightly*. These profiles gave penetration of up to half a second (two-way time), and showed that gentle faulting, uplift and erosion occurred during the late Miocene, and that Pliocene to Quaternary sediments unconformably overlie Miocene and older rocks (Jones and Holdgate, 1980). Much of the shelf consists of Miocene outcrop or subcrop below a veneer of younger sediments. Superficial sediments sampled on the same cruise showed that the inner shelf is covered by quartz sand with some shell debris, and the outer shelf by medium to coarse grained bryozoal sand and gravel (Jones and Davies, 1983). The shelf sands are mainly relict from times of lower sea level.

In 1973, Shell International Petroleum conducted a reconnaissance survey off southern Australia using the M.V. *Petrel*. This included a series of zig-zag lines going from the shelf to the abyssal plain over the Otway Basin and off west (and east) Tasmania (Figure 5). They showed 3 to 4 seconds (two-way time) of penetration. An interpretation by Boeuf and Doust (1975) showed that the margin off southern Australia was a passive margin, with a thick wedge of sediments that was bounded by oceanic crust on the edge of the abyssal plain. Beneath the continental rise, block-faulted continental basement was recognised. They stated: 'The sedimentary wedge which overlies the block-faulted and collapsed continental basement is subdivided by unconformities into: (a) a continental Lower Cretaceous unit and a fluvio-deltaic unit of Upper Cretaceous-Danian age which are taken to represent rift valley stages of deposition controlled by extensional tectonics and (b) a post-breakup sequence of Tertiary units representing regional collapse and out-building of the shelf. The Upper Cretaceous sequence is missing along much of the continental edge where Tertiary sediments appear to rest directly on the Lower Cretaceous unit. Our interpretation suggests that a prolonged period of uplift took place along the axis of the rift valley prior to continental break-up. On the basis of palaeomagnetic data and biostratigraphic analysis the breakup phase started in the Upper Paleocene.'

In 1982, BMR contracted Geophysical Services International (GSI) to carry out a multichannel seismic survey of the Bass Basin (BMR Survey 40), which also included regional seismic lines extending on either side of King Island, from the Otway and Sorell Basins out to the abyssal plain

**Deep Sea Drilling Program (DSDP)**

In 1973, Leg 29 of the Deep Sea Drilling Project (DSDP) drilled four partly cored holes in the Tasmanian region using the *Glomar Challenger*, including Site 282 on the west Tasmanian margin, which was some 310 m deep in 4202 m of water (Kennett, Houtz et al., 1973, 1975A). Site 282 lies 160 km west of Cape Sorell on *Sonne* line 36B-46, which shows it to have been on a basement high. The sequences drilled include much of the Cainozoic, but contain four major unconformities. The hole bottomed in pillow basalts of assumed middle Eocene age, which were overlain by Palaeogene siltstones and Neogene marls. The sedimentary sequence is presumed to be entirely abyssal, and includes 55 m of early Miocene to Pleistocene nannofossil ooze containing shelf-derived bryozoa and glauconite in part, 135 m of early and middle Oligocene silty clay, and 103 m of late Eocene silty clay, organic-rich and containing hydrocarbons.

DSDP Leg 29 also drilled Sites 280 and 281 on the South Tasman Rise. Site 280 was drilled to 524 metres in water 4181 m deep on the southwestern slope of the rise, and bottomed in an "intrusive basalt". It penetrated a veneer of late Miocene to late Pleistocene clay and ooze underlain, beneath a sampling gap, by 55 m of siliceous early Oligocene sandy silt, and 428 m of middle Eocene to early Oligocene sandy silt, containing chert in the upper 100 m, and glauconite and manganese micronodules below that. The lower 200 m is rich in organic carbon (0.6-2.2 %). All sediments are presumed to be abyssal types.

Site 281 was drilled to 169 metres in water 1591 m deep, southwest of the culmination of the rise, and bottomed in a quartz-mica schist of probable PreCambrian age (but K/Ar age is 306 ± 10 Ma). This is overlain by a six metre thick, late Eocene, basal conglomerate consisting of angular clasts, dominantly of schist, with lesser quartz, quartzite, glauconite, glauconitic sandstone and granite. The remainder of the late Eocene sequence also consists of shallow-marine sediments: 3 m of detrital sand and nanno chalk, and about 28.5 m of grayish-olive sandy silt and silty clay. Above a major unconformity there is 3 m of shallow-water, late Oligocene, glauconite-rich detrital sand. Above another unconformity, the hole contains 79 m of Miocene foram-nanno ooze, and 36 m of Plio-Pleistocene foram-nanno ooze.

One other DSDP Site relevant to the present study is Site 283, drilled on the abyssal plain 70 km east of the East Tasman Plateau in 4756 m of water to a sub-bottom depth of 592 m. It recovered entirely abyssal sediments above 4 m of pillow basalt. The sedimentary sequence consists of about 13 m of Plio-Pleistocene zeolitic clay, 163 m of late Eocene siliceous ooze, 139 m of mid Eocene silty clay, and 273 m of Paleocene silty clay with some chert.

A palaeo-oceanographic synthesis of DSDP Leg 29 results, by Kennett et al. (1975B), outlined the effects of the Antarctic glaciation in the region and the development of the Circum-Antarctic Current, for the first time. They stated "Cenozoic deep-sea sedimentation in the southwest Pacific area was controlled by large changes in the patterns of bottom-water circulation and erosion. The circulation patterns were largely controlled by the development of the Circum-Anatarctic Current south of Australia. Development of the Circum-Antarctic Current did not occur until the middle to late Oligocene [ca. 30 Ma] when final separation occurred south of the South Tasman Rise, although initial sea-floor spreading between Australia and Antarctica commenced in the late early Eocene [ca. 50 Ma]. Before the late Oligocene an erosive western boundary current flowed northwards through the Tasman and Coral Sea areas creating a regional unconformity centered near the the Eocene-Oligocene unconformity (Leg 21). When circum-Antarctic flow was established in the late Oligocene, a regional Neogene unconformity formed south of Australia and New Zealand, and sedimentation recommenced in the northern Tasman-Coral Sea area. This was due to the western boundary flow which earlier passed through the region and was largely diverted to the area east of New Zealand and into the Tonga Trench. A world-wide Oligocene unconformity was created by a major change in bottom-water circulation, in turn caused by increased bottom-water production related to the onset of substantial Antarctic glaciation near the Eocene-Oligocene boundary [ca. 35 Ma]. The separation of Australia from Antarctica led to a fundamental change in the world's oceanic circulation and its climate that marks the onset of the modern climatic regime."

**RV *Sonne* Cruises**

In 1985, the West German Research Vessel *Sonne* carried out two BGR-BMR co-operative cruises on the Tasmanian margin (*Sonne* Cruises 36B and C), during which also four regional multichannel seismic lines and several short tie lines (1000 km long in all) were recorded off west Tasmania, and 34 sampling stations occupied . During the same cruise, nine regional seismic lines were shot on the South Tasman Rise (Figure 5), and 19 sampling stations were occupied. A detailed cruise report was provided by Hinz et al. (1985), and a discussion of the west Tasmanian results was provided by Hinz et al. (1986). An interpretation of the west Tasmanian seismic lines, as well as that of profile BMR 40/22-23, showed that up to 5 seconds (two-way time) of section is present, and that up to 14 unconformities could be identified (Figure 6; Hinz et al., 1986). Sampling and well data from west Tasmania indicated (Figure 6) that unconformity U3 represented the regional Oligocene unconformity, U9 the basal Tertiary unconformity, and U12 the basal Late Cretaceous unconformity. The relatively thin Tertiary sequences consist essentially of Neogene carbonates and Palaeogene terrigenous sediments. The Late Cretaceous sequence appears to subcrop along the foot of the continental slope, along with continental basement which was sampled at three stations.

The South Tasman Rise was discussed by Willcox et al. (1989) on the basis of the *Sonne* seismic profiles. A continental origin is deduced from the schists drilled at ODP Site 281 and dredged by *Sonne*, from plate tectonic reconstructions, and from the relatively quiet magnetic and gravity (Figure 7) profiles. Three of the *Sonne* profiles over the South Tasman Rise are illustrated as line drawings in Figure 7, which shows that there are basement highs separated by graben with several thousand metres of sedimentary fill, most of it believed to be Cretaceous in age. Structurally, the rise consists of a triangular core of basement, flanked on all sides by sedimentary basins (Figures 7 and 8). The basement is extensively planated and it surface is continuous with the regional Oligocene unconformity.

Willcox et al. (1989) described a large extensional basin in the southwest, containing up to 6000 m of sedimentary fill, probably including syn-rift volcanics, and noted the presence of another basin in the northeast. The dominant structures were interpreted as being oriented either N-S or NW-SE, as indicated also by the GEOSAT imagery. The preliminary mapping suggested that the stratigraphy and structure of the rise was consistent with a common origin with the Otway and Sorell Basins. Willcox et al. (1989) suggested that major dislocations in the basins may represent the locations of transfer faults. The western half of the rise is characterised by northerly-trending slivers of basement, and intervening V-shaped basins, probably created by Eocene and early Oligocene transtensional movements. Wrench faults extend up to the Oligocene unconformity. The western margin is clearly a transform fault, with movement presumably ending in the Oligocene with the separation of Australia and Antarctica.

