BUREAU OF MINERAL RESOURCES, GEOLOGY AND GEOPHYSICS

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Record 1987/11

Preliminary Postcruise Report

RIG SEISMIC RESEARCH CRUISE 1987: OTWAY BASIN AND WEST TASMANIA SAMPLING

Project 1C.09
BMR Fossil Fuels Project

Principal Investigators: N.F. Exon & C.S. Lee

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Division of Marine Geosciences & Petroleum Geology

RIG SEISMIC RESEARCH CRUISE 1987: OTWAY BASIN AND WEST TASMANIA SAMPLING

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INTRODUCTION

BMR's Marine Division has been involved in three cruises on the closely related Otway Basin and west Tasmanian margins in recent years, two co-operative cruises with the Bundesanstalt fuer Geowissenschaften und Rohstoffe (BGR) using R.V. Sonne (Hinz et al., 1985), and one using R.V. "Rig Seismic" (Exon, Williamson et al, 1987). These cruises provided 3700 km of regional multichannel seismic data in the Otway Basin, and 1000 km of similar data on the west Tasmanian margin. They also provided 34 geological samples from the west Tasmanian margin and 6 from the Otway Basin.

These cruises, and earlier geological and geophysical cruises, have provided a great deal of information on the two areas, which has led to regional interpretations (Williamson et al., 1987, Hinz et al., 1985). These interpretations can be strengthened and extended by the provision of more data in critical areas, largely samples, to improve our stratigraphic and structural understanding, to better understand the Cainozoic processes operating, to better assess evidence of generation of thermogenic hydrocarbons, and to measure the flow of heat through the seabed to help hydrocarbon maturation predictions.

The present cruise, BMR Cruise 67, was the first step in carrying out BMR Project 1C.09, a study of the geological development of the offshore Otway Basin and west Tasmanian margin, which comes under BMR's "Fossil Fuels" Program. It was essentially a sampling cruise, with limited underway geophysics between stations. The vessel sailed from Adelaide on 15 January, made a port call to Portland to repair some equipment on 29-30 January, and another to King Island on 4 February to put ashore the injured Second Engineer, P. Pittiglio, and arrived in Sydney on 13 February. The field techniques included dredging and coring of older sequences, coring of younger sediments, heatflow measurements in younger sediments, and headspace analysis of gas in the surface sediments. Altogether 130 stations were occupied - 23 dredge, 54 core, 33 grab and 20 heatflow - in water depths of 50 to 5000 m (Figs. 1 and 2).

Acknowledgements

The work benefited greatly from pre-cruise discussions with J. Branson (BMR), M. Megallaa and B. Thompson (Victorian Department of Industry, Technology and Resources); P.W. Baillie (Tasmanian Mines Department); R.W. Laws, D.I. Gravestock and C.D. Cockshell (South Australian Department of Mines and Energy); S.M. Yu (Gas & Fuel Corporation of Victoria); G. Cullen (BP Australia Ltd.). SADME is thanked for the financial support they provided for the participation of D. McKirdy.

The enthusiasm and skill of the "Rig Seismic" crew was vital to the success of the cruise, especially when equipment started to fail. The ship's crew was:

Master	:	D. Harvey
Chief Officer	:	R. Hardinge
Second Officer	:	P. Mosley
Chief Engineer	:	S. Johnson
Second Engineer	:	P. Pittiglio/R. Thomas
Electrical Engineer	:	P. Jiear

