AGSO

CRUISE PROPOSAL: SWATH-MAPPING CRUISE OFF TASMANIA USING RV *L'ATALANTE*

by
N F Exon & P J Hill

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Cruise Proposal

SWATH-MAPPING CRUISE OFF TASMANIA USING R.V. *L'ATALANTE*

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SUMMARY

In early 1994, the Australian Geological Survey Organisation (AGSO) will use the multibeam sonar system of the French research vessel *l'Atalante* for 35 days mapping of 200 000 km^2 of the continental margin (southern Otway Basin, Sorell Basin, South Tasman Rise) and the adjacent abyssal plain. The cruise will start in Wellington on 16 January and finish in Adelaide on 27 February. Data will be recorded on the transits, as well as near Tasmania. The SIMRAD EM12D system provides bathymetric maps and acoustic imagery in real time, and can map an area along each track up to 20 km wide at a speed of 10 knots. The maps will define bathymetry and surface texture with a degree of accuracy and rate of coverage unobtainable in any other way. In addition we will record 6 channel seismic reflection, magnetic, gravity and bathymetric profiles. This mapping of an area three times that of Tasmania will help to clarify the region's structural pattern and tectonic history, largely controlled by the separation of Australia and Antarctica about 40 million years ago. We will also map large-scale sedimentary structures and patterns to help elucidate Tertiary sedimentary history, and morphology to help define Australia's Legal Continental Shelf for the day when Australia ratifies the Law of the Sea Convention (expected within a couple of years).

The region's geological history bears on the history of the entire southern margin of Australia. This margin is already a major producer of petroleum from the Upper Cretaceous and Paleocene sequences in the Gippsland Basin, and has encouraging exploration results in several other basins. The Otway Basin, in particular, is the scene of major recent offshore gas discoveries in the Cretaceous sequence. The very accurate bathymetric maps and sonar images arising from this survey will provide an unequalled source of structural information of great value to AGSO and the petroleum exploration industry. The mapping of the fault patterns that come to the surface on the continental margin, believed to be part of a large, NNW to NW trending strike-slip system that first formed in the Early Cretaceous, will lead to much better understanding of fault geometry. It also will aid the planning of future AGSO seismic reflection programs, aimed at mapping deep structure along the margin.

The mapping of the abyssal plain to the west will bear closely on the breakup history of Australia and Antarctica. It is generally believed that Late Cretaceous and Cainozoic spreading took place along north-south fracture zones that are clearly visible in satellite altimetry data, but also there is evidence of earlier, probably Early Cretaceous, oceanic crust in which the fracture patterns trend northwestward. Swath-mapping imagery will give us more detail of trends, and also locate good sites for sampling basalts for dating and geochemical examination. In addition, it is uncertain how far continental blocks extend out onto the plain, and the mapping of all blocks will enable future sampling is properly targeted to resolve this important scientific question.

The mapping of rocky outcrops, sedimentary structures, and sedimentary patterns will be invaluable in planning a forthcoming AGSO seafloor sampling cruise. This sampling will target Cretaceous, Paleocene and Eocene rocks to provide information on the pre-separation history of the margin, oceanic basalts to elucidate the spreading history, and Oligocene and younger sediments to provide information on changes in oceanic circulation and climate as Australia moved steadily north from Antarctica.

INTRODUCTION

Regional tectonic setting

The architecture of the southern continental margin of Australia is dominated by the Mesozoic 'Southern Rift System' which was associated with the fragmentation of Gondwana. This rift system extends for over 4000 km from Broken Ridge in the west to the South Tasman Rise in the southeast. In most places this system underlies the continental slope, where it has physiographic expression in such margin features as the Eyre, Ceduna and Beachport Terraces, and the South Tasman Rise. However, in some areas, most notably south of the Eyre Terrace and off the Otway and Sorell Basins of west Tasmania, it appears to give rise to an abnormally wide (*ca.* 200 km) lower continental slope/continental rise at nearly abyssal depths (4000-5000 m). The Southern Rift System developed in the latest Jurassic and earliest Cretaceous and was largely formed by strike-slip faulting oriented approximately NW-SE (Willcox & Stagg, 1990). The rift system filled with thick, non-marine Jurassic and Early Cretaceous syn-rift volcanogenic sediments (e.g. Otway Group in the Otway Basin).

Breakup (seafloor spreading) between Australia and Antarctica has been dated at 96 Ma (Cenomanian) on the basis of magnetic seafloor spreading anomalies (Cande & Mutter, 1982). The Southeast Indian Ocean is generally considered to have developed in three stages of seafloor spreading: a very slow stage from 96-49 Ma (Cenomanian-Early Eocene); an intermediate stage from 49-44.5 Ma (approximately mid Eocene); and a fast stage from 44.5 Ma to the present (Veevers et al., 1990). However, more recently, Stagg & Willcox (1992) report on much older, probably pre-Neocomian, oceanic crust in the western Great Australian Bight.

According to Moore et al. (1992), breakup in the Otway/West Tasmania region must have been closely related to that in the Great Australian Bight. However, seafloor spreading anomalies A22-34 appear to be absent off Tasmania, indicating that breakup may have propagated eastwards, possibly in discrete stages, and did not reach this easterly part of the margin until the mid Eocene (44.5 Ma). The subsidence history tends to support this concept: for example, shallow marine/deltaic mid Eocene rocks have been cored from 3726 m off west Tasmania (Hinz et al., 1985). By the mid Oligocene, when the Australia and Antarctic Plates are believed to have totally separated from each other south of the South Tasman Rise (Willcox et al., 1989), thermal subsidence should have been well advanced. However, the slow passage of the ridge crest along the Tasmania transform margin, and the buttressing effect of the adjacent continents, appear to have further delayed subsidence. Although the prominent and widespread mid Oligocene unconformity, which was probably created by shallow wave-base erosion, is in part the product of a global sealevel fall, it is accentuated by this delayed subsidence of the margin. Accelerated thermal sag, accompanied by the onset of mainly carbonate deposition, occurred only after the mid Oligocene. If this scenario holds, then the west Tasmania basins may contain locally thick shallow-marine Palaeogene sequences created by wrench-related block movements.

It has also been proposed either that the South Tasman Rise was attached to the Antarctic Plate during the period of slow spreading in the Late Cretaceous and Early Tertiary (starting at 96 Ma according to Cande & Mutter, 1982), and has moved southeastward from a position adjacent to the Otway Basin, or that it has moved southwestward from a position next to the South Tasman Rise between 118 and 96 Ma (Veevers et al., 1991). Satellite altimetry data (GEOSAT) show it to be a complex feature cut by northwesterly and northerly trending faults.

The study region

The region of interest to us extends from 40° to 50°S and 140° to 150°E west and south of Tasmania, from west of King Island to the crest of the South Tasman Rise, and from the outer edge of the continental shelf to the abyssal plain (Fig.1). The continental shelf around Tasmania is generally less than 50 km wide and is generally non-depositional at the present day (Jones & Holdgate, 1980), but some bryozoal sands and gravel do accumulate on the outer shelf (Jones & Davies (1983). The continental slope west of Tasmania is about 70 km wide, and falls fairly regularly from water depths of 200 m to 4000 m, so the average slope is 3-4°. The continental rise lies between about 4000 m and 4500 m, and below that is the abyssal plain, generally 4500-5200 m deep.

The South Tasman Rise is a large, NW-trending bathymetric feature that rises to less than 1000 m below sea level, and is separated from Tasmania by a WNW-trending saddle more than 3000 m deep (Fig. 1). The Deep Sea Drilling Project showed that it has a continental core when quartz-mica schist was drilled in DSDP Site 281 (Kennett, Houtz et al., 1974). The top of the rise is a gentle dome with low slopes, but slopes between 2000 and 4000 m on its eastern and southern sides are much like those in the Tasmanian continental slope, of the order of 3-4°. The western slope is not great to 3000 m, but below that there is a very steep scarp trending 350° and dropping away to 4500 m. Sampling of the scarp has returned Upper Cretaceous shallow marine mudstone, siltstone and sandstone.

This scarp and several NNW-trending ridges, in the continental slope and on the deep ocean floor, west of Tasmania and off the Otway Basin, seem to mark tilt-blocks of continental rocks, necessarily overlying highly extended and thinned continental crust. Dredging of one such ridge on the abyssal plain off Victoria by AGSO's *Rig Seismic* has led to the recovery of Tasman Geosyncline metasediments (Exon, Williamson et al., 1987). Other ridges off the west coast of Tasmania, and oblique to the continental shelf edge, may lie on the continent-ocean boundary, or may be the trace of old transforms associated with the early stages of seafloor spreading between Australia and Antarctica.

The mapping of seafloor magnetic anomalies starting with Weissel & Hayes (1972), and the interpretation of satellite altimeter data (e.g. Veevers, 1990: Seasat data) has shown that the abyssal plain west of Tasmania is characterised by fracture zones trending 350-335°, and that Late Cretaceous and Cainozoic magnetic anomalies are probably normal to the fracture zones. The anomaly pattern and a representation of the fracture zones is shown in Figure 2 (after CPCEMR, 1991).

The very recent release of the more detailed GEOSAT satellite altimetry data has enabled the compilation of a suite of satellite images of our study region by AGSO's John Creasey, such as the grey tone image shown as Figure 3. These images define basement structure very well and provide excellent information on fracture zones. They confirm the older NW-trending fracture direction (Jurasic-Early Cretaceous) close to the continental margin, and the younger 350-355° fracture direction further out on the abyssal plain. They also indicate that the South Tasman Rise is cut by major deep faults. An interpretation of the GEOSAT imagery by Hill is shown in Figure 4. The trends mentioned above are shown, as are more subtle fractures on the abyssal plain that may be related to Pacific Ocean mantle pushing westward into the Indian Ocean (as postulated by Tony Crawford of the University of Tasmania, among others). This GEOSAT interpretation, in conjunction with bathymetric and other information, led us to propose that N/O *l'Atalante* be used to swath-map the area outlined in Figure 4, in order primarily to address tectonic problems.

Cruise program

AGSO is to carry out a 35 day swath-mapping cruise in the Otway Basin/west Tasmania/South Tasman Rise region using the multibeam SIMRAD EM12D swath-mapping system aboard the French research vessel *l'Atalante*, in accord with a three-way exchange of ship time. The data collected will allow for a detailed study of the morphology of the continental slope and oceanic crust, and definition of the continent-ocean boundary, across this major Southern Ocean transform margin. An additional benefit will be sedimentological information.

The cruise will start in Wellington, New Zealand and end in Adelaide and totals 42 days. It will provide a single swath 20 km wide across the Tasman Sea to the East Tasman Rise southeast of Hobart, and 100% coverage in the main area of interest west of Tasmania, downslope from the shelf break. This work will be followed by a further *Rig Seismic* sampling cruise in the region, and later some deep seismic transects. Australian universities are involved, especially on the sedimentological side, and a research group based in Villefranche will work with us on the tectonics.

Cruise participants

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PREVIOUS STUDIES

The first regional seismic survey that included the Tasmanian region was the 1972 BMR Continental Margins Survey. 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). The east-west lines in Figure 5 represent most of its profiles, and those off west Tasmania are identified in Figure 6.

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 & 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 & 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 nine lines zig-zagging from the shelf to the abyssal plain in the Otway Basin-West Tasmania region and included in Figure 5, and those off west Tasmania are specified in Figure 6. They showed 3 to 4 seconds (two-way time) of penetration. An interpretation by Bouef & Doust (1975) showed that this 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.'

Bouef & Doust (1975) continued : 'From the continent outward several structural zones can commonly be recognised: (a) a zone of shallow basement with a thin Lower Cretaceous cover normally faulted and overlain by thin gently dipping Tertiary beds, (b) a zone of faulted and landwards tilted basement blocks and Lower Cretaceous sediments overlain (sometimes with clear unconformity) by thick Upper Cretaceous sediments, (c) a zone of thick, moderately deformed Tertiary sediments whose axis of deposition is generally offset to the south of the Upper Cretaceous basinal axis, (d) a zone of rotational faults and associated toe thrusts affecting the Cretaceous sediments and apparently related to the time of margin collapse, (e) an area of little disturbed Cretaceous and Tertiary sediments overlying continental basement. This zone extends into the "magnetic quiet zone" which is therefore believed to be, at least in part, a collapsed portion of the continental margin adjacent to oceanic crust.' This interpretation remains fundamentally correct today.

In 1973, Leg 29 of the Deep Sea Drilling Project (DSDP) drilled four partly cored holes in the Tasmanian region, including Site 282 on the west Tasmanian margin (Fig. 6), which was some 310 m deep in 4202 m of water (Kennett, Houtz et al., 1973, 1974). Site 282 lies 160 km west of Cape Sorell on Sonne line 36B-46, which shows it to have been on a basement high (Fig. 11). The sequences drilled in it 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.