Salge (1989) presented an alternative history of the South Tasman Rise from a major study of the *Sonne* profiles. He concluded that the rise had always been adjacent to Tasmania, rather than transported with Antarctica southward from an original position west of the Otway Basin. He suggested that rifting in the Early Cretaceous formed NW-SE trending basins in basement rocks, characterised by listric and low-angled faults. Apparently in the mid or Late Cretaceous, when slow spreading between Australia and Antarctica started, there was left-lateral movement between Australia and Antarctica to the west of Tasmania and the South Tasman Rise, and this resulted in wrench faulting of the basin-fill sediments. Major transcurrent fault zones caused the formation of transpressional features in the basins. An extensional zone developed between Tasmania and the rise. With the formation of oceanic crust in the adjacent Indian Ocean in the middle Eocene, subsidence and drift sedimentation began. Marginal marine detrital sediments were derived from high areas and show progradation or onlap in places. The continuing subsidence, the development of the Circum-Antarctic current as Antarctica cleared this southern prolongation of the Australian continent in the early Oligocene, and the fall in oceanic bottom water temperature as the Antarctic ice sheet developed in the latest Eocene and Oligocene (Kennett et al., 1972), led to major erosion that formed the regional Eocene-Oligocene unconformity, and to major changes in sediment type from detrital to pelagic. There was little Neogene sedimentation in high areas, because of current erosion and slumping into deeper water.

There is a major disagreement between Salge's (1989) view that the rift basins of the South Tasman Rise formed in the Early Cretaceous and filled with Cretaceous sediments, and the earlier view of Hinz et al. (1985) and Willcox (1989) that they formed in the Late Cretaceous and most of the fill is Palaeogene in age. Which interpretation is correct remains to be proven. The other open question is whether the South Tasman Rise was originally located northwest or south of Tasmania.

## RV *Rig Seismic* Cruises

In early 1987, RV *Rig Seismic* carried out a research cruise (BMR Cruise 67) over the Otway Basin and the Sorell Basin of the west Tasmanian margin, to provide new geological, geochemical and heatflow data, in an area with considerable petroleum potential (Exon and Lee, 1987; Exon et al., 1992). Altogether, 130 sampling stations were occupied using dredges, corers, grabs and a heatflow probe. Among the rocks recovered were: Palaeozoic volcanics and metasediments; Late Cretaceous sandstones, siltstones and mudstones; early Tertiary siltstones; and late Tertiary carbonates. The Cretaceous sequence was dated by palynology at five localities as Santonian to early Campanian, Campanian and Maastrichtian, and the depositional environment in all cases was marginal marine (M.K. Macphail, Appendix D *in* Exon et al., 1992). Two early Tertiary samples were identified as early Eocene and marginal marine, and two as middle Eocene and marginal to open marine. All samples were taken along seismic profiles, so that the results could be incorporated easily into the regional geological framework. In general, the further down the continental slope, the older the rocks. Palaeontological results indicate that there has been very considerable post-Eocene subsidence of the slope.

A great variety of Quaternary sediments were recovered, and these have allowed a detailed sedimentation model to be developed. Shelf areas are characterised by relatively high-energy deposits: shelly bryozoal sands and fine sandy oozes. These sediments are dominantly calcareous, and most likely sourced by a middle to outer shelf `carbonate factory', dominated by bryozoa, pelecypods, gastropods and benthic foraminifera. There is extensive bioturbation by a relatively large infauna giving thick homogeneous units. Shelf sands periodically move downslope as turbidity currents or grain flows; their contribution to overall slope sedimentation is considerable (V. Drapala, pers. comm.). However, slope and abyssal areas appear to be dominated by pelagic and hemipelagic carbonates, typically olive-grey and greenish grey, foraminiferal and nannofossil oozes.

Heatflow calculations from 20 stations suggest that the present zone of thermal maturation of hydrocarbons is 2-4 km deep. Headspace gas analyses of many cores indicate that thermogenic hydrocarbons are widespread, with particularly high readings in both the eastern and the western Otway Basin and on the west Tasmanian margin. Thus, mature hydrocarbon source rocks must also be widespread.

In early 1988, RV *Rig Seismic* carried out BMR research cruise 78 on the Tasmanian margin (Exon et al., 1989). Half of this cruise was devoted to multichannel seismic profiling and the other half to geological sampling. Off west Tasmania (Figure 5), 1750 km of seismic data were recorded with a single airgun string (1600 cubic inches) and a 1200 m seismic cable (48 channels). Off southeast Tasmania, 265 km of seismic data were recorded near Hobart. The west Tasmanian survey better defined the King Island and Strahan Sub-basins of the Sorell Basin, tested the structure from the continental shelf to undoubted oceanic crust, and provided a mid-slope tie through the thick sedimentary sequence of the Sorell Basin right along the Tasmanian margin. The survey showed that the area has tectonic complexities and that there is normally more than 3 seconds (twt) of sedimentary section. The magnetic and gravity profiles, in conjunction with seismic reflection and sonobuoy refraction profiles, show that there is a transition zone about 50 km wide on the abyssal plain between the foot of the continental slope and undoubted oceanic crust. The southeast Tasmanian survey was bedevilled by the presence of Jurassic sills, and is of little use.

During the geological work on the west Tasmanian margin, twelve dredge stations were designed to sample basement and other relatively old outcropping sequences, in order to help elucidate the early history of the margin. The palynology of four samples showed that one was a Santonian-Campanian marginal marine mudstone. The other three were Paleocene to early Eocene marginal marine mudstones. Younger sediments were cored at

37 stations and grabbed at 9 stations, to build on our model for Cainozoic sedimentation and to provide material for analysis for thermogenic gas. Sixteen cores were sampled for gas, and provided the first evidence that thermogenic gas is being generated in the Sandy Cape Sub-basin. Five stations gave thermal gradients which, when combined with conductivity measurements on three cores, suggest that heatflow may be lower (average 30 $mW/m^2$) than on the Otway Basin margin to the northwest.

## Petroleum Indications Off West Tasmania And On The STR

Organic-rich Late Eocene silty clays at DSDP Site 282 west of Tasmania have considerable petroleum source rock potential (Hunt, 1975; 1984). In Cape Sorell No. 1 (Amoco, 1982) extensive traces of oil were found in the latest Cretaceous/earliest Paleocene. A shipboard study of 27 *Sonne* cores (Whiticar et al., 1985) indicated that wet gas of thermogenic origin is abundant in surface sediments on the west Tasmanian margin, indicating the presence of mature source rocks. Fourteen cores were analysed for gases on the STR and most were relatively poor in hydrocarbons. However, three stations in the east gave higher yields with a thermogenic signature. More than 20 exploration wells have been drilled in the offshore Otway and Sorell Basins.

The petroleum prospects of the continental margin of western Tasmania were reviewed by Moore et al. (1992). The margin is underlain by sedimentary sequences of the southern Otway Basin and the Sorell Basin (Figure 6). The latter lies mainly under the continental slope, but it includes four sub-basins (the King Island, Sandy Cape, Strahan and Port Davey Sub-basins) underlying the continental shelf. In general, these depocentres are interpreted to have formed at the 'relieving bends' of a major left-lateral strike-slip fault system, associated with 'southern margin' extension and breakup. The sedimentary fill could have commenced in the Jurassic.

Maximum sediment thickness is about 4300 m in the southern Otway Basin, 3600 m in the King Island Sub-basin, 5100 m in the Sandy Cape Sub-basin, 6500 m in the Strahan Sub-basin, and 3000 m in the Port Davey Sub-basin. Megasequences in the shelf basins are similar to those in the Otway Basin. There are Lower Cretaceous non-marine conglomerates, sandstones and mudstones, which probably include the undated red beds recovered in two wells, and Upper Cretaceous shallow marine to non-marine conglomerates, sandstones and mudstones. The Cainozoic sequence often commences with a basal shallow marine sandstones, mudstones and marls, and grades up into Eocene shallow marine limestones, marls and sandstones, and Oligocene and younger shallow marine marls and limestones.

The presence of active source rocks has been demonstrated by the occurrence of free oil near the base of Cape Sorell No. 1 well (Strahan Sub-basin), and thermogenic gas from surficial sediments recovered from the upper continental slope and the Sandy Cape Sub-basin.

## CRUISE OBJECTIVES

### *TASGO*

- Map, in 3-D, offshore extensions of major Tasmanian crustal structures (eg. Figure 9; Corbett and Turner (1989)) that have been mapped geologically or geophysically onshore.
- Investigate the nature, geometry and origins of major crustal features revealed by recent TASGO offshore/onshore aeromagnetic surveys.
- Establish the crustal architecture and nature of tectonic provinces around the periphery of Tasmania, and investigate the petroleum and mineral resource implications.
- Map the crustal structure of Tasmania by refraction tomography using the airguns as seismic source and shore-based receiving stations.

### *STR*

- Map the deep crustal structure of the STR and ETP, and investigate how these features relate to the Tasmanian craton.
- Determine the structure of the continental slope southwest of Tasmania, particularly the geometry of continental tilt-blocks which appear to be present out to water depths of more than 4000 metres.
- Examine the relationships between the direction of lithospheric extension, the azimuth of the seafloor spreading phases, and the formation of the transform margin along southwest Tasmania and the STR.
- Map the crustal structure of the northern and western flanks of the South Tasman Rise, and investigate the basement blocks which lie between it and the Tasmanian slope.
- Establish whether the deep-water basin between the East Tasman Plateau and the South Tasman Rise is oceanic or floored by highly extended continental crust; determine the opening/extension direction.
- Map the structure, stratigraphy and depth extent of deep sedimentary basins on the southwest Tasmanian margin, on the STR and its northern flanks and between the ETP and Tasmania.
- Assess the petroleum potential of these basins.
- Deduce a kinematic evolution for the South Tasman Rise and account for its anomalous position in some plate reconstructions.