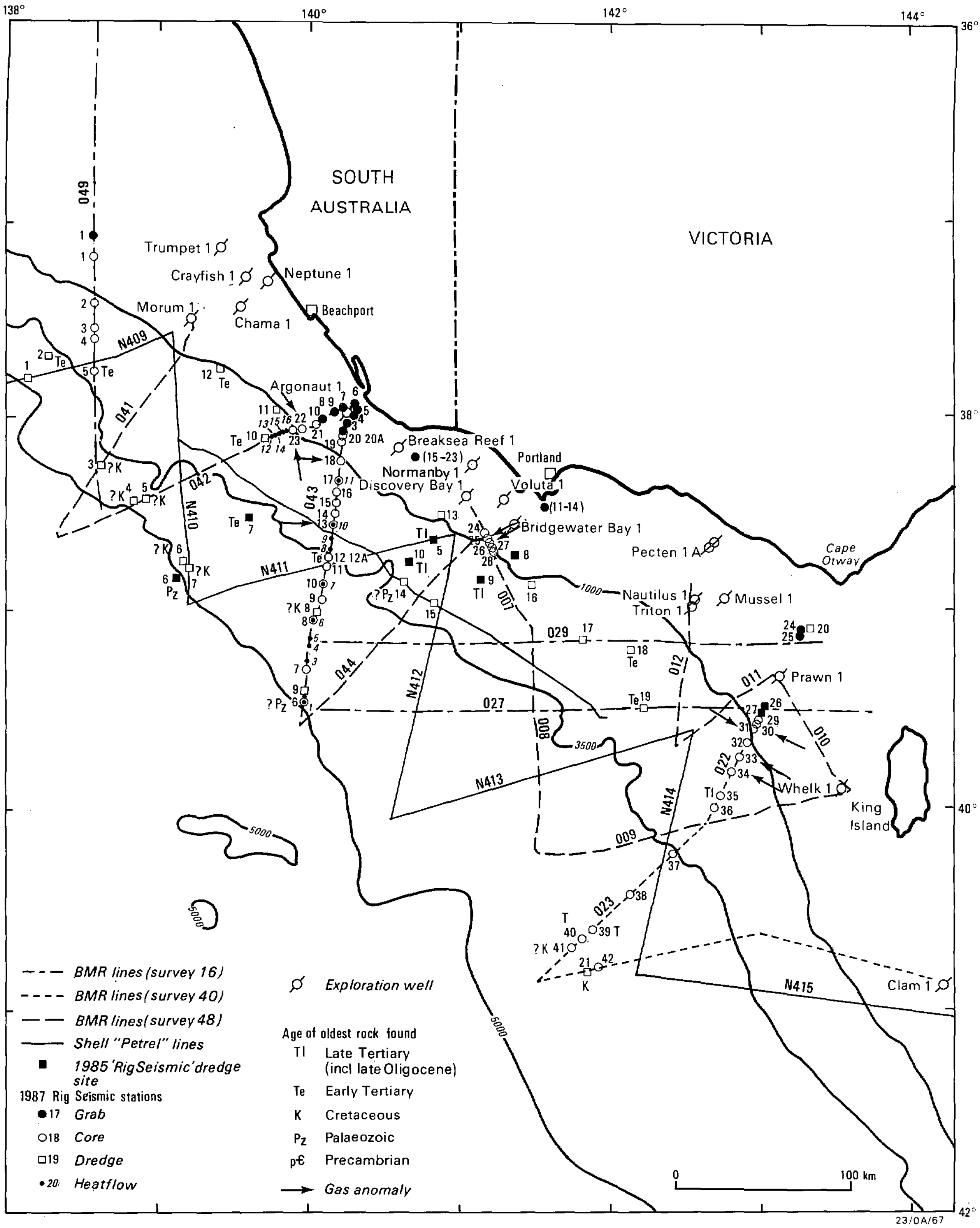
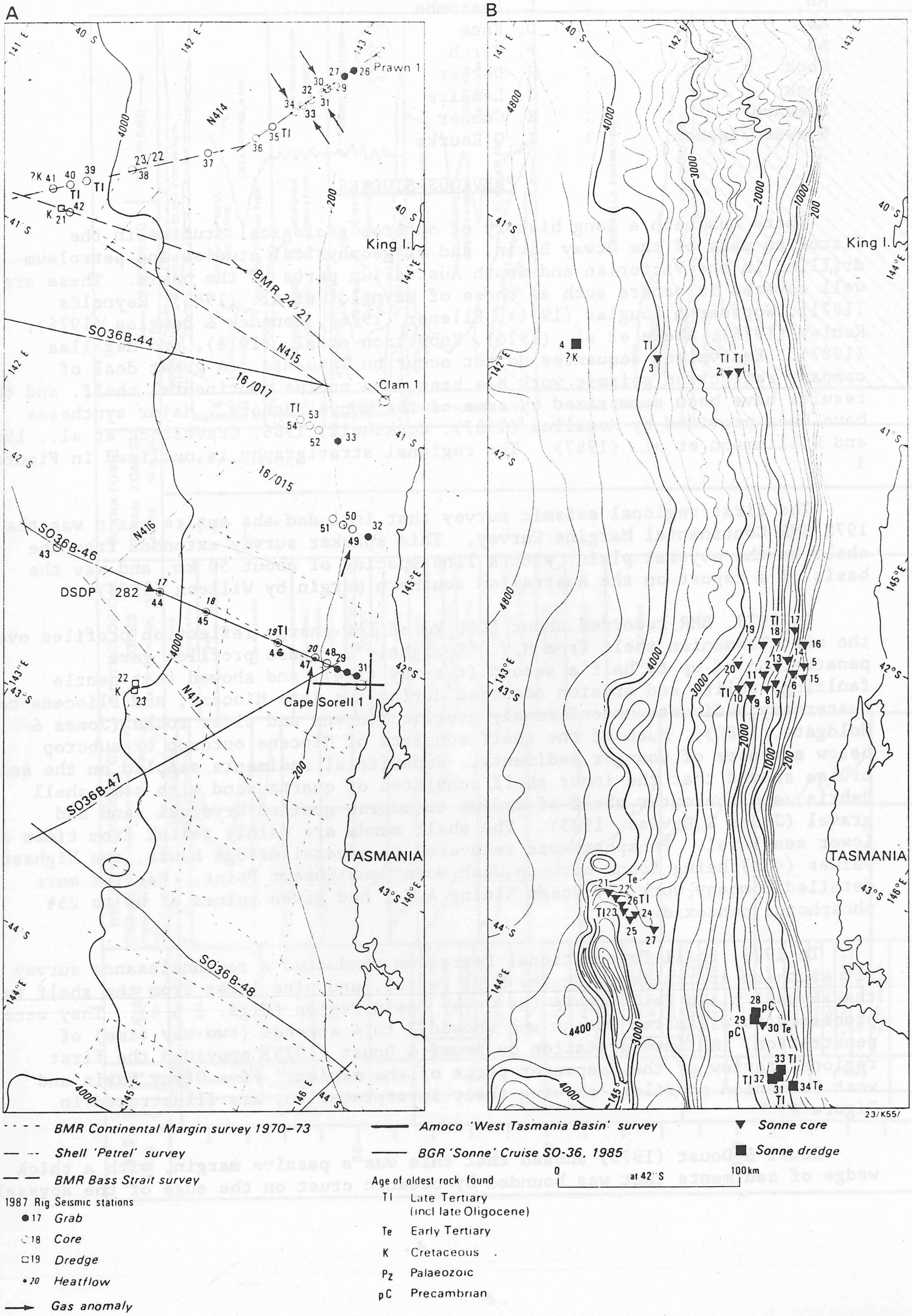


Fig. 1. Sampling and heatflow stations for 1985 and 1987 "Rig Seismic" Otway Basin cruises, showing petroleum exploration wells, key deepwater seismic lines, and major gas anomalies in surface sediments.

Fig. 2. Sampling and heatflow stations for 1985 "Sonne" and 1987 "Rig Seismic" west Tasmanian cruises, showing petroleum exploration wells, bathymetry, key deepwater seismic lines and major gas anomalies in surface sediments.