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 at least 80 m of siliceous Oligocene sandy silt, and 390 m of late Eocene sandy silt, containing chert in the upper 100 m, and glauconite and manganese micronodules below that. 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. This is overlain by a six metre thick basement conglomerate consisting of angular clasts, dominantly of schist, with lesser quartz, quartzite, glauconite, glauconitic sandstone and granite. The hole contains 36 m of Plio-Pleistocene foram-nanno ooze, 79 m of Miocene foram-nanno ooze, and 3m of late Oligocene glauconite-rich detrital sand. Below a major unconformity there is about 33 m of late Eocene sediment: an upper 28.5 m of grayish-olive sandy silt and silty clay, a middle 3 m of detrital sand and nanno chalk, and the basal conglomerate.

One other DSDP Site relevant to the present study is Site 283, drilled on the East Tasman Rise in 4756 m of water to a depth of 592 m. It recovered about 160 m of late Eocene siliceous ooze, 130 m of ?Eocene silty clay, and 270 m of Late Cretaceous or Paleocene silty clay with some chert, above basalt basement.

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. These lines are included in Figure 5. Seismic profile BMR 40/22-23, from Esso Prawn No. 1 well to the base of the continental slpoe, is illustrated in Figure 7 and located in Figure 6.

In 1985, the West German Research Vessel *Sonne* carried out two BGR-BMR co-operative cruises on the Tasmanian margin (*Sonne* Cruises 36B & 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 (Fig. 6). During the same cruise, nine regional seismic lines were shot on the South Tasman Rise (Fig. 8), and 19 sampling stations were occupied (Fig. 9). 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). The core results for both west Tasmania and the South Tasman Rise are summarised in Figure 10. An interpretation of the west Tasmanian seismic lines (Figs. 11 & 12), as well as that of profile BMR 40/22-23 (Fig. 7), showed that up to 5 seconds (two-way time) of section was present and that up to 14 unconformities could be identified (Hinz et al., 1986). Sampling and well data from west Tasmania indicated (Fig. 13) 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 J.B. Willcox in Willcox et al. (1989) on the basis of the *Sonne* seismic profiles. It covers an area of 140 000km^2 between 800 and 3000 m (Fig. 9). A continental origin is deduced from the schist drilled at ODP Site 281 and dredged by *Sonne*, from plate tectonic reconstructions, and from the relatively quiet magnetic and gravity Fig. 14) profiles. Three of the profiles from *Sonne* Cruise 36B over the South Tasman Rise are illustrated as line drawings in Figure 14, 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 (Figs. 14 & 15). The basement is extensively planated and it surface is continuous with the regional Oligocene unconformity.

The sampling results were outlined by Hinz et al. (1985). Bolton et al. (1988) discussed manganese crusts and their substrates in a paper on the geochemistry of ferromanganese nodules and crusts recovered by the *Sonne* from the rise. Basement rocks were recovered from dredge 44KD (locations in Fig. 9): garnet-bearing schist and gneiss, granodiorite and pegmatite. Dredge 52KD recovered a basaltic breccia consisting largely of palagonitic basalt fragments in a collophane-bearing fine grained matrix, and encrusted with manganese. Pre-Tertiary basement rocks were recovered in cores 49KL and 53KL - fine grained graywacke and quartzite respectively. Eocene olive or grey-green mudstones were present in dredges 43KD and 44KD, and cores 40KL, 45 Kl and 56 KL. They contain zeolites, and are highly bioturbated with little evidence of bedding. They also contain poorly preserved radiolaria and arenaceous forams, and occasional glauconitic sands. Belford (1989) has confirmed the Eocene age on the basis of forams for 45KL and 56KL. Neogene sediments from above the Oligocene unconformity are nanno-foram and foram-nanno ooze and chalk.

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 (Fig. 3). 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 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 (Figs. 9 & 15) is clearly a transform fault, with movement presumably ending in the Oligocene with the separation of Australia and Antarctica.

In early 1987, R.V. *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 & Lee, 1987; Exon et al., 1992). Altogether, 130 sampling stations were occupied using dredges, corers, grabs and a heatflow probe (Fig. 6) 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 easily incorporated 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.

Heatflow calculations from 20 stations suggested 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, R.V. *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 (Fig. 16) and the other half to geological sampling (Fig. 17). Off west Tasmania, 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 with an 80 cubic inch water gun and a 600 m seismic cable (48 channels). 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 (Fig. 18). 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 older 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. The sampling results from this cruise and its predecessors were combined in a map of surface sediments (Fig. 19).

Tectonic studies which have touched on this region include that of Falvey (1974) who produced a model of this margin as a typical Atlantic margin, with breakup between Australia and Antarctica in the late Paleocene, in line with the interpretation of magnetic anomalies by Weissel & Hayes

(1972), and that of Deighton & others (1976). Cande & Mutter (1982) revised the magnetic identification and concluded that margin formation commenced in the Santonian, with a period of slow spreading from 90 to 43 Ma, followed by more normal spreading rates until the present. Falvey & Mutter (1981) and Willcox (1982) included the region in general reviews of Australia's continental margins. Veevers (1985) has suggested that breakup started 95 Ma ago.

PETROLEUM EXPLORATION

Organic-rich Late Eocene silty clays at DSDP Site 282 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 & others, 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 South Tasman Rise 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) and this section is drawn from their work. The margin is underlain by the southern Otway Basin and the Sorell Basin. 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 (Fig. 20). 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 (seafloor spreading). 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, and are generally separated by unconformities. 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. Geohistory maturation modelling of wells and source rock 'kitchens' has shown that the best locations for liquid hydrocarbon entrapment in the southern Otway Basin are in structural positions marginward of the location of Prawn No. 1 well. In such positions, basal Lower Cretaceous source rocks could charge overlying Pretty Hill Sandstone reservoirs. In the King Island sub-basin, the sediments encountered by the Clam No. 1 well are thermally immature, though hydrocarbons generated from within mature Lower Cretaceous rocks in adjacent depocentres could charge traps, providing that suitable migration pathways are present. Whilst no wells have been drilled in the Sandy Cape sub-basin, basal Cretaceous potential source rocks are considered to have entered the oil window in the early Late Cretaceous, and are now capable of generating gas/condensate. Upper Cretaceous rocks appear to have entered the oil window in the Paleocene. In the Strahan sub-basin, mature Cretaceous sediments in the depocentres are available to traps, through considerable migration distances would be required.

Moore et al. (1992) concluded that the west Tasmania margin, which has five strike-slip related depocentres and the potential to have generated and entrapped hydrocarbons, is worthy of further consideration by the exploration industry. The more prospective areas are the southern Otway Basin, and the Sandy Cape and Strahan sub-basins of the Sorell Basin.

CRUISE OBJECTIVES

The main objectives of the survey off west Tasmania and over the South Tasman Rise (STR) are given below:

- Determine the structure of the continental slope in the west Tasmania region, particularly the geometry of the continental tilt-blocks which appear to be present out to water depths of more than 4000 metres.
- Determine in detail the azimuth and possibly nature of deep-ocean ridges west of Tasmania, which seem to lie oblique to the trend of the coastline and shelf-edge.
- Examine the relationships between the direction of lithospheric extension, the azimuth of the seafloor spreading phases, and the formation of the transform margin along west Tasmania and the South Tasman Rise.
- Map the 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.
- Deduce a kinematic evolution for the South Tasman Rise and acount for its anomalous position in some plate reconstructions.
- Upgrade our understanding of the evolution of the Australian southern margin and the Southern Ocean, particularly the way in which it may have affected the age and formation of petroleum source rocks and the development of migration paths.
- Map sedimentary structures and patterns, and work toward an understanding of Neogene sedimentary processes and their variations with time.

CRUISE PLAN

Southern Tasman Sea Transit

It is planned to collect EM12D swath-mapping and other geophysical data during the transit from Wellington to the main survey area off southwest Tasmania. This work will assist future geomarine studies of the southern Tasman Basin and its margins. An almost direct route will be followed to allow maximum time for the main survey. The plan is to start data acquisition from just north of Cape Farewell (northern tip of the South Island of New Zealand), cross the southern part of the Challenger Plateau and proceed in an WSW direction across the southern Tasman Basin. The transit line will tie to the DSDP 283 site (Appendix 1) and continue due west to the summit of the East Tasman Plateau. Way-points are as follows:

Cape Farewell	40° 25' S	172° 40' E (approx.)
Just east of DSDP 283	43° 54.60' S	155° 00.00' E
DSDP 283	43° 54.60' S	154° 16.96' E
Summit of East Tasman Plateau	43° 54.60' S	150° 24.00' E

The transit distance from Wellington to the summit of the East Tasman Plateau is about 2050 km. Estimated transit time at a ship's speed of 10 knots is 4 days 15 hours.

Main Survey

EM12D swath-bathymetry and acoustic imagery, 6-channel GI gun seismic, 3.5 kHz high resolution seismic, gravity and magnetic data will be collected at a nominal ship's speed of 10 knots. Of the data-sets to be acquired, the EM12D is the most important. For this reason, the survey has been designed to make the best use of this system.

Approximately 42 days of ship time are available, of which about 6 days will be required for transits (Wellington-Tasmania and Tasmania-Adelaide). Assuming 5% of the remaining time will be taken up in transits between survey lines, the total time available for running survey lines is 34.2 days. Thus a maximum of 15 200 line-km of data can be acquired over the Tasmanian survey area at a ship's speed of 10 knots. Bad weather or equipment problems would reduce this amount.

The proposed survey coverage is indicated in Figure 4. EM12D operations are most efficient and data quality is best when lines are run along submarine slope and parallel to seafloor structural trends (Hill, 1993). For this reason, the primary line orientation was adopted as 150° azimuth. This azimuth corresponds to the trend of the continental slope off west Tasmania, and lies between the two main deep-water structural trends seen in the existing bathymetry data and Geosat imagery, ~140° (?Jurassic/Cretaceous Australia-Antarctica spreading direction) and ~170° (latest Cretaceous-Cainozoic spreading direction). Several short lines over the far southern Tasmanian continental slope are oriented at 079° to match the local topographic trend.

The survey lines have been positioned to provide 100% EM12D data coverage over most of the survey area, with about 10% overlap of data coverage between adjacent lines. An exception is the relatively shallow (~1000 m water depth) summit area of the STR, where the proposed lines will provide about 70% EM12D coverage. The reduced coverage is warranted because bedrock structures in this area appear to have little or no expression in the seafloor topography due to blanketing by late Cainozoic sediments.

The survey lines shown in the area shown in Figure 4 have a total length of about 18 500 km, which is about 18% more than can be surveyed in the time available. The extra line-kms have been planned deliberately to allow for the elimination of some lines or parts of lines after assessment of results early in the survey. There is little value in running the EM12D system in areas where rift and transform structures are not reflected in the seafloor topography. Late Cainozoic sediments may hide much of the bedrock structure, particularly in the northern part of the survey area. It is planned to run two long exploratory lines (which are part of the proposed grid) off west Tasmania at the start of the survey. One line will be run along the mid continental slope and the other will be located about 140 km west (in water depths of 4500-5000 m). Results from these lines will provide sufficient information to consolidate the survey program.

The plan is to divide the survey area into three sectors (northern, central and southern) for acquisition purposes, and to complete the survey work in one sector before starting on the next. This will facilitate post-processing of the data onboard ship. The proposed sector boundaries are at approximately 42° 30' S and 45° 30' S. If it is decided not to run a significant proportion of lines in the northern sector, due to paucity of rift/transform-related seafloor structure, it may be advantageous to combine the northern and central sectors into one.

The survey lines will tie to, or at least closely approach, all DSDP sites in the area (280, 281 and 282 - see Appendix 1). Multichannel seismic surveys in the region, BGR SO-36B (Hinz et al., 1985) shot in 1985, and AGSO Survey 78 shot in 1988 (Exon et al., 1989), provide cross ties between most of the proposed *L'Atalante* lines and also tie to the DSDP holes and petroleum wells (including Cape Sorell No.1 and Clam No. 1) on the shelf.

EQUIPMENT

L'Atalante (Appendix 2) is a modern 85-metre oceanographic research vessel specifically built for high-technology seafloor mapping. It is equipped with the advanced SIMRAD Dual EM12 multibeam echo-sounder (Appendix 3). This system maps bathymetry and acoustic reflectivity of the seafloor at a ship's speed of up to 10 knots or more. The swath width is ~7 times water depth; the maximum effective coverage in deep water (several kilometres or more) is about 20 km. Further information on the EM12D system and a discussion of operational considerations are provided by Hill (1993).

Appendix 4 lists the scientific and navigation equipment that will be used during the survey. The proposed geophysical acquisition parameters are provided in Appendix 5.