- Improve our understanding of the evolution of the Australian southern and southeastern margins, particularly the way in which it may have affected the age and formation of petroleum source rocks and the development of migration paths.

## CRUISE PLAN

In planning the survey it has been assumed that total of 31 days are available for the combined (TASGO and STR) geophysical survey. A period of 14 days has provisionally been allocated to the TASGO component. If fully utilised, this will leave 17 days for the STR survey. The 23 TASGO lines 1-23 (Figure 1, Table 1) amount to a total of 1839 line-km (Table 2), while the 5 STR lines A-E (Figures 2 and 3, Table 3) total about 2300 km (Table 4), making the total line-km (with run-outs) for the full survey about 4200 km. A mean production rate (from leaving port to returning to port) of about 135 km per day will be required to achieve this.

Such a target may be optimistically high, particularly for the TASGO survey, because significant down-time could be experienced due to encounters with fishing gear (particularly crayfish pots), bad weather (notorious on the West Coast) and extra caution required while operating in shallow waters and nearshore where small-boat traffic can be expected. Gales and large swells (4-5 m not uncommon) may hamper operations at the higher latitudes over the STR.

Over the past 1-2 years seismic production rates on *Rig Seismic* have been in the order of 130 km per day. Most of the surveys were shot on the NW Shelf where weather and general operating conditions are generally good. Recent experience closer to Tasmania in the Otway Basin (Surveys 137 and 146) has seen a dramatic decrease in production rates due to bad weather, large swells and considerable trouble with cray-pots (despite having a chaser boat available). Some revision and pruning of the Tasmanian program may well be needed as the survey progresses to compensate for adverse operating conditions. A representative from the Tasmanian fishing industry will be on board to liaise with local fishermen in order to minimise disruption to fishing activities and avoid damage to deployed geophysical gear.

It is planned to run the TASGO survey in an anticlockwise direction around Tasmania, in the line number sequence 1-23 (Figure 1). Strong tidal currents reported in the passages between mainland Tasmania and King Island and also mainland Tasmania and Flinders Island are the main reason for this. The strongest flows are from the west. In order to avoid excessive feather angles on the streamer and/or to avoid excessive speed over the ground (possibly resulting in requirement for too high a shot rate), it is preferable to shoot the lines in these areas in a westerly direction, against the main current flow.

In the event that less than the planned 31 days are available for the survey, a reduced program will be undertaken with the TASGO sub-program taking priority over the STR work. Line priorities have been assigned within each of the TASGO and STR sub-programs (Tables 2 and 4).

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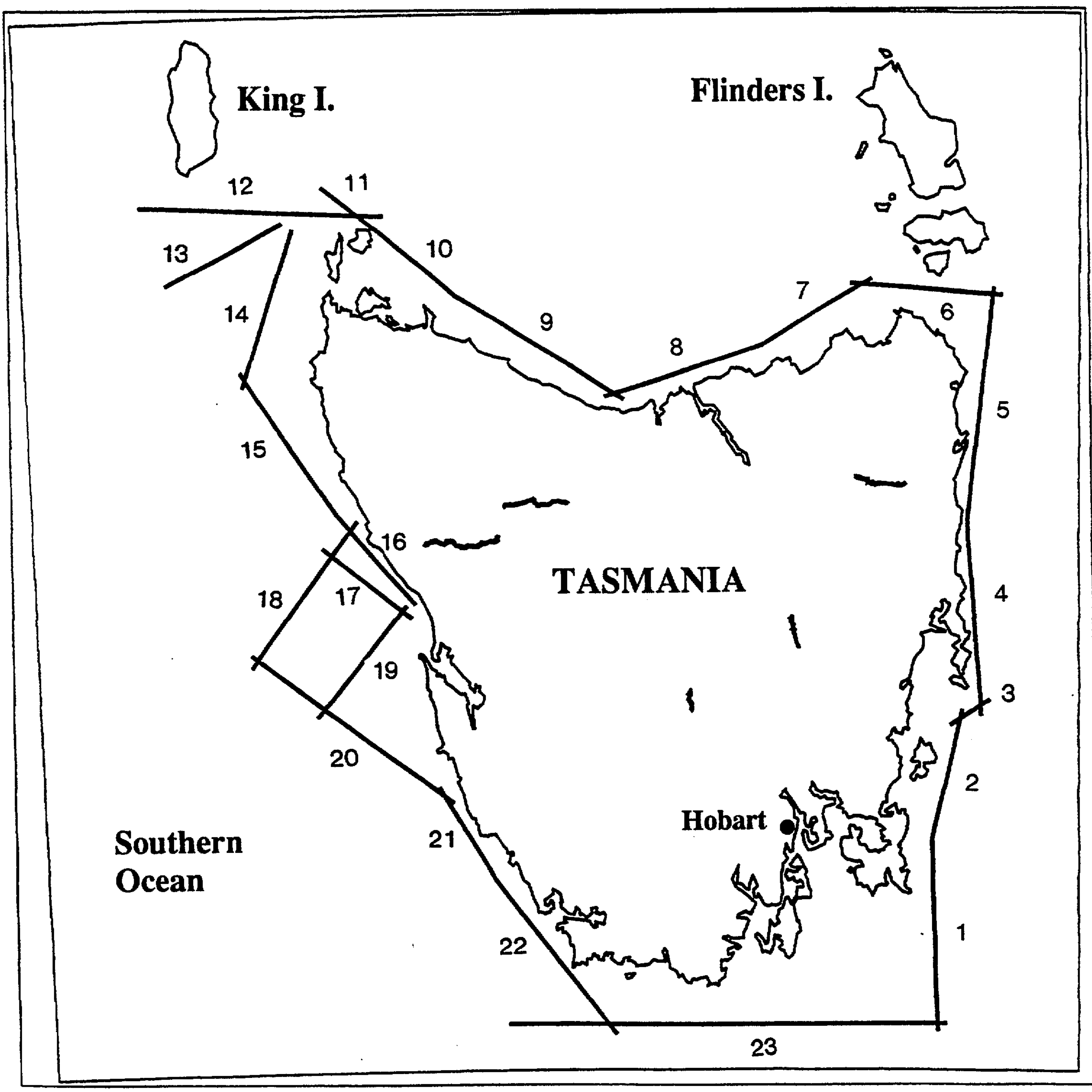