EA/Seaman	:	K. Halliday
AB	:	L. Luscombe
AB	:	D. Kane
AB	:	P. Birch
Cook	:	H. Dekker
Cook	:	G. Lemaire
Steward	:	M. Cumner
Steward/Seaman	:	J. O'Rourke

PREVIOUS STUDIES

There has been a long history of outcrop geological studies in the Victorian part of the Otway Basin, and of geophysical studies and petroleum drilling in the Victorian and South Australian parts of the basin. These are well covered in papers such as those of Reynolds et al. (1966), Reynolds (1971), Wopfner & Douglas (1971), Ellenor (1976), Benedek & Douglas (1976), Kenley (1976), Abele et al. (1976), Robertson et al. (1978), and Megallaa (1987). Equivalent sequences do not occur on Tasmania. A great deal of company reflection seismic work has been done on the continental shelf, and the results have been summarized by some of the above authors. Major syntheses have been provided by Megallaa (1987), Cockshell, 1986, Gravestock et al., 1986 and Williamson et al. (1987). The regional stratigraphy is outlined in Figure 3.

The first regional seismic survey that included the entire basin was the 1972 BMR Continental Margins Survey. This sparker survey 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 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 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 consisted of quartz sand with some shell debris, and the outer shelf of medium to coarse grained bryozoal sand and gravel (Jones & Davies, 1983). The shelf sands are mainly relict from times of lower sea level. Phosphate was recovered in several dredge hauls, the highest values (<4%) being found between West Point and Rupert Point. Earlier more detailed company work, by Ocean Mining A.G., had given values of up to 26% phosphorus pentoxide.

In 1973, Shell International Petroleum conducted a reconnaissance survey off southern Australia using the M.V. Petrel, and nine lines from the shelf to the abyssal plain fell within the Otway Basin region (Figs. 2 & 4). They were processed to a limited extent and showed 3 to 4 seconds (two-way time) of penetration. An interpretation by Bouef & Doust (1975) provided the first regional review of the deepwater parts of the region. Five Otway Basin and west Tasmanian profiles, showing their interpretation, are illustrated in Figure 6.

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

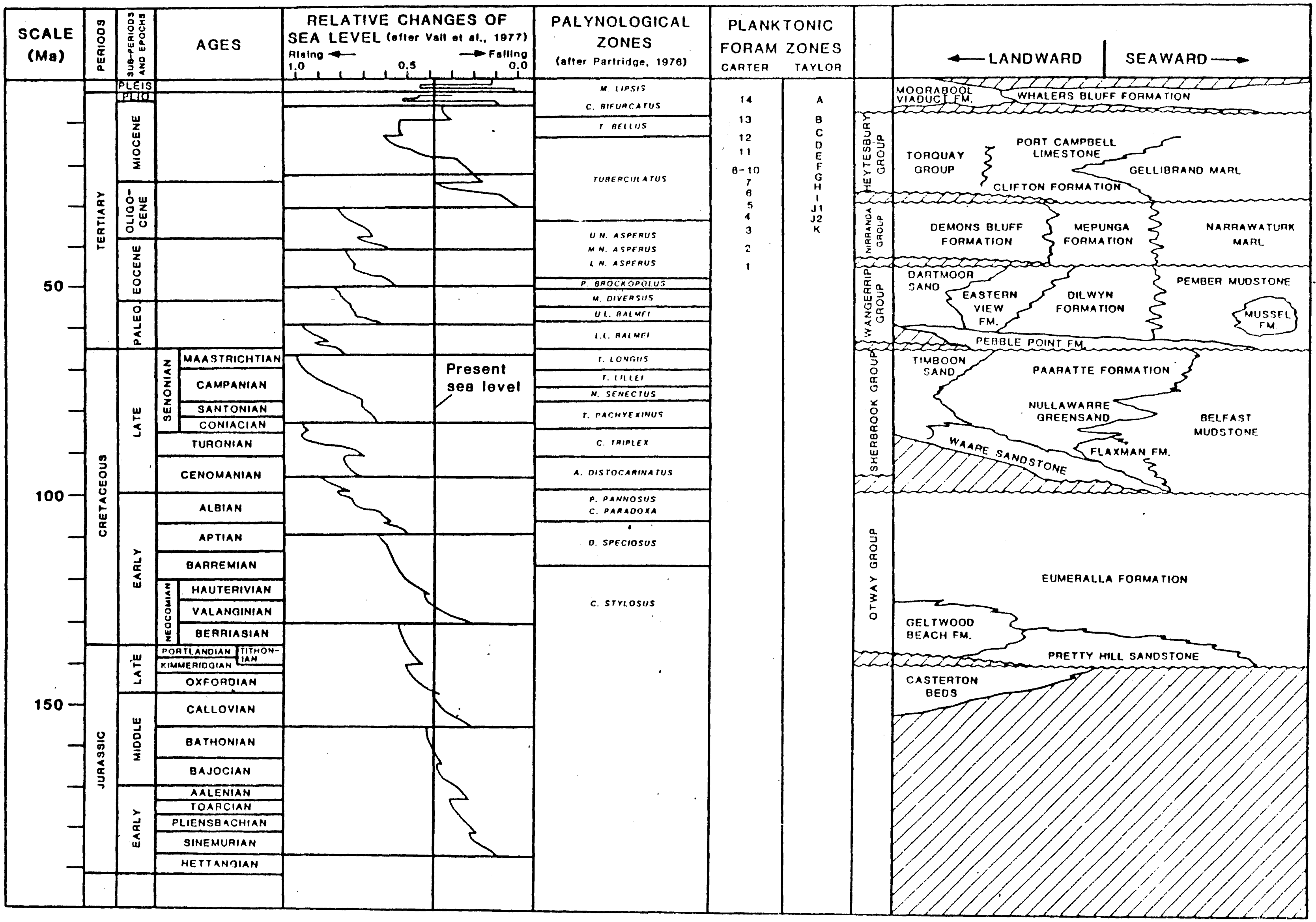


Figure 3 : Regional stratigraphy of the Otway Basin. After Megallaa (1986)

Figure 4 : Regional seismic coverage of the Otway Basin, showing petroleum exploration wells.