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APPENDIX 1
DSDP Sites To Be Tied During Survey

Site	Lat. (S)	Long. (E)	Water Depth (m)	Penetration (m)	Max. Age of Seds	Basement type
280	48° 57.44'	147° 14.08'	4176	524	Early to mid Eocene	Intrusive basalt
281	47° 59.84'	147° 45.85'	1591	169	Late Eocene	Paleozoic schist
282	42° 14.76'	143° 29.18'	4202	310	Late Eocene	Pillow basalt
283	43° 54.60'	154° 16.96'	4729	592	Paleocene	Altered basalt

Ref.: Kennett, J.P., Houtz, R.E. et al., (1975)

APPENDIX 2
Information on *L'Atalante*

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

Propulsion:

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

Deck Equipment:

22 ton rotating stern A-frame

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

Accommodation:

Total complement of 59 in single/double berth cabins

Officers and crew, 17-30

Scientists and technicians, 25-29

Operating company:

GENAVIR

APPENDIX 3
SIMRAD EM12D Multibeam Echo-sounder, Technical Information

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

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

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

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

APPENDIX 4
Scientific and Navigation Equipment

Swath-mapping

SIMRAD Dual EM12 multibeam bathymetric / acoustic imagery system

Geophysical

6-channel seismic reflection system, digital acquisition

Digi-Data 9-track tape drive

DOWTY Model 3710 thermal linescan recorder (fast seismic monitor)

DOWTY Thermaline Hard Copy Recorder Series 195 (slow seismic monitor)

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

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

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

BODENSEEWERK KSS30 gravity meter (accuracy ~1 mGal)

BARRINGER M244 magnetometer (~1 nT accuracy)

Navigation

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

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

Vessel heading: 2 BROWN SGB 1000 gyrocompasses

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

APPENDIX 5
Geophysical Acquisition Parameters

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

Magnetics
Magnetometer sensor towed 250 m astern

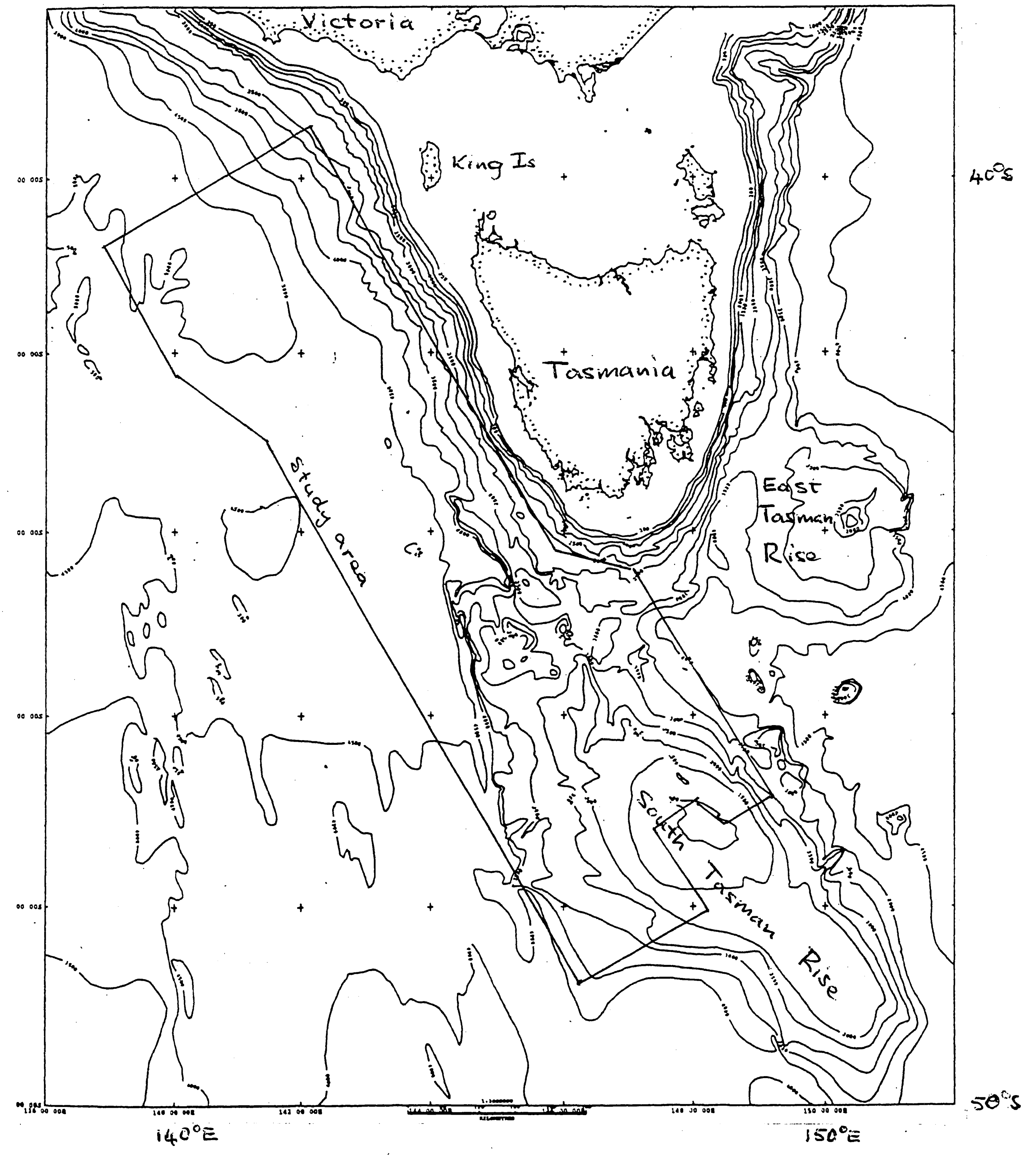

Figure 1. Bathymetric map of the Tasmania and South Tasman Rise region. From GEBCO digital file and G. Wissmann (BGR). Contours in 500 m intervals.

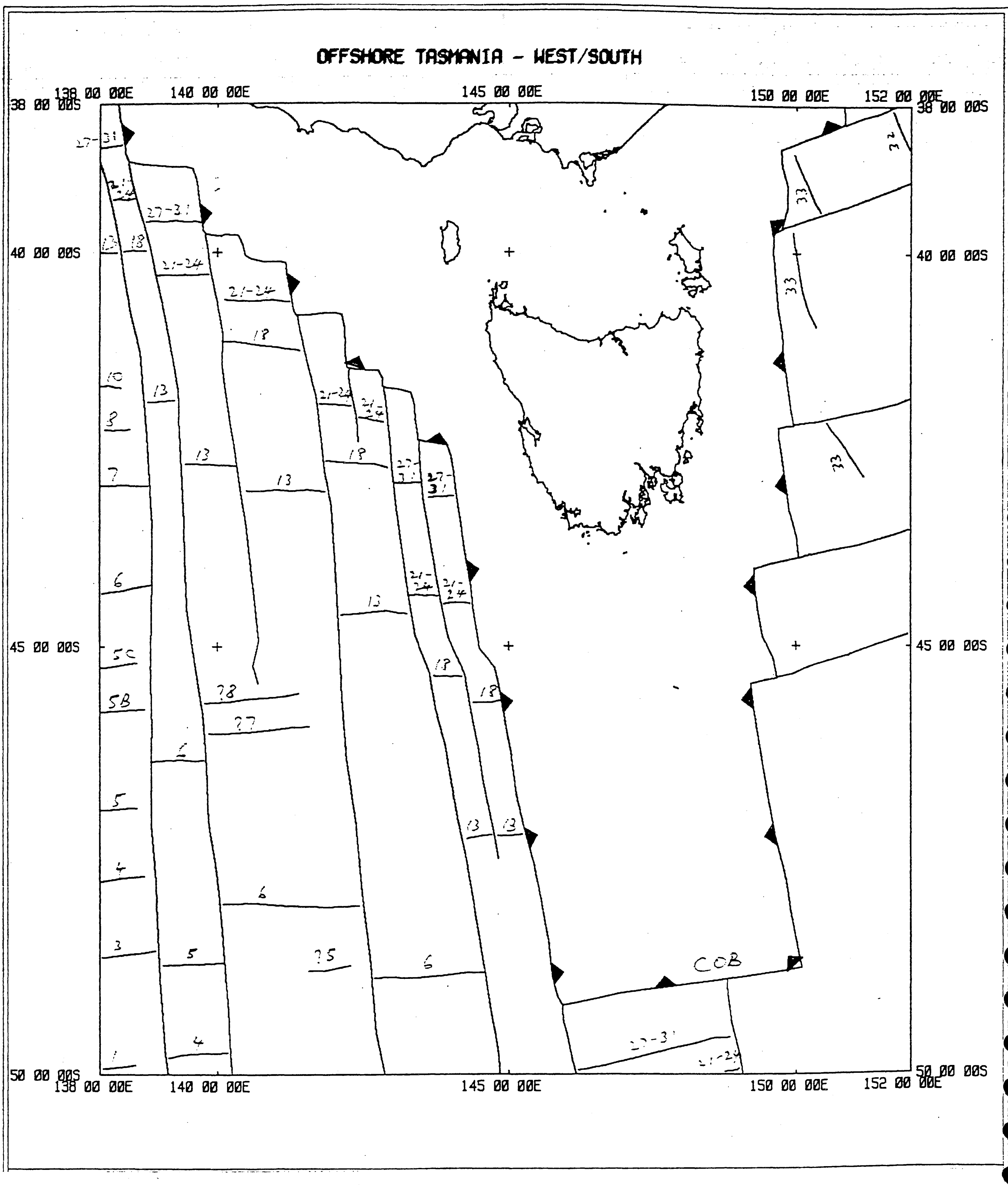

Figure 2. Map of deepsea magnetic lineations and fracture zones in the Tasmania and South Tasman Rise region. After CCEMR (1991). Magnetic anomalies are in Tertiary series.

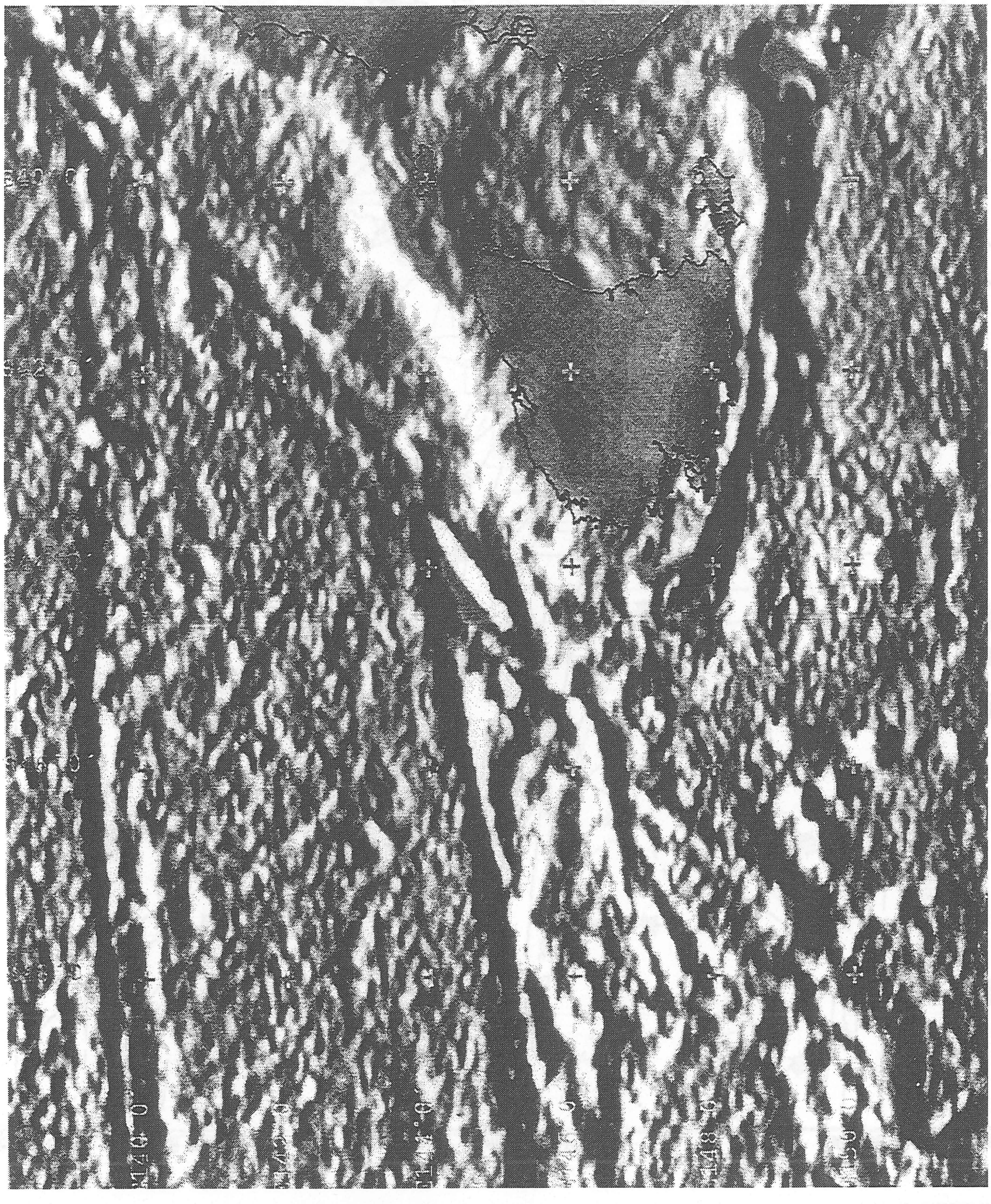

Figure 3. Map of GEOSAT satellite altimeter imagery from the Tasmania and South Tasman Rise region. Grey tone imagery prepared by J. Creasey at AGSO.