**FIGURE 1.** Location of proposed *Rig Seismic* TASGO deep seismic lines (1-23) off Tasmania (NGMA Project).

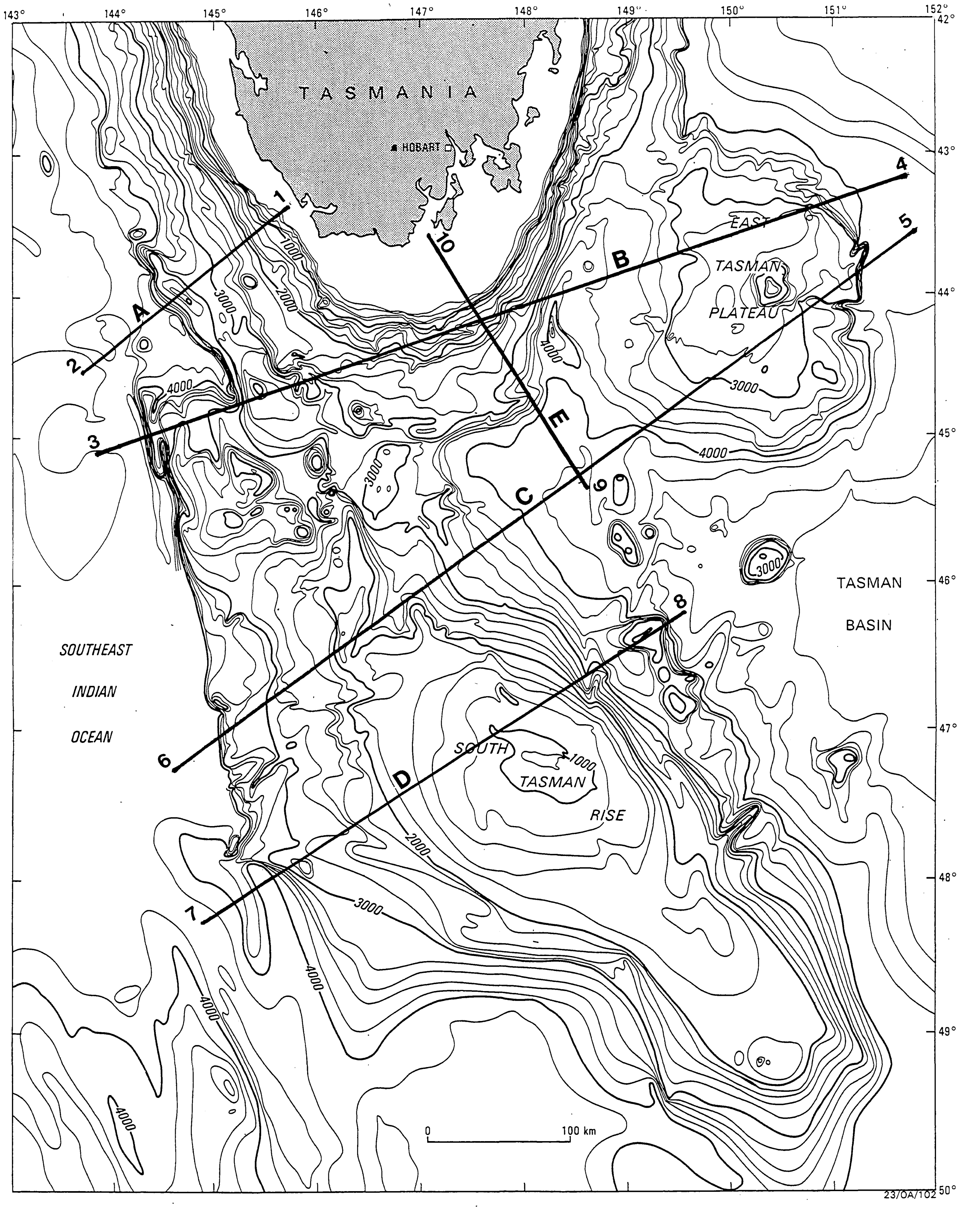
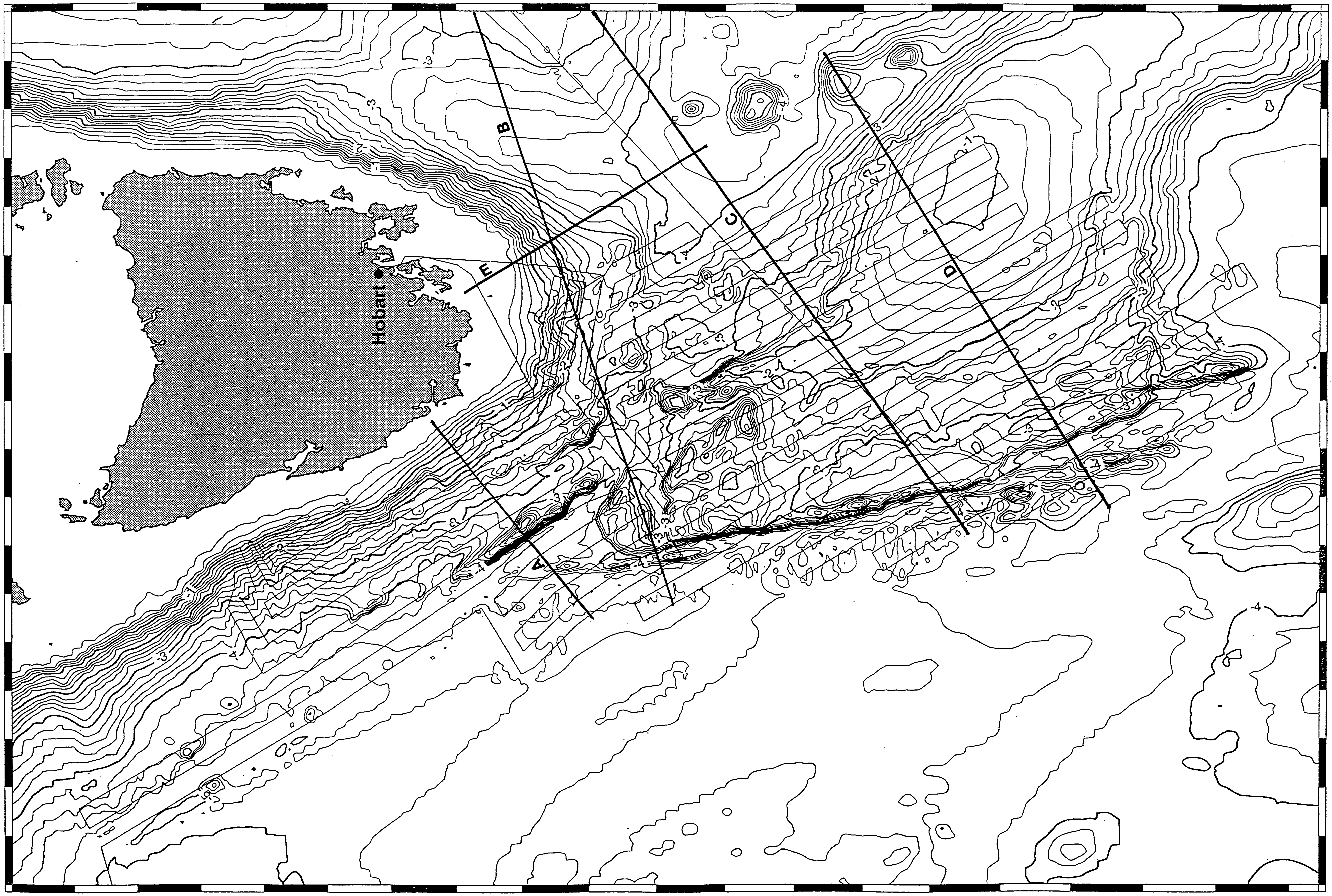



**FIGURE 2.** Location of proposed *Rig Seismic* deep seismic lines (A-E) over the South Tasman Rise and adjacent areas (bathymetry after D. Jongsma and G. Wissmann).




The bathymetric contours are from merged conventional bathymetric data (ETOPO5, 5'x5' grid)) and *L'Atalante* swath bathymetry (Exon et al., 1994). Contour annotation is in km; contour interval is 200 m.

**FIGURE 3.** Proposed *Rig Seismic* transects (A-E) in relation to 1994 *L'Atalante* tracks (fine lines) and to detailed bathymetry of the South Tasman Rise and offshore Tasmanian region.

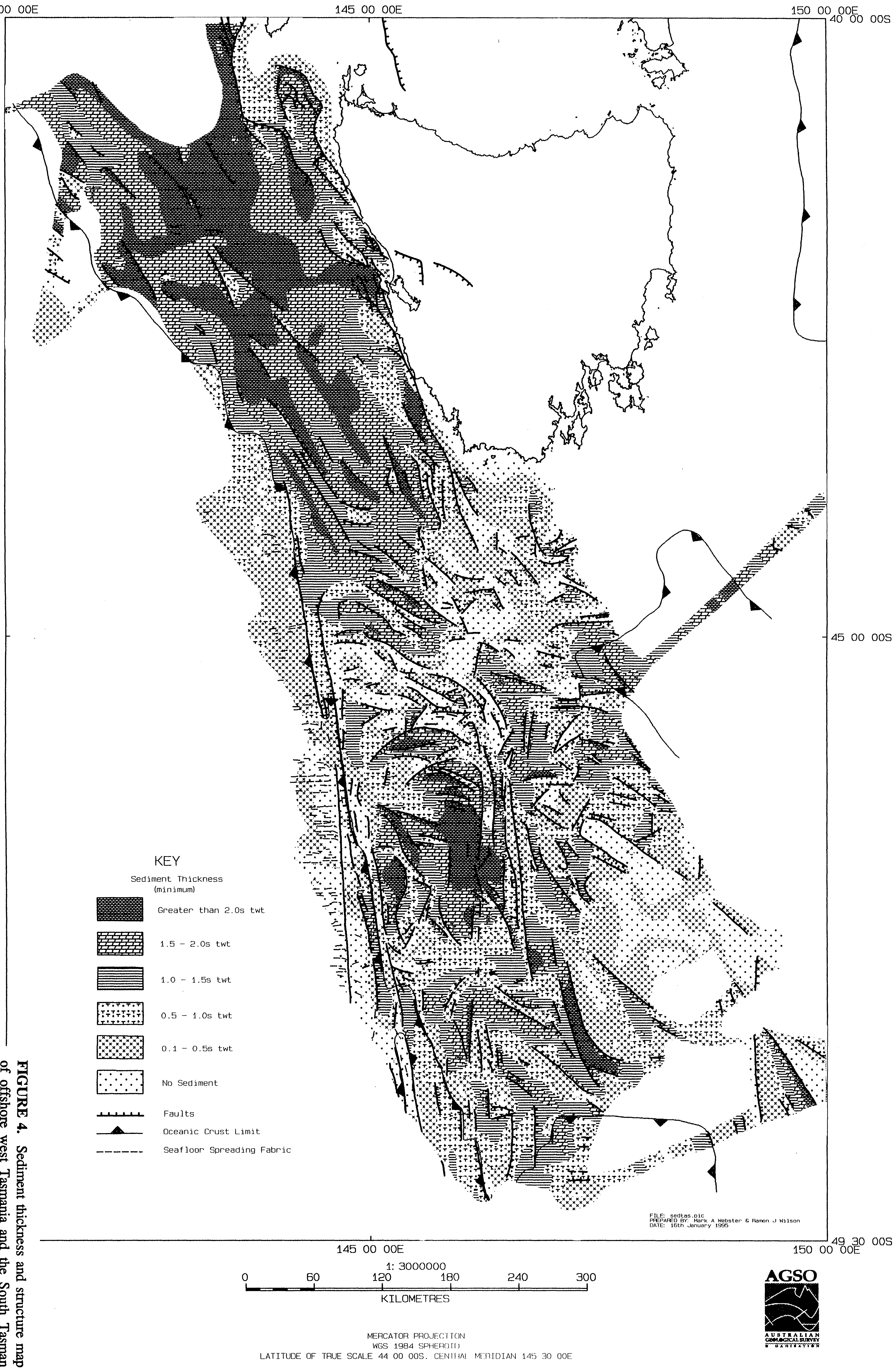



**FIGURE 4.** Sediment thickness and structure map of offshore west Tasmania and the South Tasman Rise based mainly on interpretation of *L'Atalante*, *Sonne*, *Rig Seismic* and oil company reflection seismic data.