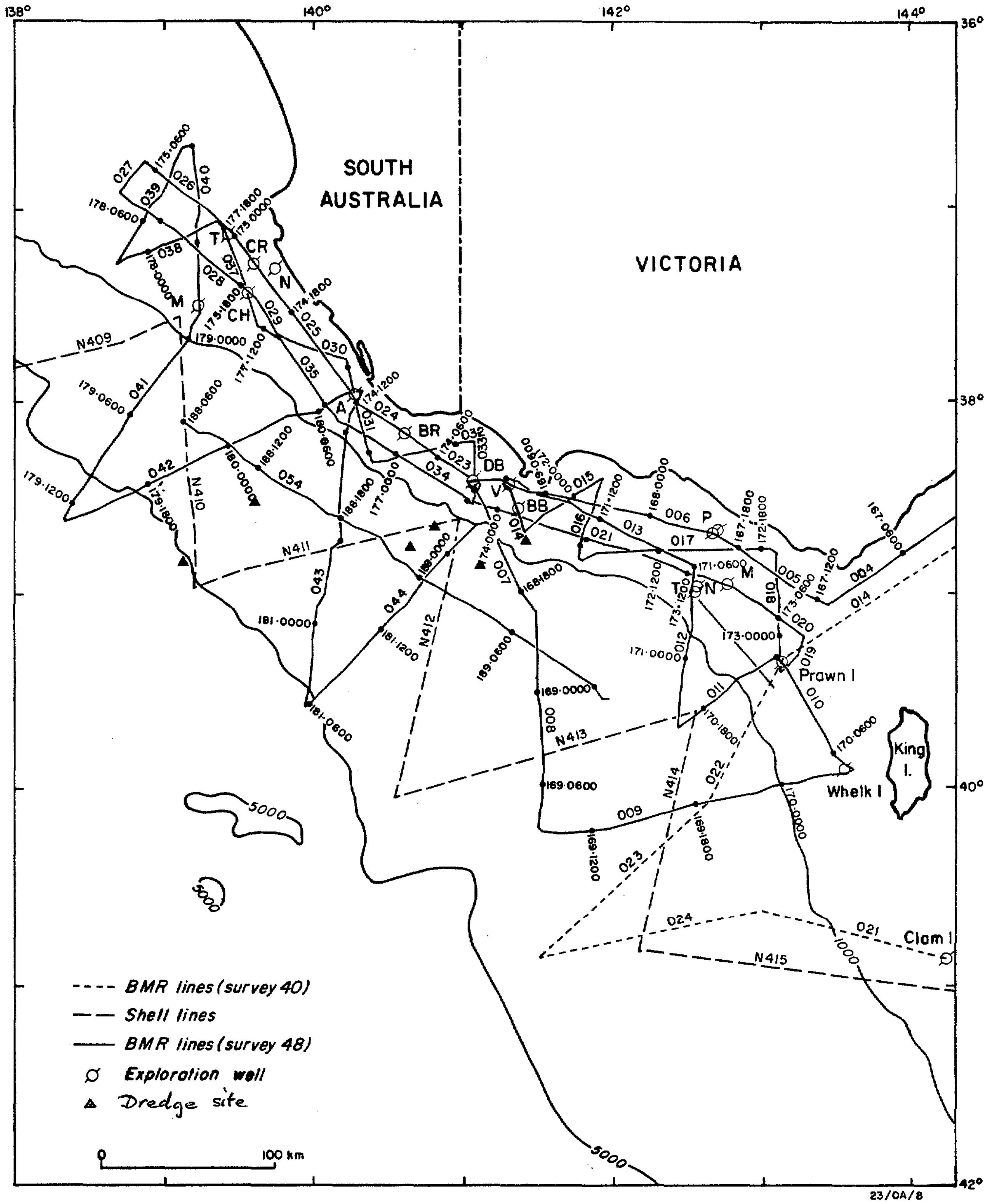
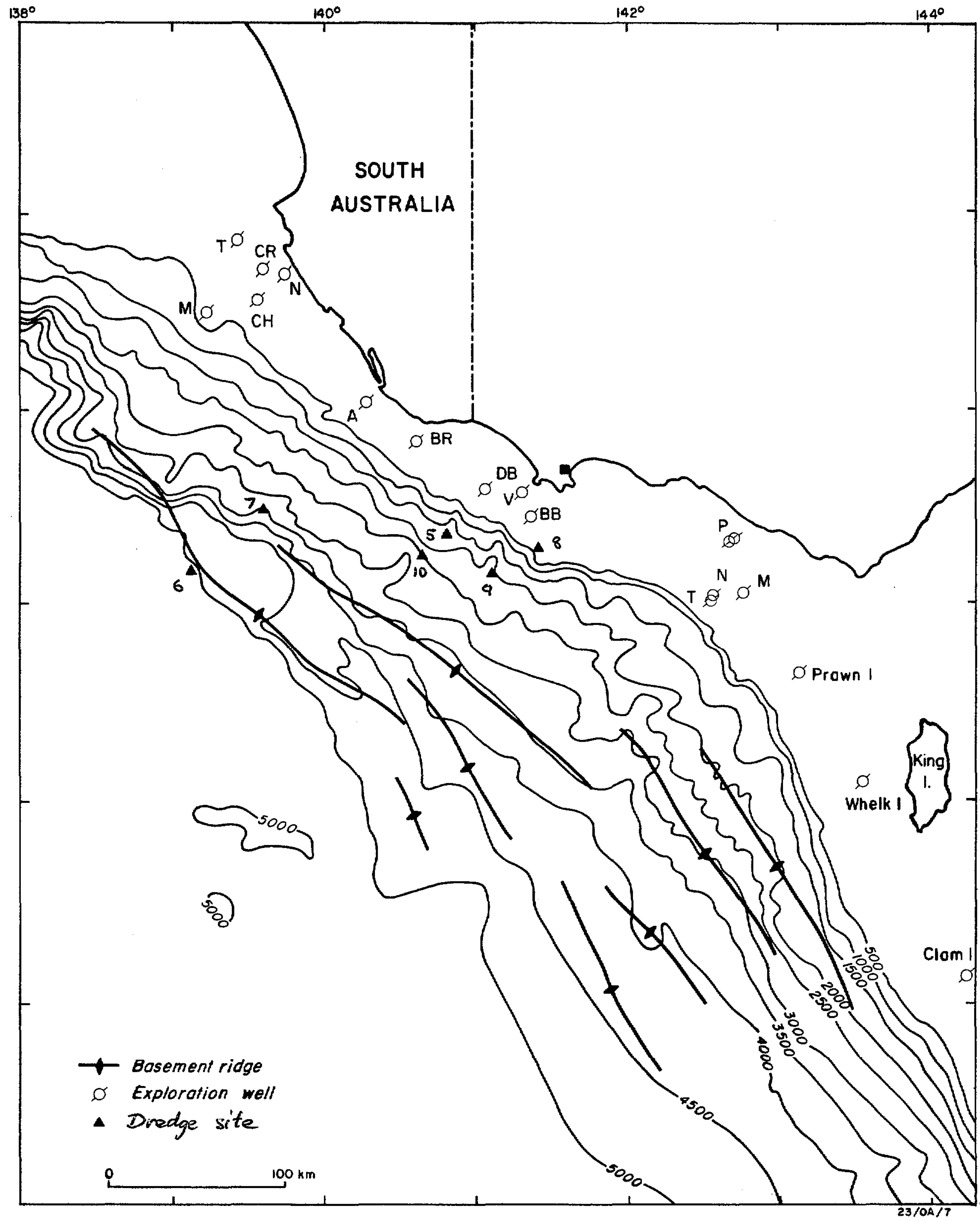