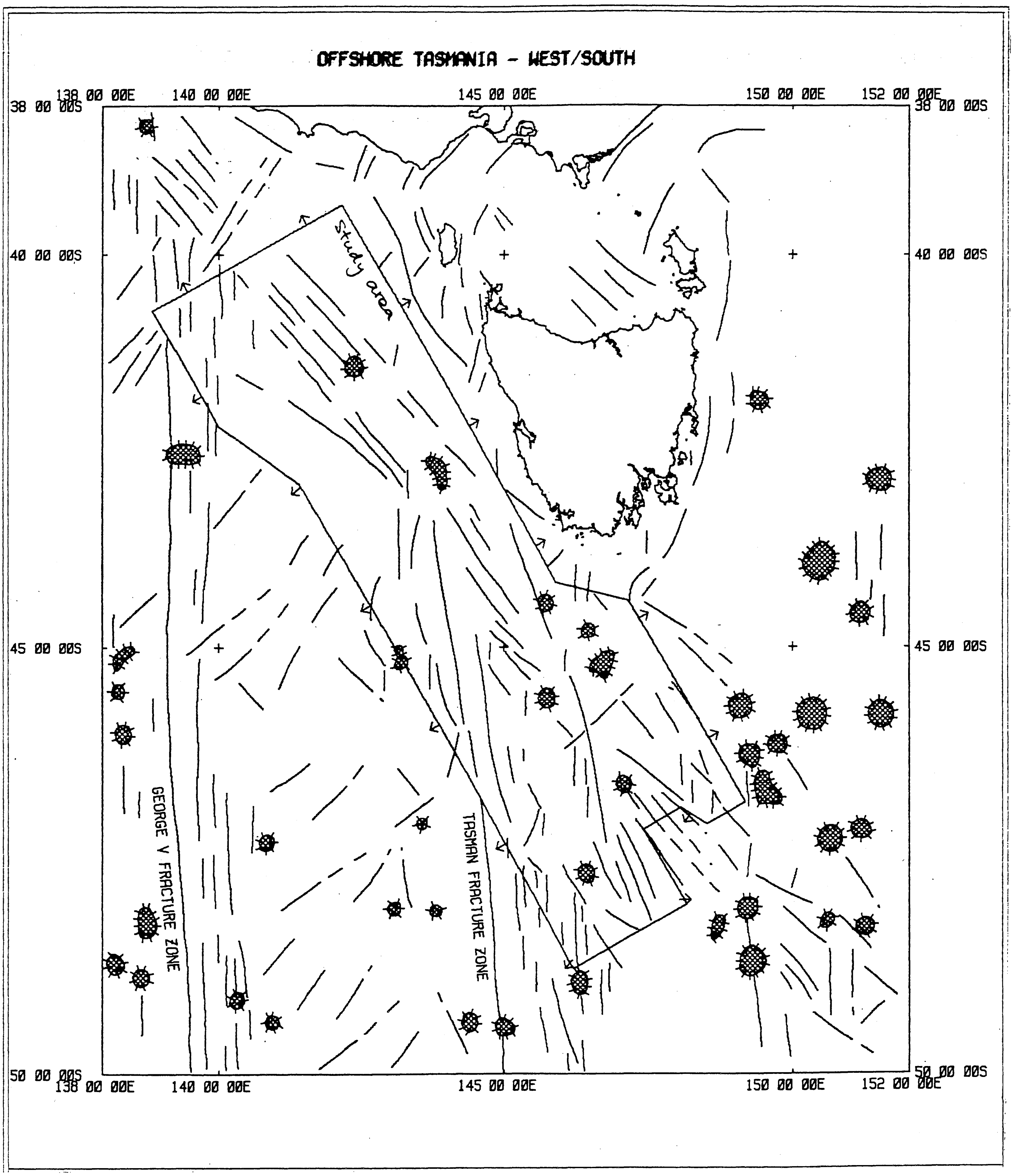

Figure 4. Map of lineations and bathymetric highs interpreted from GEOSAT images in the Tasmania and South Tasman Rise region. Interpretation by P.J. Hill.

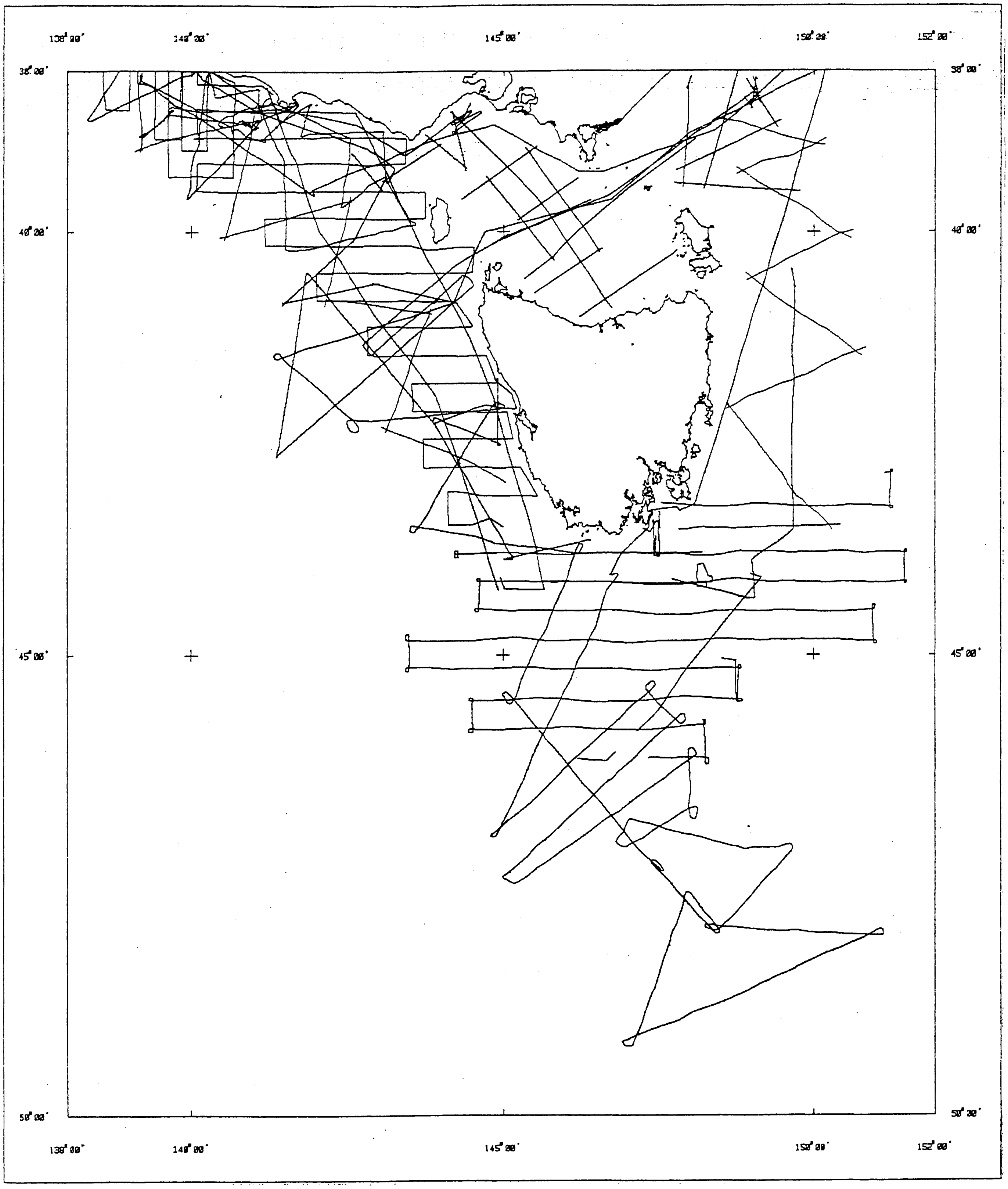

Figure 5. Map of multichannel seismic profiles in the Tasmania and South Tasman Rise region.

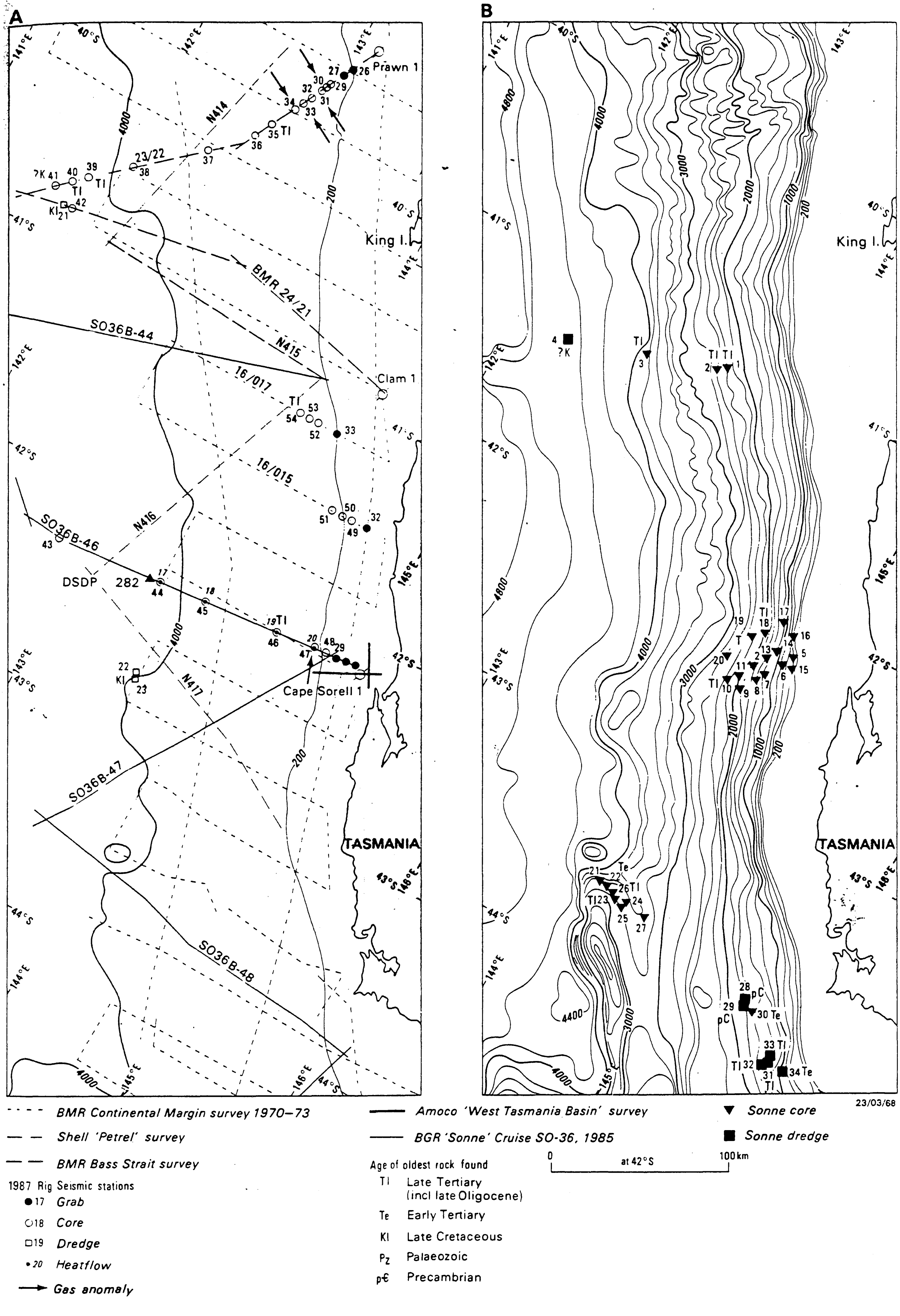

Figure 6. Map of sampling and heatflow stations for 1985 *Sonne* (SO-36C) and 1987 *Rig Seismic* (BMR 67) cruises off west Tasmania. Shows bathymetry, petroleum exploration wells, key deepwater seismic lines, and major gas anomalies in surface sediments. After Exon et al. (1992).