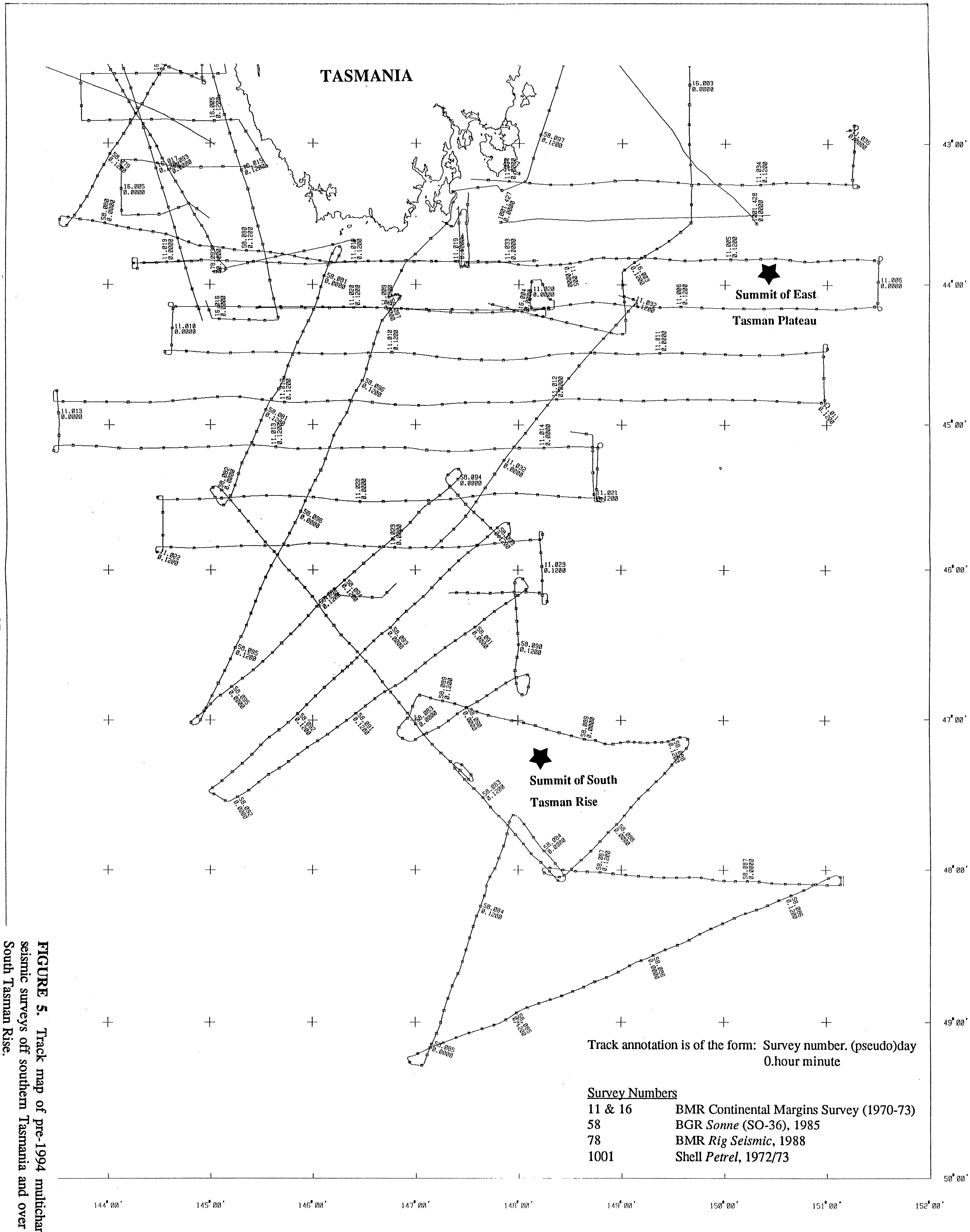



**FIGURE 5.** Track map of pre-1994 multichannel seismic surveys off southern Tasmania and over the South Tasman Rise.

| Unconform (Sequence) | Characteristics | Tectonic Significance | Facies Interpretation | Approx Thickness (m) | Proposed Age Identification: Stratigraphic | m.y. | Equivalent Mag Anom | Otway Basin Shelf Equivalent and Unconformities | Comment |
|---|---|---|---|---|---|---|---|---|---|
| | Low frequency, stratified and folded Floors Jurassic or Early Cretaceous rift beneath the lower continental slope | Pre-rift Tasman Geosyncline Crustal extension and first stage rifting at about U14 time | Varied metasediments and volcanics | Unknown | Palaeozoic and ? Precambrian | | | | "Basement" |
| U14 ~~~~ | | | | | | ? 140 | | ~~~~~~~~ | |
| S(13–14) | Low frequency, stratified on rift shoulder<br>Contorted fill in first stage rift | Lower rift-fill | Continental–? fluvial, lacustrine<br>Alluvial fan and/or volcanics | 1000<br>3000 + | Jurassic and Early Cretaceous | | M Series | Casterton Beds and Otway Group Non-marine clastics and volcanogenic sediments | |
| U13 ~~~~ | | | | | | 105 | | | |
| S(12–13) | Bedded fill in first stage rift Now incorporated into tilted blocks beneath lower continental slope | Upper rift-fill, probably preceding marine transgression ? Development of shelf edge on U12 | Fluvial–lacustrine possibly grading to marginal marine | 0–?1000 | "late" Early Cretaceous (? Albian) | | | Probably time equivalent to Eumeralla Formation (Otway Gp) Continental environments with volcanism | This sequence appears confined to the first stage rift |
| U12 ~~~~ | | | | | | 95 | 34 | ~~~~~~~~ | |
| S(11–12) | Well stratified with onlap onto U12 U12/13 block-faulted beneath continental shelf | U12 (possibly U13) is main rift-onset unconformity in Otway Basin S(11–12) marine transgression | Marginal marine–marine (foram evidence from Ribis and Apthorpe, 1969) | 0–?1000 | Late Cretaceous (approx Cenomanian) | | Slow spreading episode (Cande and Mutter, 1982) | Approximate Waarre Formation (Sherbrook Group) equivalent Shoreline facies | Wrenching and uplift of the tilted blocks beneath lower slope commenced (Willcox and Symonds, in preparation) |
| U11 ~~~~ | | | | | | | | | |
| S(10–11) | Stratified sediment wedge with onlap onto U11 Basal channelling land ward of old shelf edge | U11 eustatic lowstand in ? Coniacian (Vail et al., 1977) S(10–11) basin transgr restricted by blocks below lower continental slope | Shallow marine (restricted basin) | 0–1000 + | Late Cretaceous | | | Belfast Mudstone and Flaxman Formation (Sherbrook Group) Marginal marine–marine | 1570 m Belfast Mudstone in Voluta 1 |
| U10 ~~~~ | | | | | | | | | |
| S(9–10) | Stratified sediment wedging out below lower slope Downlap onto U10 | U9 and U10 relative falls in sea level U9–slowing or termination of movement of tilted blocks beneath lower slope | Shallow marine (regressive) | 0–500 + | Late Cretaceous (approx Maastrichtian) | | | Curdies/Paaratte Formations (Sherbrook Group) Shoreline–continental | Slow spreading episode in southeast Indian Ocean has less influence on outer Otway Basin |
| U9 ~~~~ | | | | | | 65 | 29 | ~~~~~~~~ | |
| S(8–9)<br>U8 ~~~~<br>S(7–8)<br>U7 ~~~~<br>S(6–7)<br>U6 ~~~~<br>S(5–6) | S(5–6) to S(8–9) are distinctive, high frequency, downlapping sequences beneath lower continental slope<br>Lower frequency, continuous, high amplitude beneath upper continental slope | A period of minimal subsidence in the outer Otway Basin due to contact between Australian and Antarctic plates in Tasmanian region Sedimentation influenced by elevated blocks beneath lower continental slope Outbuilding of fine clastics with minimal aggradation Unconformities largely reflect eustatic changes in sea level | Shelf clastics, grading into fine grained progradational wedges at palaeoshelf–edge (largely terrigenous) | 200–1500 | Paleocene—Middle Eocene | | ? | Age equivalent of the Wangerrip Group Shallow marine→shoreface→continental (regressive) | Sequences S(5–6) to S(8–9) are believed equivalent to depositional cycles TP1, TP2, TE1 and ?TE2 of Vail et al., (1977) |
| U5 ~~~~ | | | | | | 42 | 18 | ~~~~ ? ~~~~ ? ~~~~ | |
| S(4–5)<br>U4 ~~~~<br>S(3–4) | Stratified, onlapping S(3–4) extends across outer tilted blocks | Accelerated movement along Australian–Antarctic plate boundary Major wrenching and development of flower structures in southeast Otway Basin and western margin of Tasmania | Shallow marine (largely terrigenous) | 0–800 | Late Eocene—earliest Oligocene | | | Nirranda Group (transgressive) — shallow marine | ? Minor volcanism at U5 time |
| U3 ~~~~ | | | | | | 35 | 13 | ~~~~~~~~ | |
| S(2–3)<br>U2 ~~~~<br>S(1–2)<br>U1 ~~~~ | Stratified, channelled, shelf–edge progradation | U3 is widespread Early Oligocene unconformity marking clearance of Australian and Antarctic plates and establishment of open marine conditions | Shelf – open marine (largely carbonate) | 0–600 | Late Oligocene and Neogene | | Southeast Indian Ocean spreading | Heytesbury Group (transgressive) marine carbonates | Main episode of seafloor spreading |

23/K55/15

*For stratigraphy refer to BMR line 22/23 (Figure )*
*Tectonic events after Willcox and Symonds (in preparation)*

**FIGURE 6.** Tabular representation of seismic stratigraphic sequences, with unconformities and tectonic events, for Otway and Sorell Basins (Hinz et al., 1986).