Figure 5 : Bathymetry of the Otway Basin showing petroleum exploration wells and "Rig Seismic" dredge locations in 1985.



plain. Beneath the continental rise, block-faulted continental basement was recognized. 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 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.

The following year, Denham & Brown (1976) reviewed well and seismic data in the offshore area between King Island and the Victorian-South Australian border, most of it on the continental shelf. They regarded the Otway Basin as an intercratonic Upper Cretaceous basin, and a marginal Tertiary to Recent basin. The northeast flank of the basin was formed by a series of down-to-basin faults, and increased movement on these faults and overall tilting gave a marginal basin in Tertiary time so that the section was a series of outbuilding sedimentary wedges. They recognized that the sequences present in the wells could be traced widely beneath the shelf and slope, and produced structure contour maps of three horizons, the deepest being the base of the Upper Cretaceous, which showed that there was widespread coast-parallel normal faulting in the Cretaceous sequence. Fault blocks generally dip landward. A more recent interpretation of the structure at the base of Tertiary is shown in Figure 7.

In 1982, BMR contracted Geophysical Services International (GSI) to carry out a multichannel seismic survey of the Bass Basin (BMR Survey 40), with regional seismic lines extending on either side of King Island, into the Otway Basin and out to the abyssal plain (Figs 2 & 4). Data from this survey, and the Shell 1972 survey, were combined to produce a review of Otway Basin tectonic development and depositional history (Branson, in press).

In 1984-86 SADME undertook a review of the Otway Basin in South Australia (Cockshell, 1986; Gravestock et al., 1986, Morton & Cockshell, 1987). All known company data were compiled and Gamma Ray and Sonic Logs for all wells were digitized. Recent high quality seismic data were also included to provide