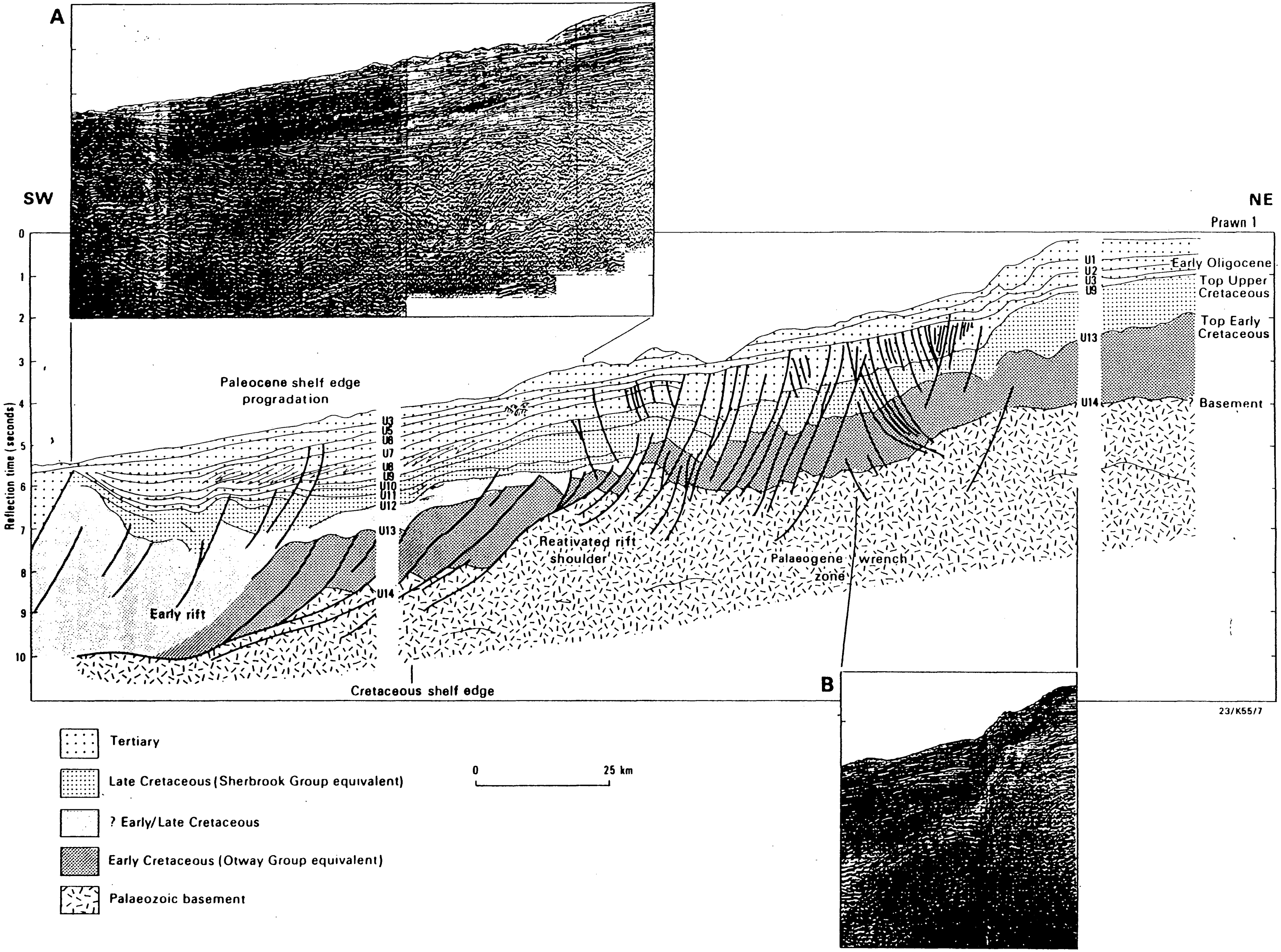

Figure 7. Line drawing of BMR seismic profile 40/22-23 from Prawn No. 1 well to southwest.
After J.B. Willcox in Hinz et al. (1986). Location in Figure 6.

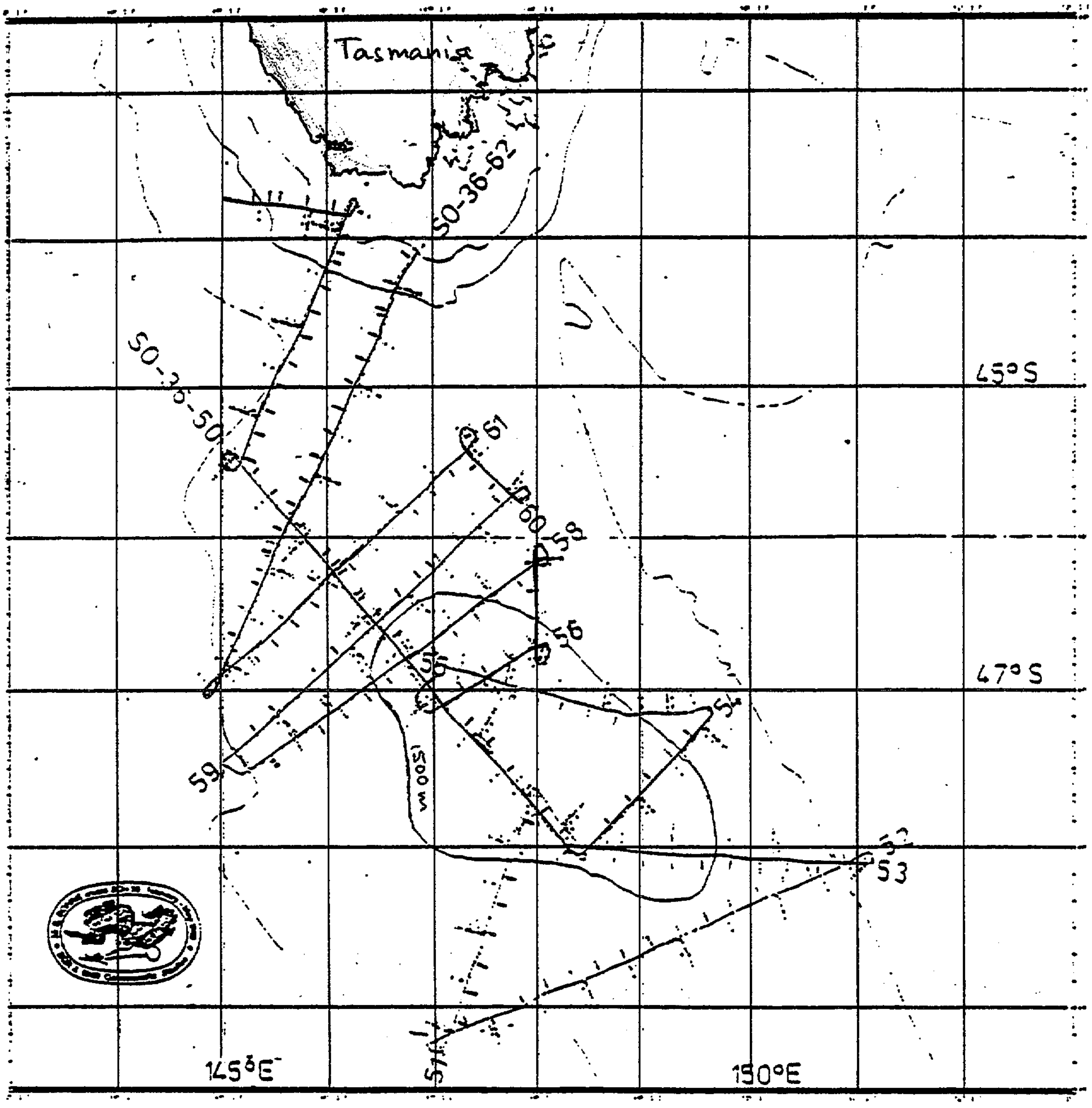

Figure 8. Map of multichannel seismic profiles across the South Tasman Rise recorded on Sonne Cruise SO-36B. After Hinz et al. (1985).

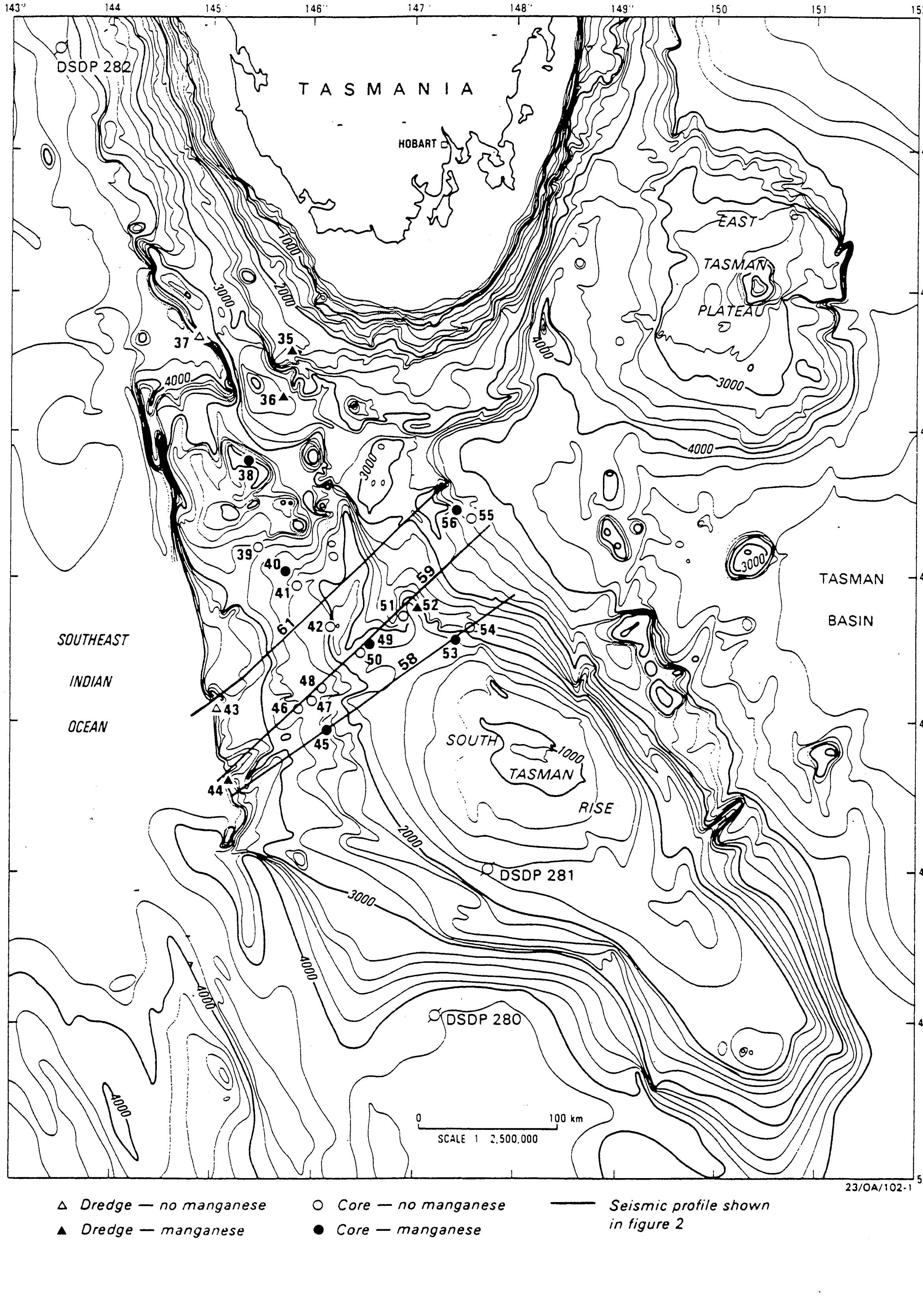

Figure 9. Bathymetric map of the South Tasman Rise. After D. Jongsma and G. Wissmann. Shows *Sonne* sampling locations, and key seismic lines illustrated in Figure 14.