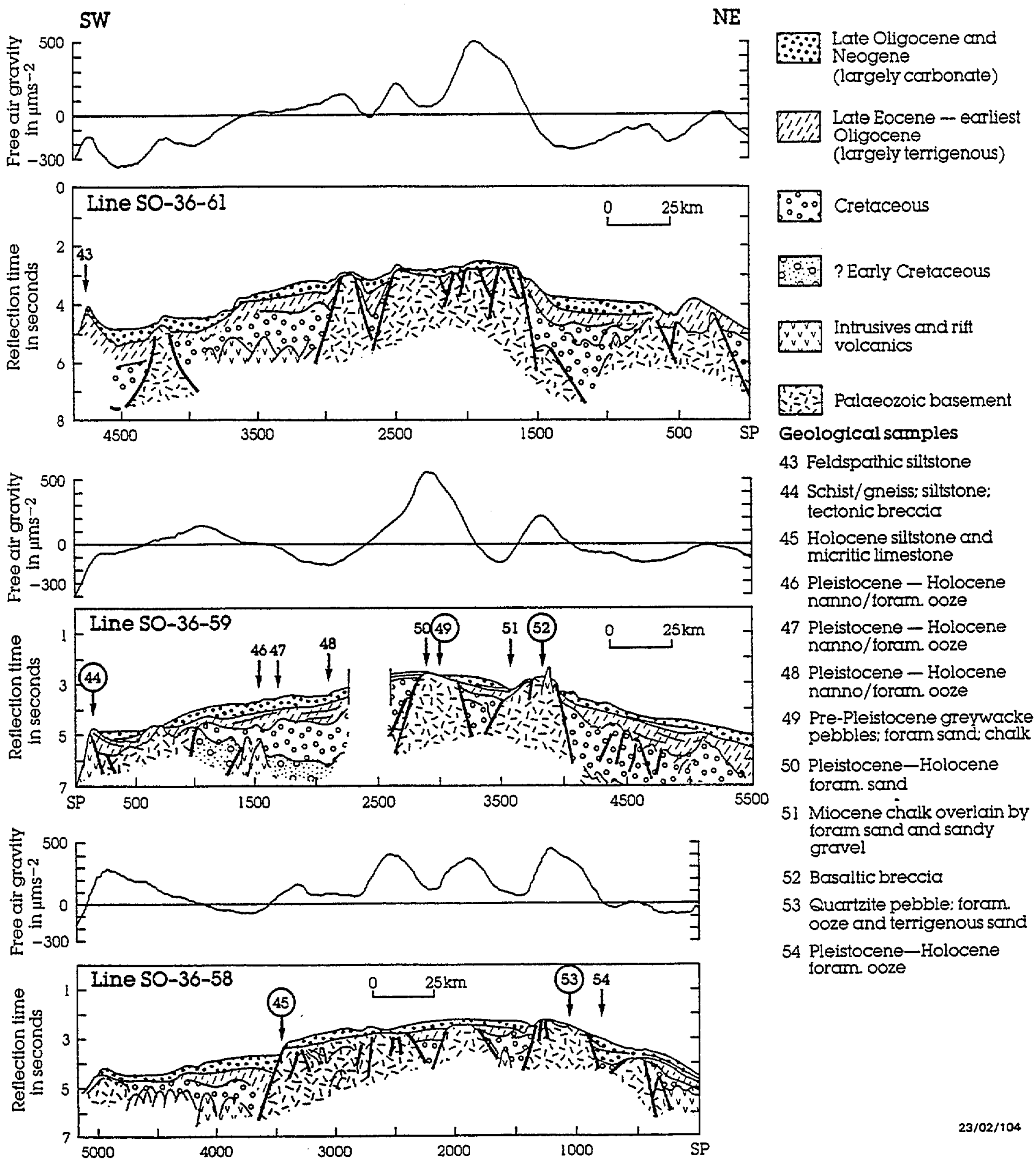



**FIGURE 7.** Line drawings of *Sonne* SO-36B seismic profiles from the South Tasman Rise, with free-air gravity anomalies and sampling sites (Willcox et al., 1989).