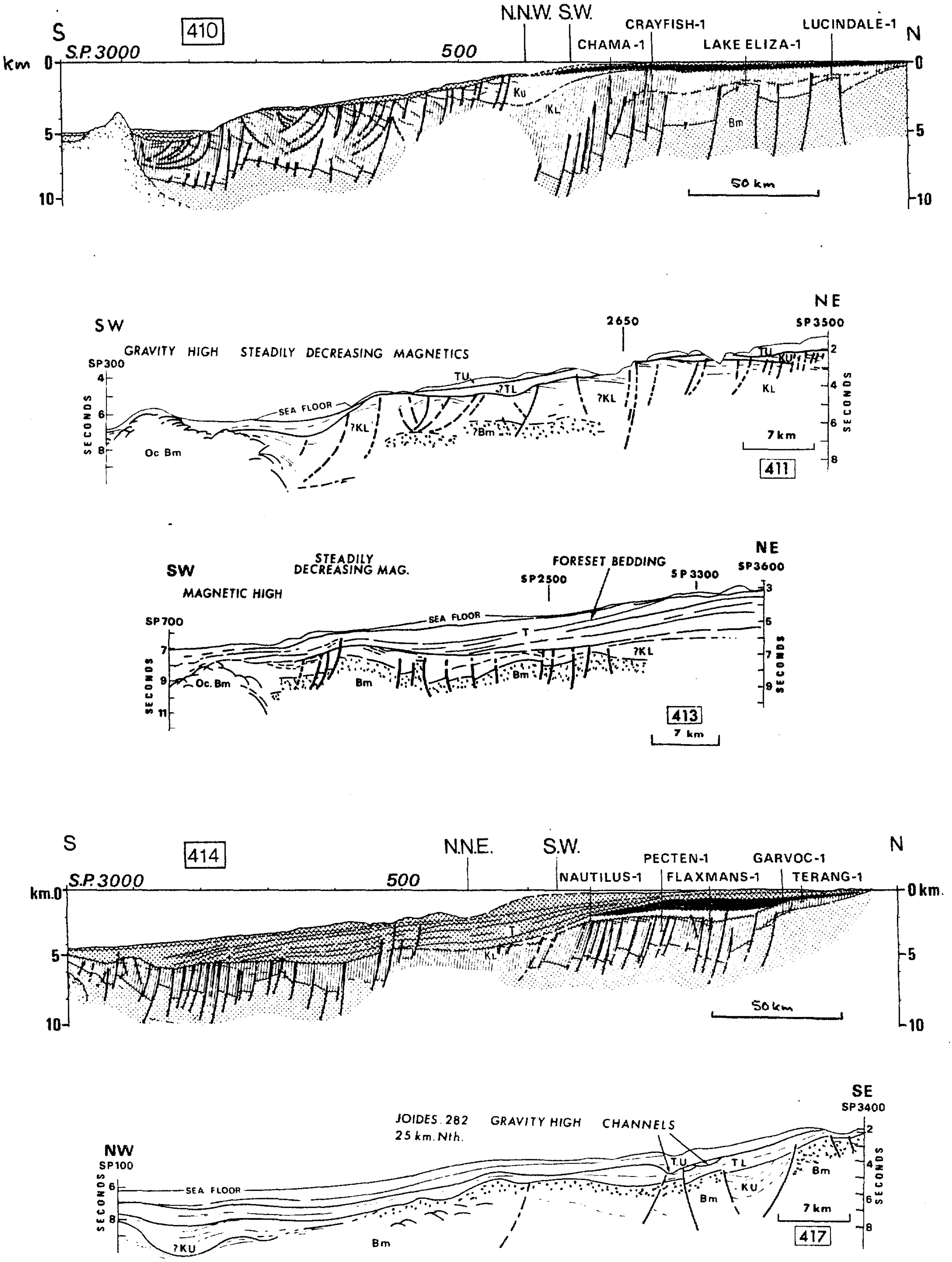


Figure 6 : Five interpreted seismic sections, after Bouef & Doust (1975), from the Otway Basin and west Tasmanian margin; north-westernmost at the top and south-easternmost at bottom (locations in Fig. 2 & 4).

Figure 7 : Structure contour map of the base of the Tertiary sequence in the Otway Basin (from Megallaa, 1986).

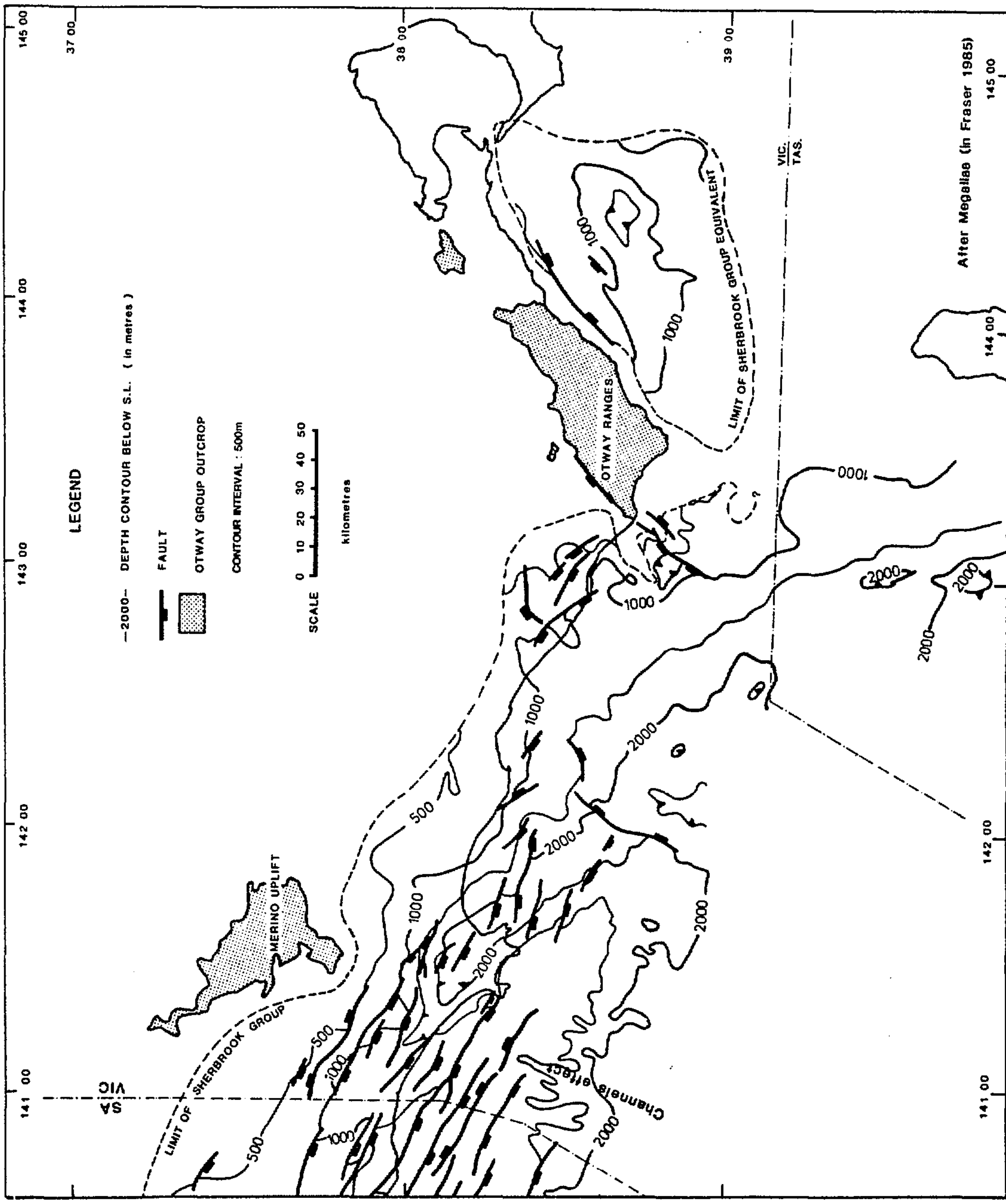


Figure 8 : Line drawings of "Sonne" seismic sections SO36B-44 & 46 on the West Tasmanian margin, showing sample locations (see Tables 1 and 2; Fig. 4). After Hinz et al., 1986