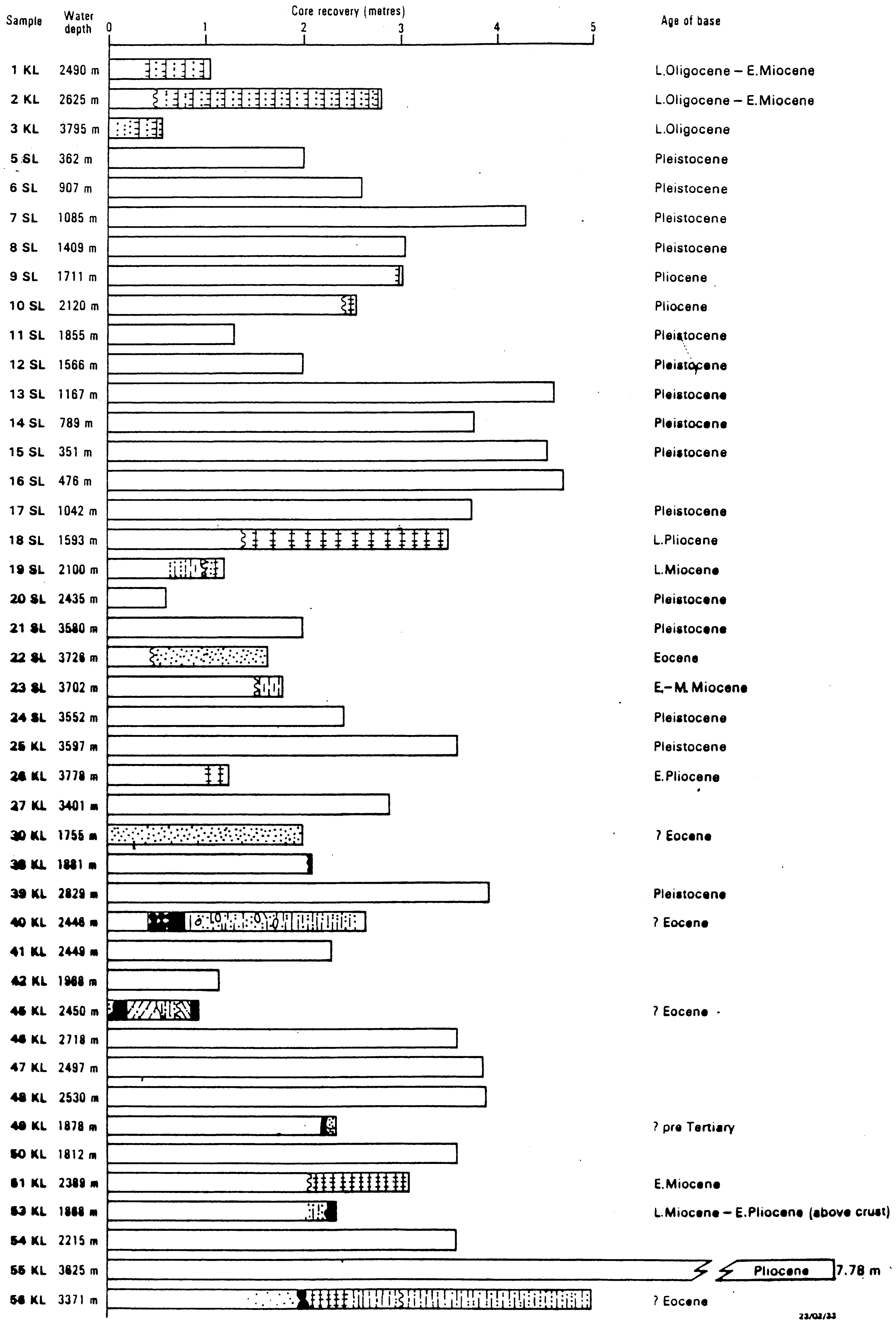

Figure 10. Simplified core logs for *Sonne* Cruise SO-36C. Modified from Hinz et al. (1985).

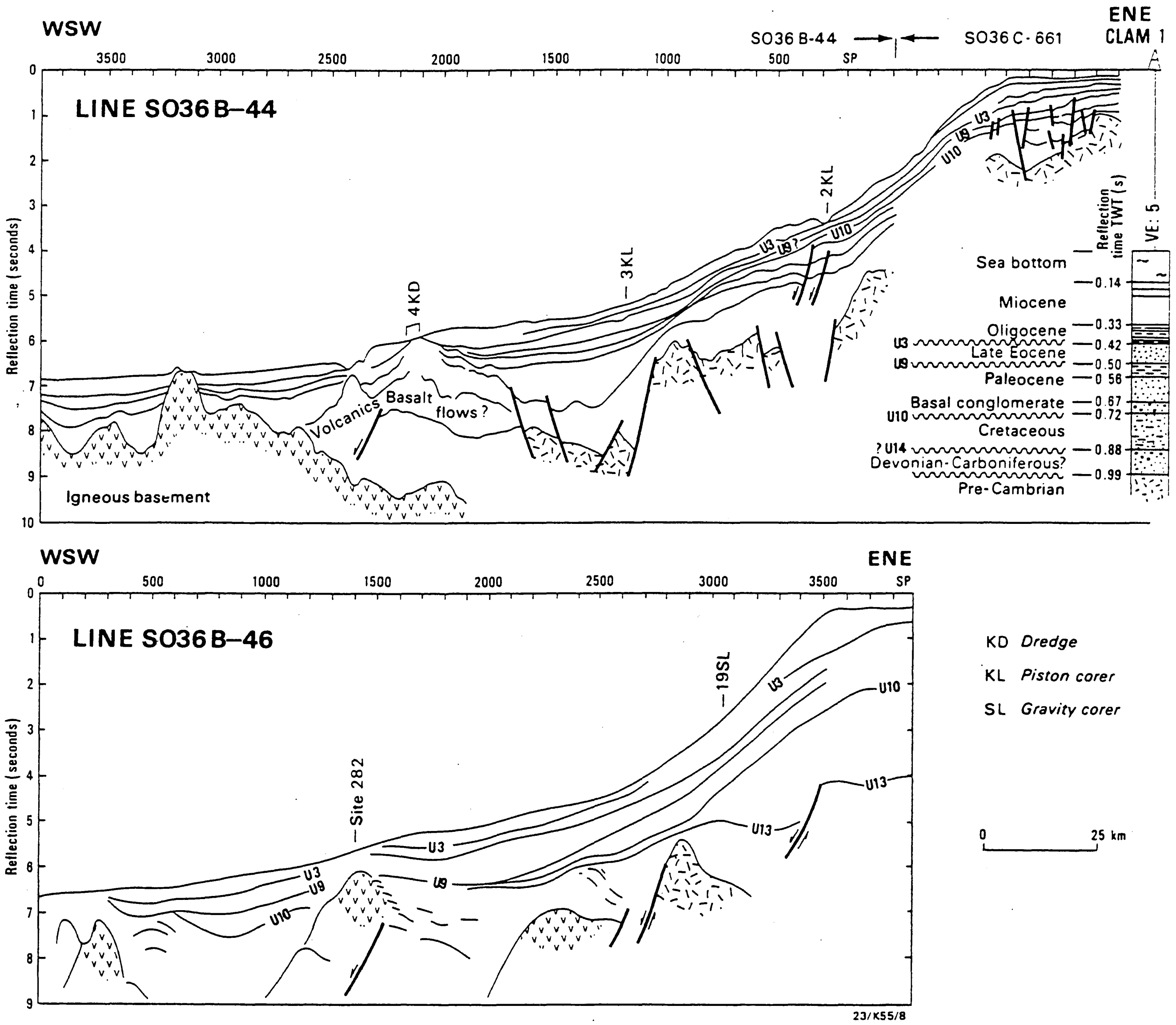

Figure 11. Line drawings of *Sonne* seismic profiles SO-36/44 & 46 from northwest Tasmanian margin. After Hinz et al. (1986). Location in Figure 6.

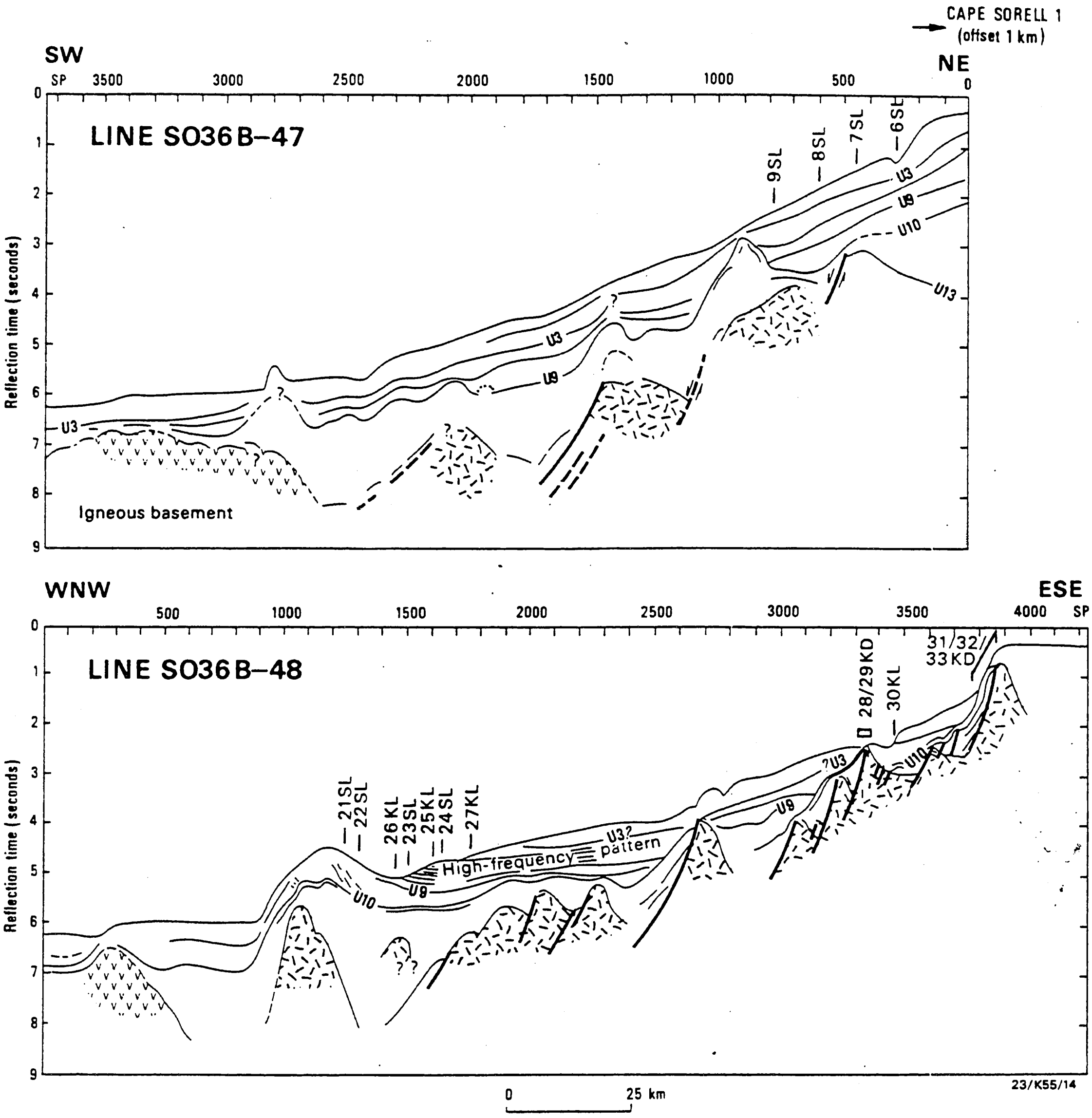

Figure 12. Line drawings of *Sonne* seismic profiles SO-36/47 & 48 from southwest Tasmanian margin. After Hinz et al. (1986). Location in Figure 6.

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 S(13–14)	Low frequency, stratified on rift shoulder		Continental–? fluvial, lacustrine	1000	Jurassic and Early Cretaceous	? 140	M Series	Casterton Beds and Otway Group Non–marine clastics and volcanogenic sediments	
	Contorted fill in first stage rift	Lower rift–fill	Alluvial fan and/or volcanics	3000 +					
U13 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)	105		Probably time equivalent to Eumeralla Formation (Otway Gp) Continental environments with volcanism	This sequence appears confined to the first stage rift
U12 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)	95	34 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
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 S(8–9) U8 S(7–8) U7 S(6–7) U6 S(5–6)	S(5–6) to S(8–9) are distinctive, high frequency, downlapping sequences beneath lower continental slope 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	65	29 ?	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 S(4–5) U4 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	42	18	? ? Nirranda Group (transgressive) — shallow marine	? Minor volcanism at U5 time
U3 S(2–3) U2 S(1–2) 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	35	13 Southeast Indian Ocean spreading	Heytesbury Group (transgressive) marine carbonates	Main episode of seafloor spreading

*For stratigraphy refer to BMR line 22/23 (Figure 3)

23/K55/15

Figure 13. Tabular representation of seismic stratigraphic sequences, with unconformities and tectonic events, for Otway and Sorell Basins. After J.B. Willcox in Hinz et al. (1986).