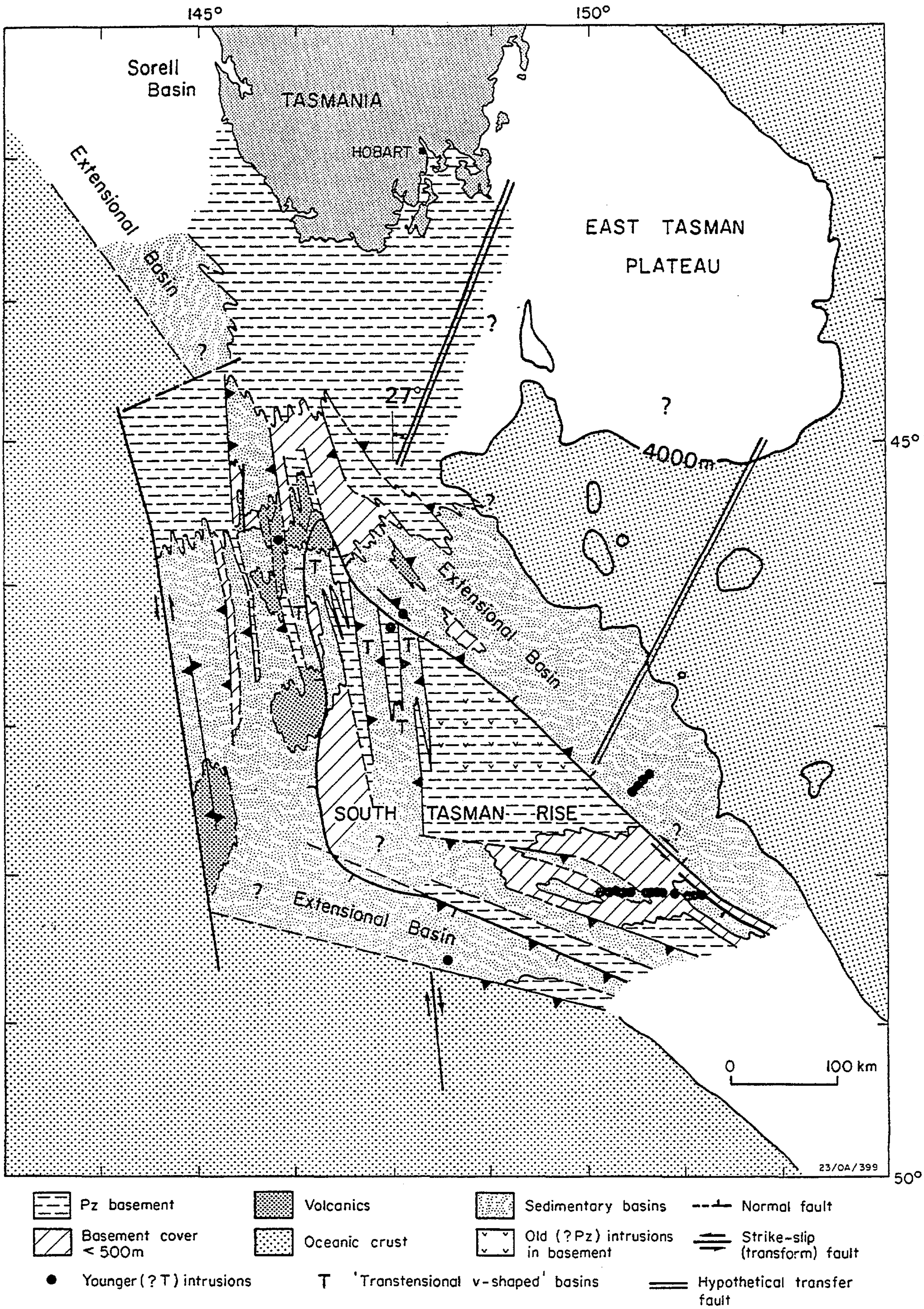



**FIGURE 8.** Preliminary structural map of the South Tasman Rise (Willcox et al., 1989).

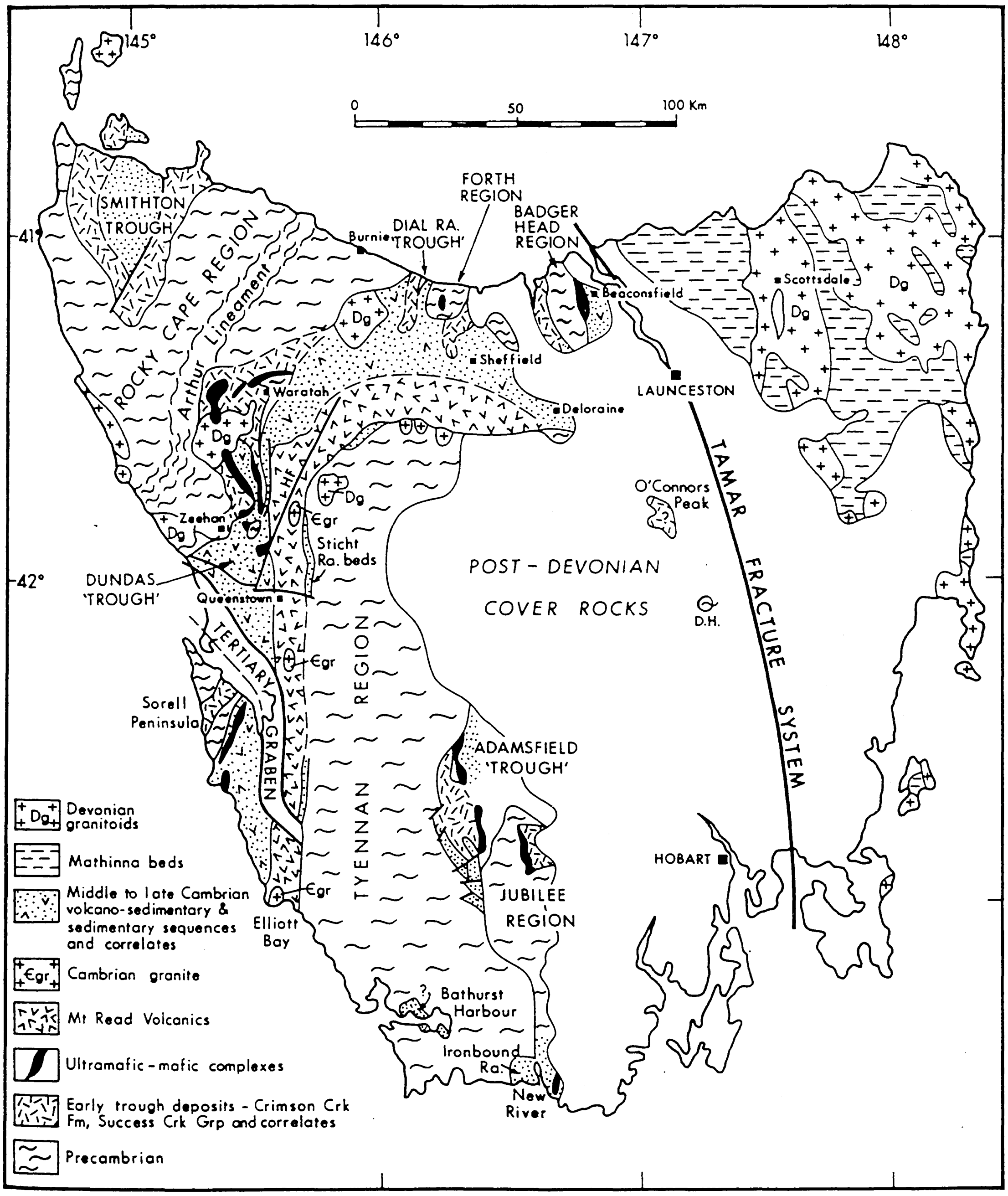



**FIGURE 9.** Major early Palaeozoic tectonic elements of Tasmania (Corbett and Turner, 1989).

**TABLE 1**
**Way-points for TASGO survey**

| Line | Way-point | Latitude / Longitude (dec. deg.) |
|---|---|---|
| 1 | a | 43.8317° S 148.1621° E |
| 1 | b | 42.9941° S 148.1391° E |
| | | |
| 2 | a | 42.9933° S 148.1380° E |
| 2 | b | 42.4331° S 148.3209° E |
| | | |
| 3 | a | 42.5011° S 148.2490° E |
| 3 | b | 42.3897° S 148.4793° E |
| | | |
| 4 | a | 42.4595° S 148.4321° E |
| 4 | b | 41.6181° S 148.3522° E |
| | | |
| 5 | a | 41.6169° S 148.3538° E |
| 5 | b | 40.6373° S 148.5127° E |
| | | |
| 6 | a | 40.6670° S 148.5614° E |
| 6 | b | 40.6264° S 147.7074° E |
| | | |
| 7 | a | 40.6050° S 147.8234° E |
| 7 | b | 40.8805° S 147.1938° E |
| | | |
| 8 | a | 40.8812° S 147.1957° E |
| 8 | b | 41.0952° S 146.2872° E |
| | | |
| 9 | a | 41.1070° S 146.3949° E |
| 9 | b | 40.6700° S 145.4389° E |
| | | |
| 10 | a | 40.6711° S 145.4384° E |
| 10 | b | 40.3790° S 144.9894° E |
| | | |
| 11 | a | 40.3803° S 144.9894° E |
| 11 | b | 40.2047° S 144.7014° E |
| | | |
| 12 | a | 40.3298° S 145.0426° E |
| 12 | b | 40.2720° S 143.6775° E |
| | | |
| 13 | a | 40.3501° S 144.4782° E |
| 13 | b | 40.6058° S 143.8096° E |
| | | |
| 14 | a | 40.3773° S 144.5340° E |
| 14 | b | 41.0383° S 144.2223° E |

Table 1 (cont.)

| Line | Way-point | Latitude / Longitude (dec. deg.) |
|---|---|---|
| 15 | a | 40.9743° S 144.2124° E |
| 15 | b | 41.5912° S 144.7332° E |
| | | |
| 16 | a | 41.5906° S 144.7333° E |
| 16 | b | 41.9774° S 145.1599° E |
| | | |
| 17 | a | 42.0356° S 145.1369° E |
| 17 | b | 41.7316° S 144.6461° E |
| | | |
| 18 | a | 41.6153° S 144.8456° E |
| 18 | b | 42.2362° S 144.2191° E |
| | | |
| 19 | a | 41.9823° S 145.1108° E |
| 19 | b | 42.4524° S 144.5878° E |
| | | |
| 20 | a | 42.1806° S 144.2193° E |
| 20 | b | 42.8291° S 145.3474° E |
| | | |
| 21 | a | 42.7601° S 145.2646° E |
| 21 | b | 43.1684° S 145.5854° E |
| | | |
| 22 | a | 43.1672° S 145.5848° E |
| 22 | b | 43.8446° S 146.2758° E |
| | | |
| 23 | a | 43.7968° S 145.6374° E |
| 23 | b | 43.7969° S 148.2123° E |

**TABLE 2**
**TASGO survey: seismic line lengths and priorities**

| Line | Length (km) | Priority |
|---|---|---|
| 1 | 93 | A |
| 2 | 64 | B |
| 3 | 23 | B |
| 4 | 94 | B |
| 5 | 110 | B |
| 6 | 70 | A |
| 7 | 61 | A |
| 8 | 80 | A |
| 9 | 94 | A |
| 10 | 50 | A |
| 11 | 31 | A |
| 12 | 114 | A |
| 13 | 63 | A |
| 14 | 78 | A |
| 15 | 81 | A |
| 16 | 56 | A |
| 17 | 53 | A |
| 18 | 86 | A |
| 19 | 68 | A |
| 20 | 117 | A |
| 21 | 52 | A |
| 22 | 94 | A |
| 23 | 207 | A |

Total line-km = 1839

**TABLE 3**
**Way-points for STR survey**

| Line | Way-point | Latitude / Longitude |
|---|---|---|
| A | 1 | 43° 19' S 145° 45' E |
| A | 2 | 44° 32' S 143° 43' E |
| | | |
| B | 3 | 45° 08' S 143° 52' E |
| B | 4 | 43° 10' S 151° 46' E |
| | | |
| C | 5 | 43° 32' S 151° 51' E |
| C | 6 | 47° 16' S 144° 34' E |
| | | |
| D | 7 | 48° 18' S 144° 53' E |
| D | 8 | 46° 11' S 149° 34' E |
| | | |
| E | 9 | 45° 21' S 148° 36' E |
| E | 10 | 43° 35' S 147° 08' E |

**TABLE 4**
**STR survey: seismic line lengths and priorities**

| Line | Length (km) | Priority |
|---|---|---|
| A | 210 | A |
| B | 670 | A |
| C | 720 | A |
| D | 440 | A |
| E | 230 | B |

Total line-km = 2270

## APPENDIX 1
## Information on Research Vessel *Rig Seismic*

RV *Rig Seismic* is a seismic research vessel with dynamic positioning capability, chartered and equipped by AGSO to carry out the Continental Margins Program. The ship was built in Norway in 1982 and arrived in Australia to be fitted out for geoscientific research in October 1984. It is registered in Newcastle, New South Wales, and is operated for AGSO by the Australian Maritime Safety Authority (AMSA).

| | | | |
|---|---|---|---|
| Owner: | Galerace Limited | | |
| Radio call sign: | VMMR | | |
| Official number: | 851492 | | |
| Gross Registered Tonnage: | 1545 tonnes | | |
| Length, overall: | 72.5 metres | | |
| Beam: | 13.8 metres | | |
| Draft: | 6.0 metres | | |
| Nett tonnage: | 421 tonnes | | |
| Displacement tonnage: | 3000 tonnes | | |
| Engines: | Main: | Norma KVMB-12 | 2640 H.P./825 r.p.m. |
| | Aux: | 2 x Caterpillar | 564 H.P./482 KVA |
| | | 1 x Mercedes | 78 H.P./56 KVA |
| | Shaft generator: | | AVK 1000 KVA; 440 V/60 Hz |
| | Side Thrusters: | | 2 forward, 1 aft, each 600 H.P. |
| Cruising speed: | 10 knots | | |
| Maximum speed: | 13 knots | | |
| Propellers: | 1 x Variable pitch | | |
| Fuel capacity: | 483.55 tonnes | | |
| Fresh water capacity: | 107.98 tonnes | | |
| Radar: | Furuno FAR-2832S 10cm (ARPA) | | |
| | Furuno FR-2020 3cm | | |
| Gyro compass: | Sperry Mk 37 | | |
| Helicopter deck: | 20 metres diameter, rear mounted. | | |
| | Markings as per AGA 7 General Conditions. | | |
| | Suitable for Bell 206B Longranger / Squirrel | | |
| Accommodation: | 38 single cabins, 3 double cabins | | |
| | 42 persons total | | |
| Hospital: | 1 berth | | |
| Life boats: | 2 x enclosed 40-man motor-driven lifeboats | | |
| Life rafts: | 4 x 20-man inflatable | | |
| | 1 x 6-man inflatable | | |
| Communications: | Inmarsat C | | |
| | Sailor MF radio | | |
| | 2 x VHF fixed antenna radios | | |
| | 4 x VHF hand-held radios | | |
| | 4 x Motorola UHF hand-held radios | | |
| | Aircraft radio | | |