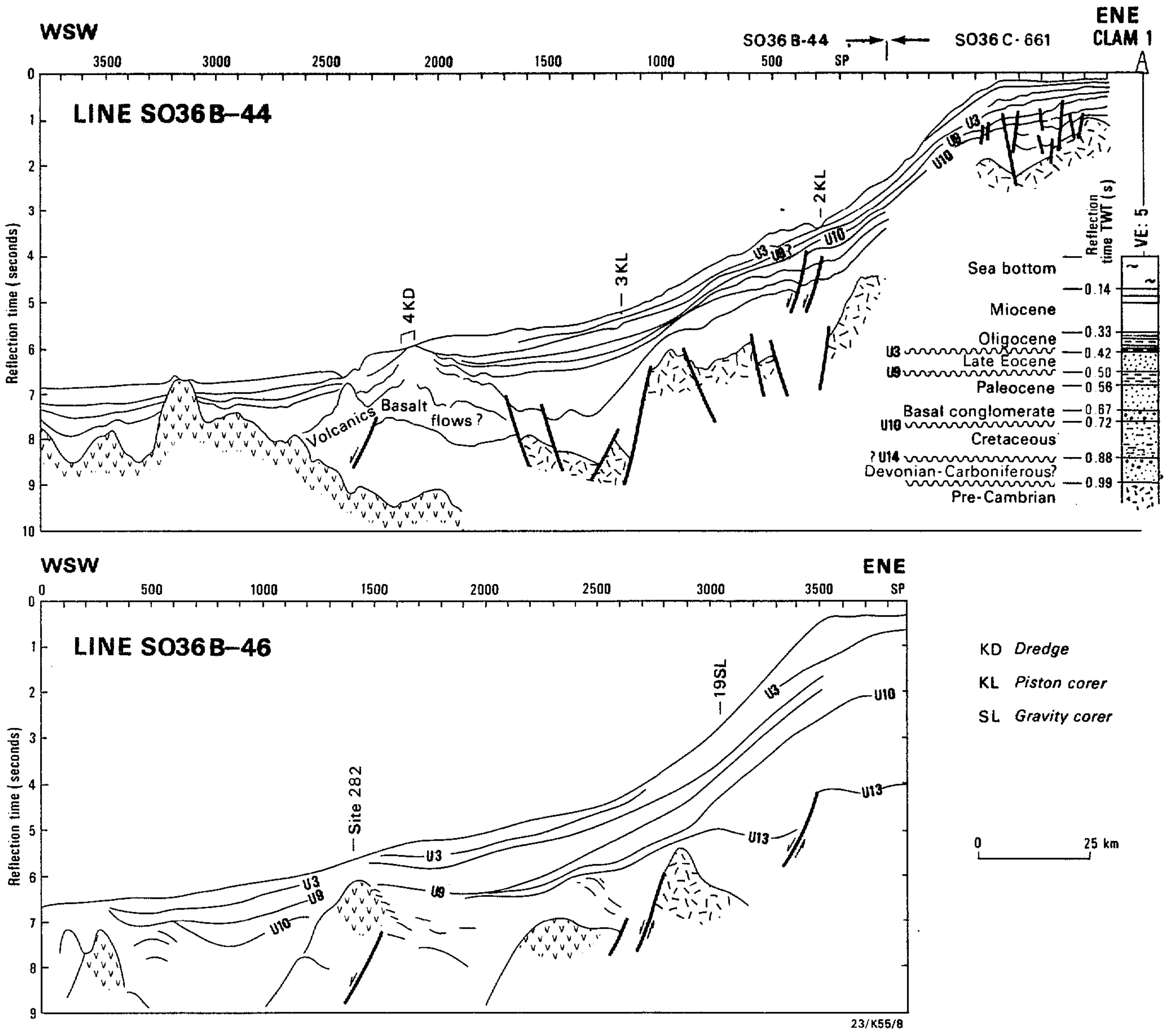
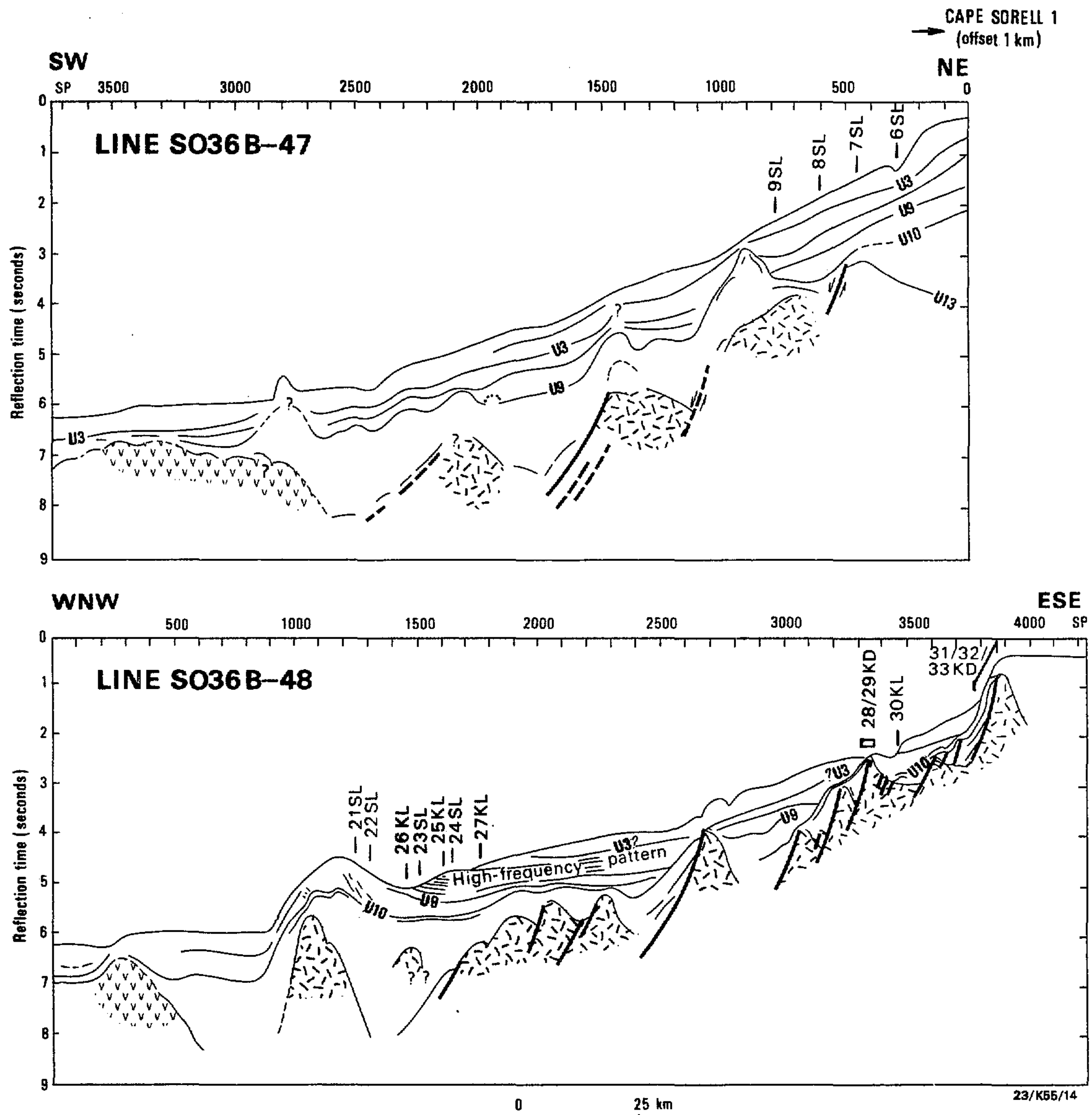