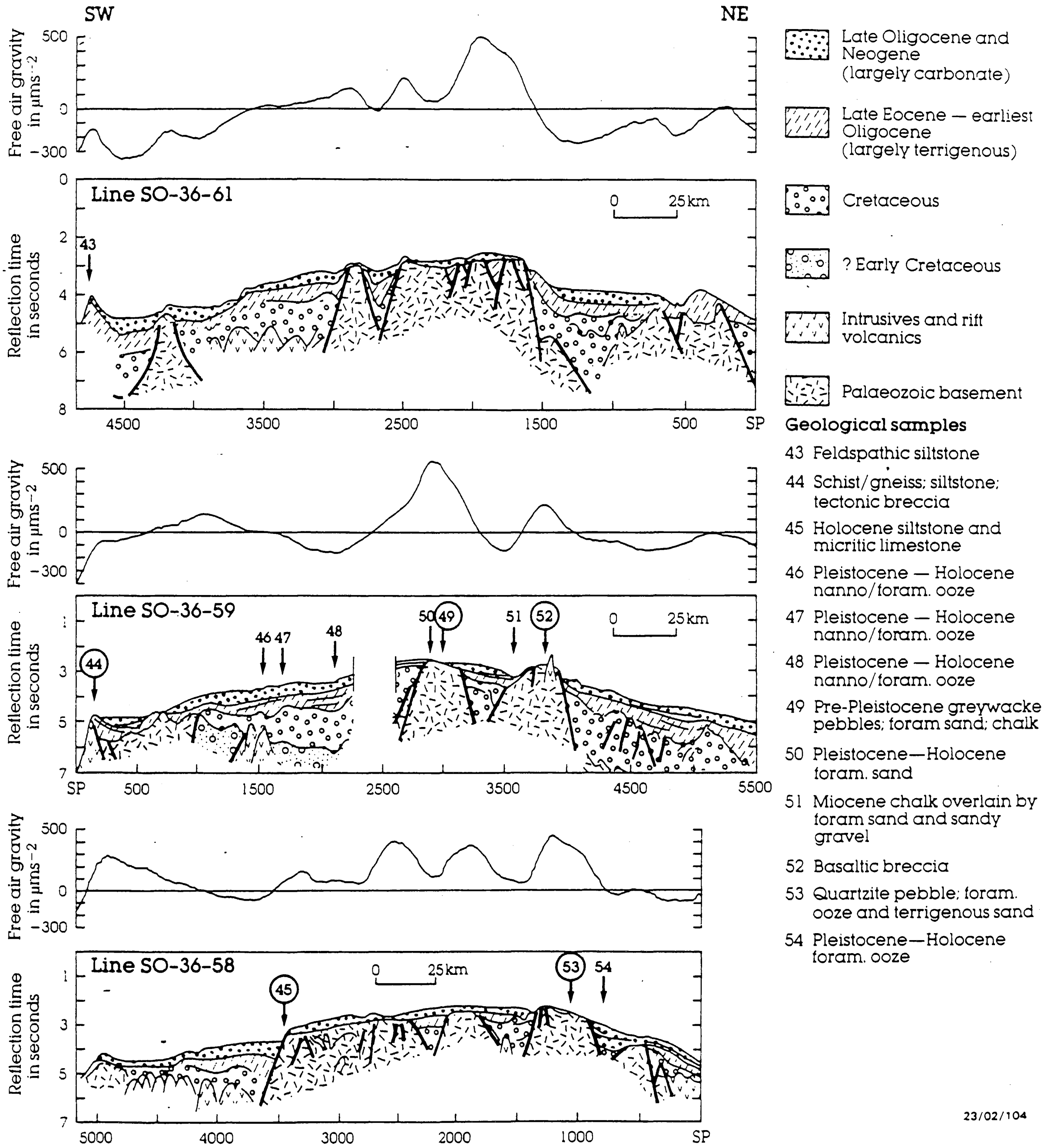

Figure 14. Line drawings of *Sonne* SO-36B seismic profiles from the South Tasman Rise, with free-air gravity anomalies and sampling sites. After Willcox et al. (1989) and Bolton et al. (1988). Locations in Figure 9.

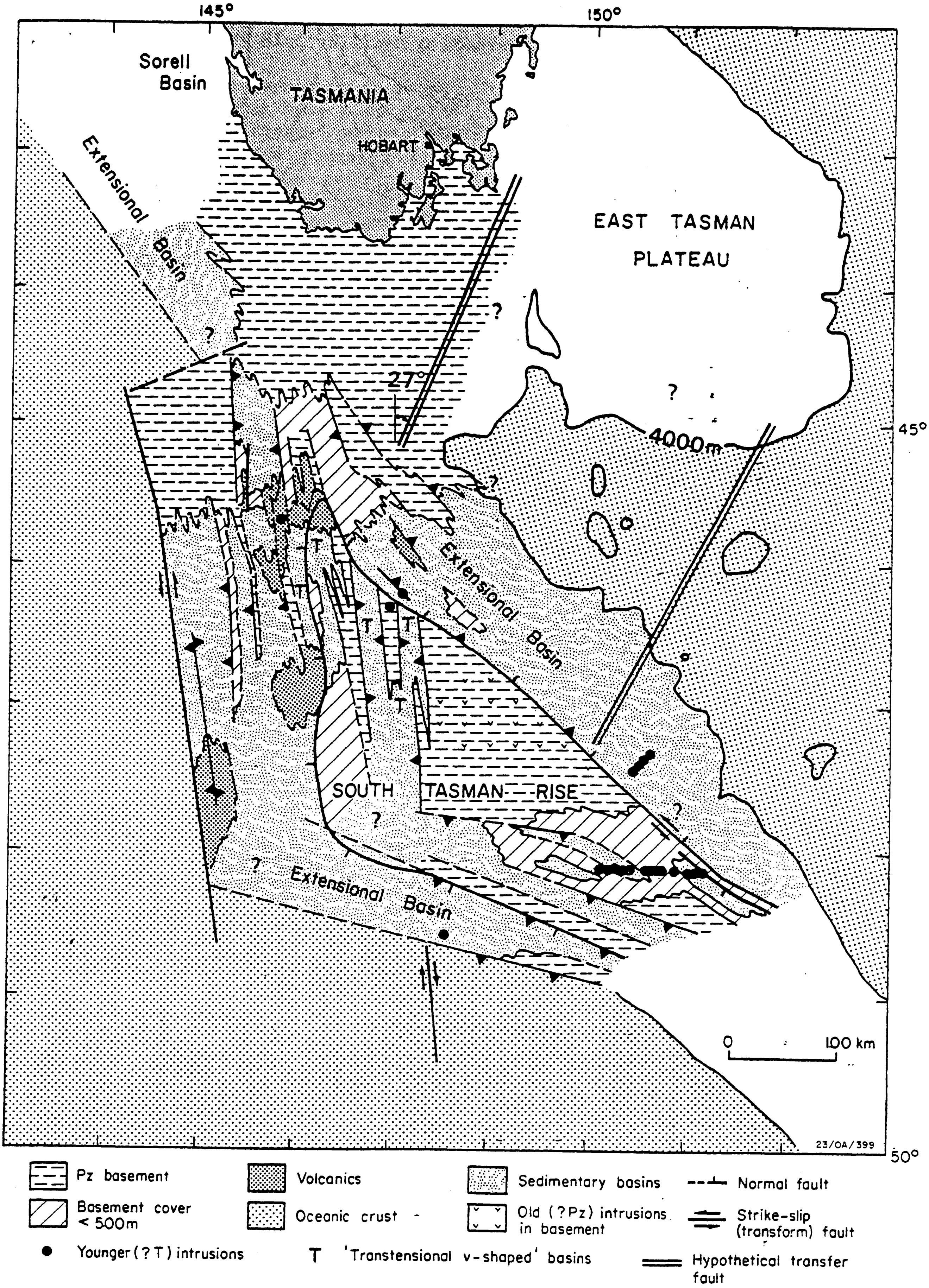

Figure 15. Preliminary structural map of the South Tasman Rise. After Willcox et al. (1989).

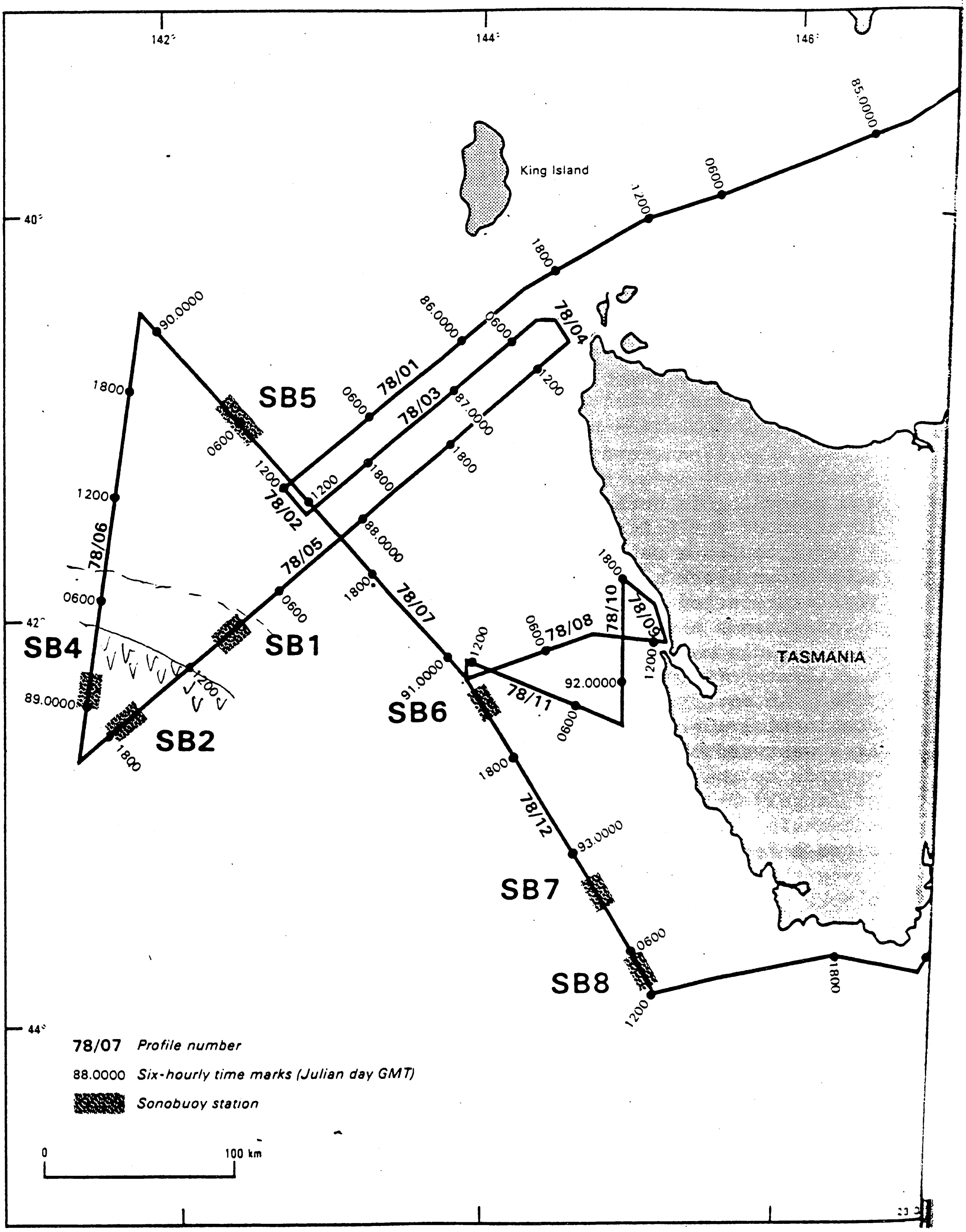

Figure 16. Map of west Tasmanian region showing 1988 BMR multichannel seismic profiles 78/1-12, and sonobuoy locations. After Exon et al. (1989).

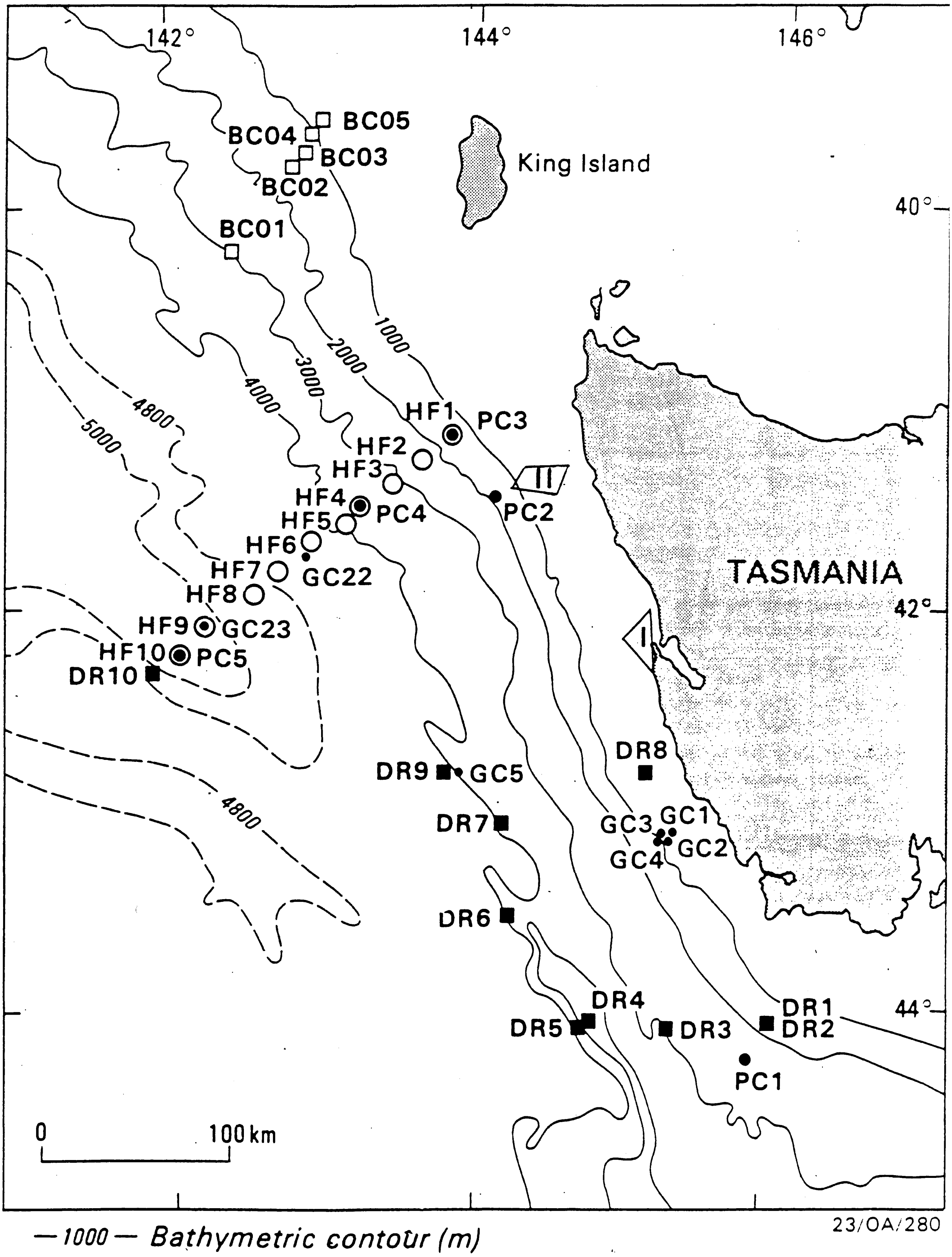

Figure 17. Map showing 1988 BMR Cruise 78 sampling and heatflow stations off west Tasmania. After Exon et al. (1989).