27 MHz citizen's band radio
Bridge mobile telephone
Inmarsat A (2 identification numbers)
3 x general use mobile telephones
Facsimile

*Contact numbers*

| | |
|---|---|
| Inmarsat (Indian /Pacific Satellite): | 872-1545120 (telephone/telex) |
| | 872-1545121 (fax/data) |
| Mobile telephone: | 018 898 200 (telephone) |
| | 018 620 515 (telephone) |
| | 018 632 656 (fax) |

## APPENDIX 2
## Main Seismic Acquisition Parameters

**Seismic Streamer Configuration**

| | |
|---|---|
| Length (active section) | 4800 m |
| Group length | 25 m |
| No. channels | 192 |
| Towing depth | 10 or 12 m, depending on sea state |

**Seismic Source**

| | |
|---|---|
| Dual airgun array capacity | 50 litres (3000 cu in) |
| Airgun pressure | 1800-2000 psi (normal)<br>1600 psi (minimum) |
| Shot interval | 50 m (19.4 sec shot rate @ 5 knots) |
| Towing depth | 10 m |

**Fold**

4800 %

**Recording Parameters**

| | |
|---|---|
| Record length | 16 seconds |
| Sample interval | 2 ms |
| Passband | 4-180 Hz |

## APPENDIX 3
## Survey and Equipment Specifications

<u>Seismic Recording System</u>

| | |
|---|---|
| Instrument type: | MUSIC Recording System |
| Manufacturer: | AGSO |
| Serial number: | 150964 |
| Recorded seismic data channels: | 192 per streamer |
| Recorded auxiliary channels: | 16 per streamer<br>Channels 193-194: Dummy<br>Channels 195-202: Near-field gun signatures<br>Channels 203-207: Water-break phones<br>Channel 208: Sonar buoy (not used) |
| Streamer front channel number: | 1 |
| Sample interval: | 2 milliseconds |
| Low-cut filter / slope: | 4 Hz at 18 dB/octave |

| | |
|---|---|
| High-cut filter / slope: | 180 Hz at 140 dB/octave |
| Record length: | 16 seconds |
| Recording medium: | High density cartridges M2841 |
| Recording format: | Demultiplexed (modified) SEG-Y |
| Recording density / speed: | 37871 bpi 18 track / 39.37 ips (1000 mm / sec) |
| Recording polarity: | Pressure increase = negative number on tape |
| External header format: | N/A |
| Maximum input RMS: | +/- 7.07 volts |
| A/D linearity: | 0.20% |
| Accuracy of gain ranging: | 0.25% |
| Channel-channel accuracy: | 0.40% |
| Harmonic distortion: | 0.01% at 3200 mV 31.25 Hz / 0.22% at 1 mV 31.25 Hz |
| Multi-trace plotter: | Epson DFX-8000 printer |
| Time difference between first scan recorded and timebreak: | 60.0 milliseconds |

Seismic Streamer

| | |
|---|---|
| Streamer: | Fjord Instruments analogue streamer |
| Manufacturer: | Fjord Instruments |
| Length (active): | 4800 m |
| Section length: | 100 m |
| Number of active sections: | 48 |
| Active groups: | 192 (configured by in-streamer program plugs) |
| Hydrophones per group: | 40 |
| Group length: | 25 m |
| Group interval: | 25 m |
| Hydrophone sensitivity: | 44 Volts/Bar |
| Hydrophone type: | Transformerless charge-coupled Teledyne T-1 |
| Depth transducer type: | N/A (using cable leveller depths) |
| Cable levellers (birds): | 25 x Syntron RCL-3 |
| Cable leveller positions: | Located after channels 0, 8, 16, 24, 32, 40, 48, 56, 64, 72, 80, 88, 96, 104, 112, 120, 128, 136, 144, 152, 160, 168, 176, 184, 192 |
| Cable compasses: | 5 x Syntron RCU-831 fluxgate vector magnetometer externally mounted |
| Cable compass positions: | Located after channels 28, 68, 108, 148, 188 |
| Water-break detectors: | 5 x T-1 phones |
| Water-break positions: | Located after channels 0, 44, 92, 140, 188 |
| Towing depth: | 10.0 ± 1.5 m |

Seismic Source

| | |
|---|---|
| Source type: | 3000 cu. inch sleeve airgun array |
| Airgun type: | HGS sleeve airgun |

| | |
|---|---|
| Number of sub-arrays: | 2 |
| Number of guns per sub-array: | 10 active plus 6 spare<br>Cluster 1: 4 active, 2 spare<br>Cluster 2: 3 active, 2 spare<br>Cluster 3: 2 active, 1 spare<br>Cluster 4: 1 active, 1 spare |
| Length of source array: | 13.5 m |
| Gun spacing: | 0.5 m between individual guns in clusters<br>2.5 m between clusters in each sub-array |
| Width of source array (sub-array spacing): | 15 m |
| Nominal air pressure: | 1800 psi ±10% |
| Depth sensors: | 4 per sub-array |
| Near-field phones: | 1 per gun cluster |
| Number of active guns: | 20 |
| Number of spare guns; | 12 |
| Compressors: | 6 x A-300 300 scfm Price compressors |
| Gun timing unit: | AGSO GCM |
| Timing variance: | ±1.5 milliseconds |
| Firing delay midpoint: | 60.0 milliseconds |
| Firing aiming point: | Midpoint + 0.00 milliseconds |
| Timebreak: | Fixed at 60.0 milliseconds |
| Shotpoint interval: | 50.0 m |
| Nominal shooting speed: | 5.0 knots |
| Towing depth: | 10.0 ± 1.5 m |

Navigation/Positioning and Geophysical Data Acquisition (non-seismic)

| | |
|---|---|
| Navigation/Acquisition system: | AGSO DAS - Data Acquisition System |
| Data storage: | Andataco 4320NT cartridge drives |
| *Primary navigation*: | Racal Multifix Differential Global Positioning System |
| Primary navigation equipment: | Receiver: Trimble 4000DL/II<br>Demod: Racal Skyfix Satellite Differential Demodulator 2402<br>Medium: Racal Inmarsat satellite dish<br>Frequency: 72.475 Mhz<br>Reference: Sydney, Melbourne, Adelaide and Perth Reference Stations |
| *Secondary Navigation*: | Racal DeltaNav Differential Global Positioning System |
| Secondary Navigation Equipment: | Receiver: Trimble 4000DL/II<br>Demod: Racal Skyfix Satellite Differential Demodulator 2402<br>Medium: Racal Inmarsat satellite dish<br>Frequency: 82.475 MHz |

| | |
|---|---|
| | Reference: Melbourne Reference Station |
| *Tertiary Navigation*: | Global Positioning System |
| Tertiary navigation equipment: | Magnavox MX4400 GPS receiver |
| Sonar dopplers (dual-axis): | Magnavox MX610<br>Raytheon DSN 450 |
| Gyrocompass: | Sperry Mk 37 Gyrocompass |
| Echo sounders: | Raytheon CESP III 3.5 kHz (2 kW), 16 transducer sub-bottom profiler and 12 kHz (2 kW) |
| Gravity: | Bodenseewerk Geosystem KSS-31 Marine Gravity Meter |
| Magnetics: | Geometrics G801/G803 proton magnetometer |

# APPENDIX 4
## Provisional Crew List

### Scientific Crew

| | |
|---|---|
| Peter Hill | Project Representative |
| Kevin Webber | Ship Manager |
| Norm Johnston | Systems Expert |
| Maria De Deuge | Quality Control / Systems Expert |
| Donna Cathro | Scientific Officer |
| Mark Timms | Electronics Technician |
| Claude Saroch | Electronics Technician |
| Jim Bedford | Science Technician |
| John Ryan | Science Technician |
| Steven Ridgway | Science Technician |
| Greg Atkinson | Science Technician |
| Fenji Stradwick | Science Technician |
| Steve Wiggins | Mechanical Technician |
| Andrew Hislop | Mechanical Technician |
| Andy Hogan | Mechanical Technician |
| Ross Bodger | Mechanical Technician |
| Andrew Hinds | Mechanical Technician |

### AMSA Crew of the *Rig Seismic*

| | |
|---|---|
| R.N. Hardinge | Master |
| W.H. Orgill | Chief Officer |
| I.C. Watson | Second Officer |
| R.W. Thomas | Chief Engineer |
| R.D. Heaton | Second Engineer |
| R.A. Dickman | Electrical Engineer |
| B.P. Noble | Chief Integrated Rating |
| D.J. McDonald | Integrated Rating |
| D.A. Kane | Integrated Rating |
| (to be advised) | Integrated Rating |
| G.R. Conley | Chief Steward / Cook |
| A.A. King | Cook |

| | |
|---|---|
| A.Z. Clark | Catering Attendant |
| A.C. Blackman | Catering Attendant |

**Adviser, Tasmanian Fisheries**

| | |
|---|---|
| Rod Treloggan | Retired President of the Tasmanian Crayfishing Association |