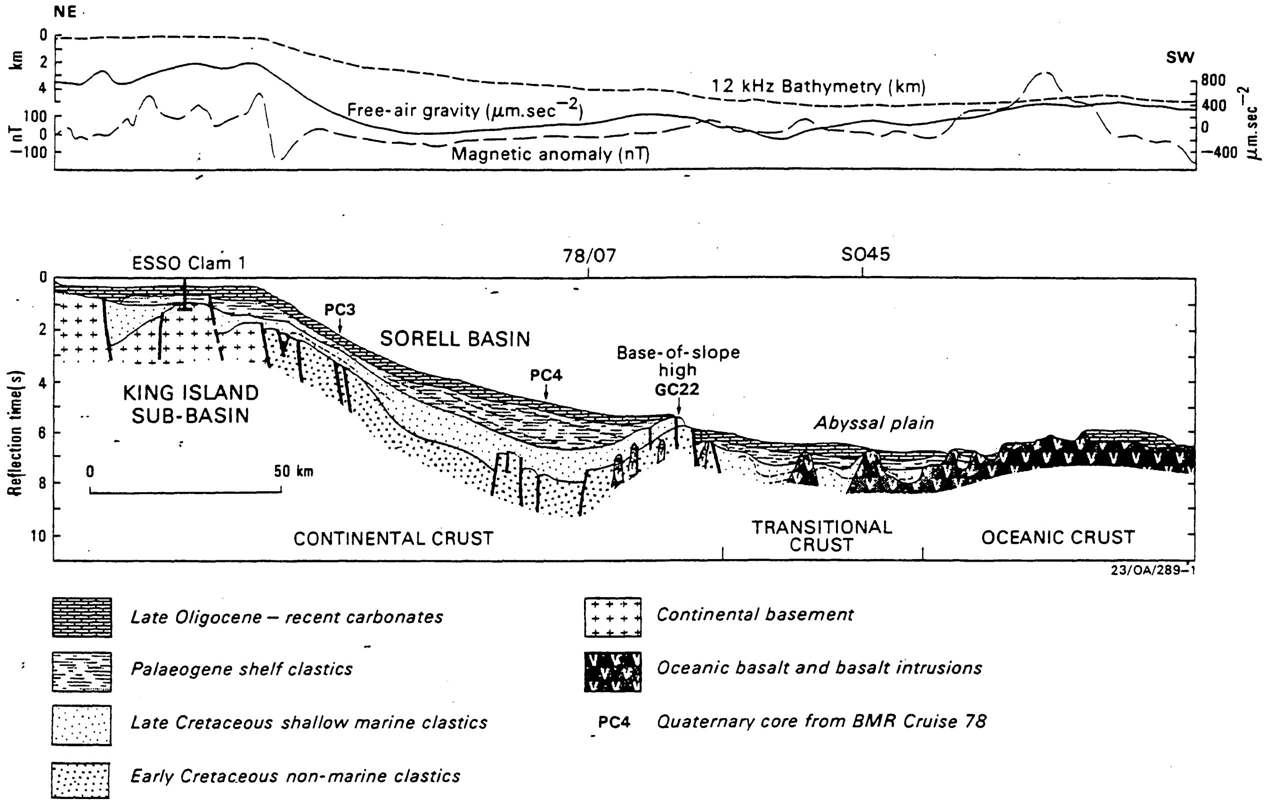

Figure 18. Line drawing of BMR seismic profile 78/05 on the west Tasmanian margin. From *BMR 1989*. Includes magnetic and gravity data southwest from Clam no. 1 well to abyssal plain. Location in Figure 19.

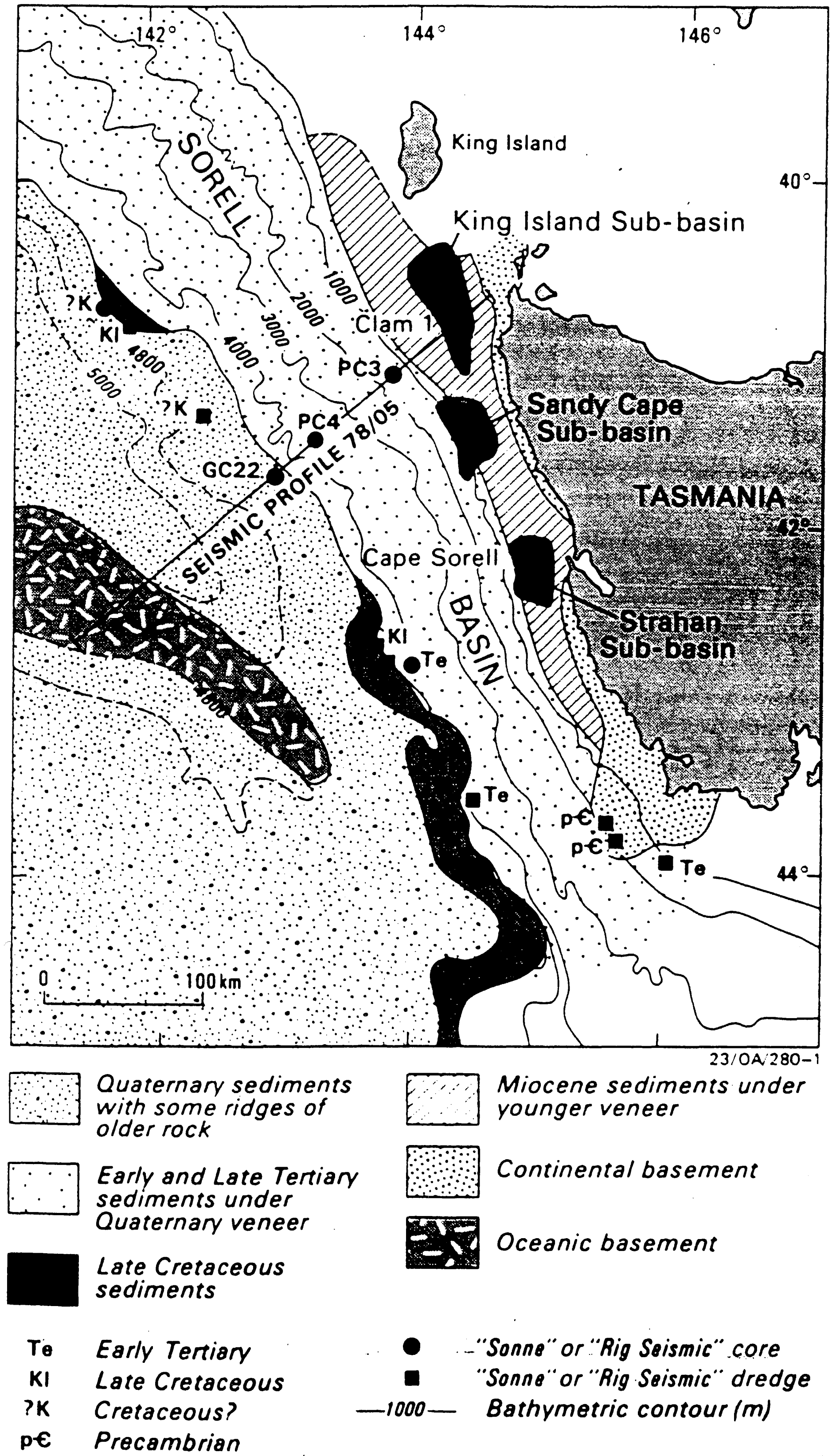

Figure 19. Map of surface sediment distribution off west Tasmania. From *BMR 1989*. Shows all dredges and cores that have recovered Lower Tertiary or older rocks, and location of BMR seismic profile 78/05 (see Fig. 18).

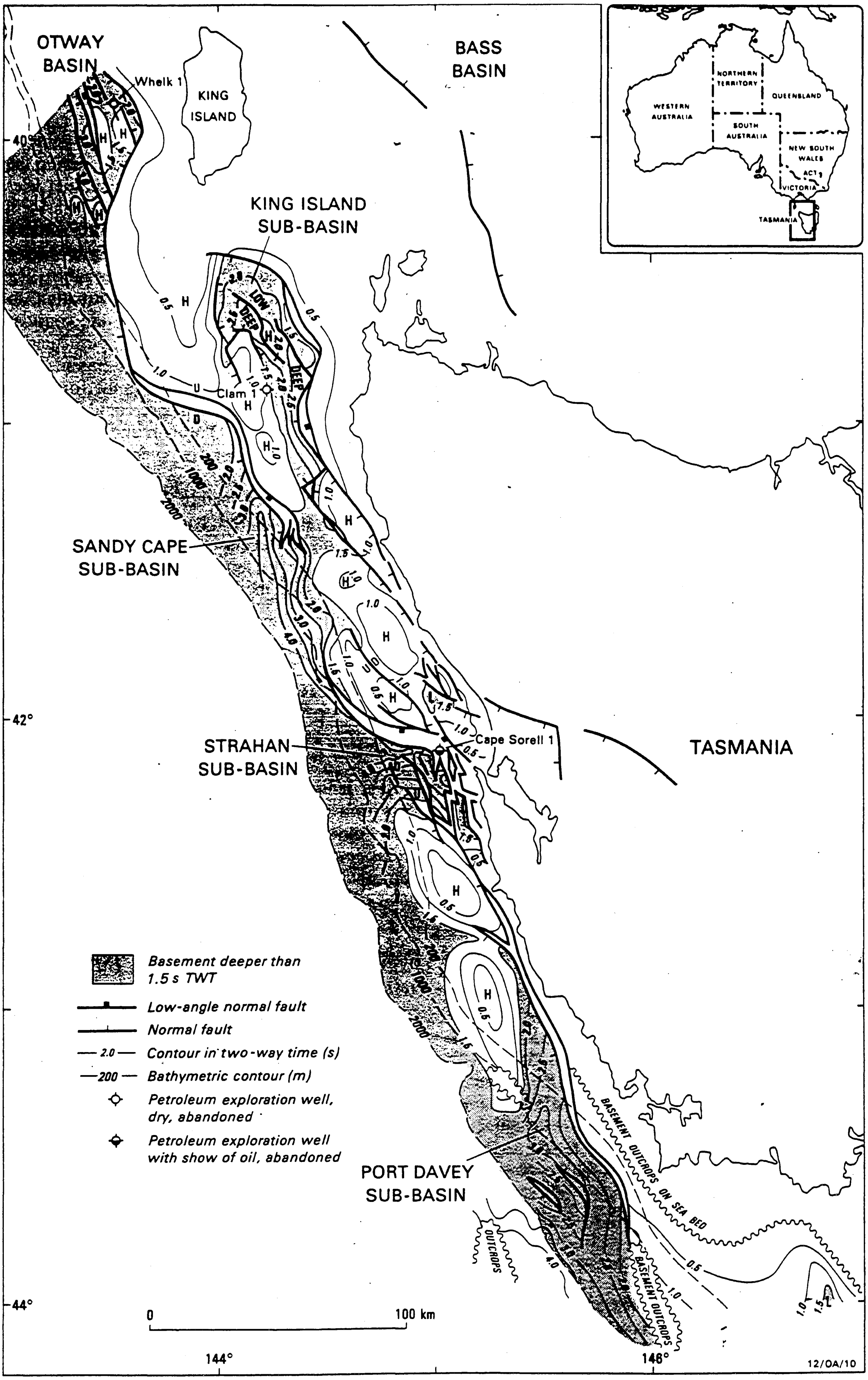

Figure 20. Map of basement structure off west Tasmania. After Moore et al. (1992). Shows basins and sub-basins in water shallower than 1000 m.