Figure 9 : Line drawings of "Sonne" seismic sections SO36B-47 & 48 on the west Tasmanian margin, showing sample locations (see Table 1 and 2; Fig. 4). After Hinz et al., 1986.



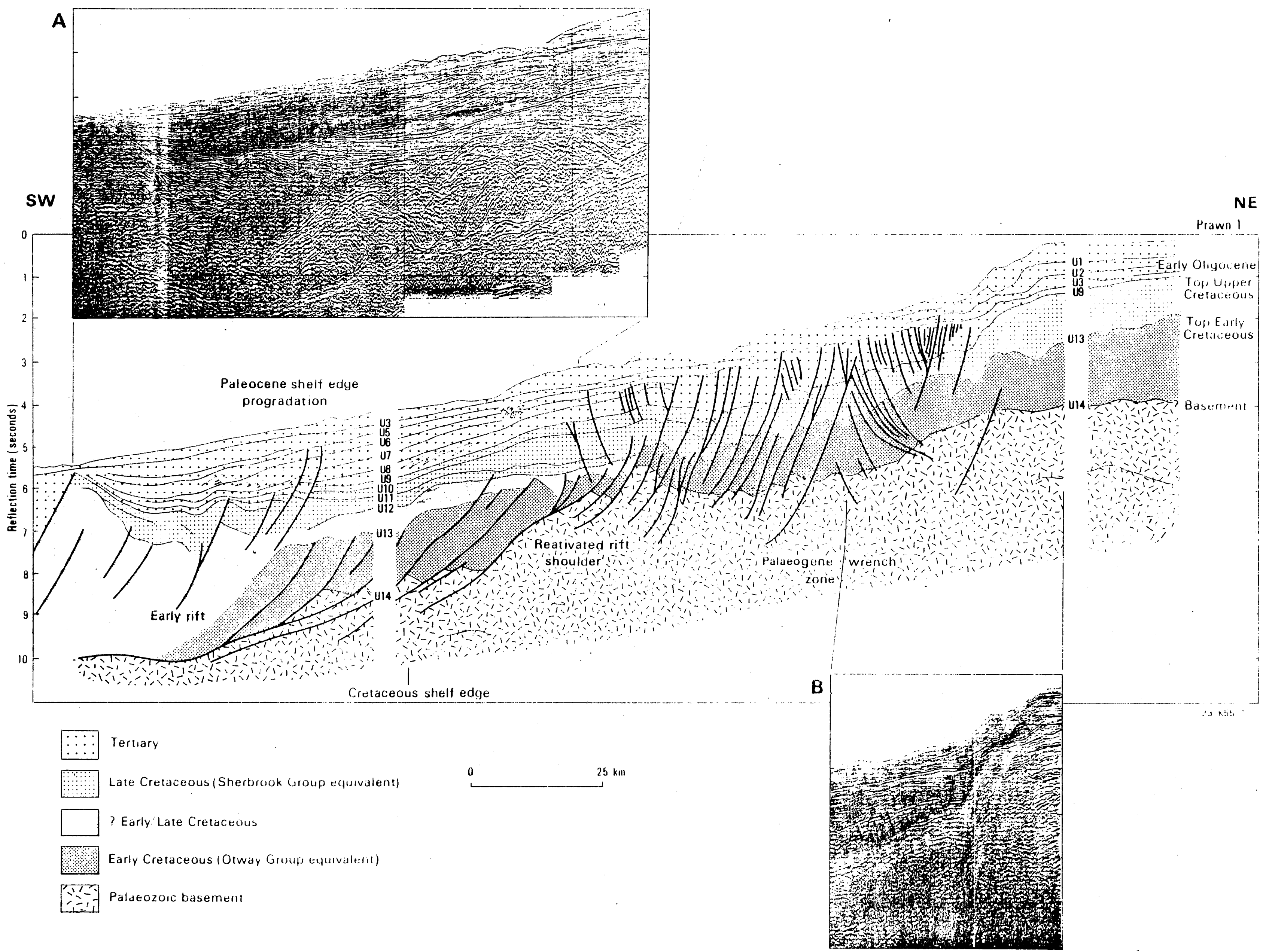


Figure 10: Interpretation of BMR seismic profiles 40-22/23, tied tentatively to Prawn No. well (location Figs. 2 & 4). After Hinz et al., 1986. Unconformities U1 to U14 described in Table 1. After Hinz et al., 1986.

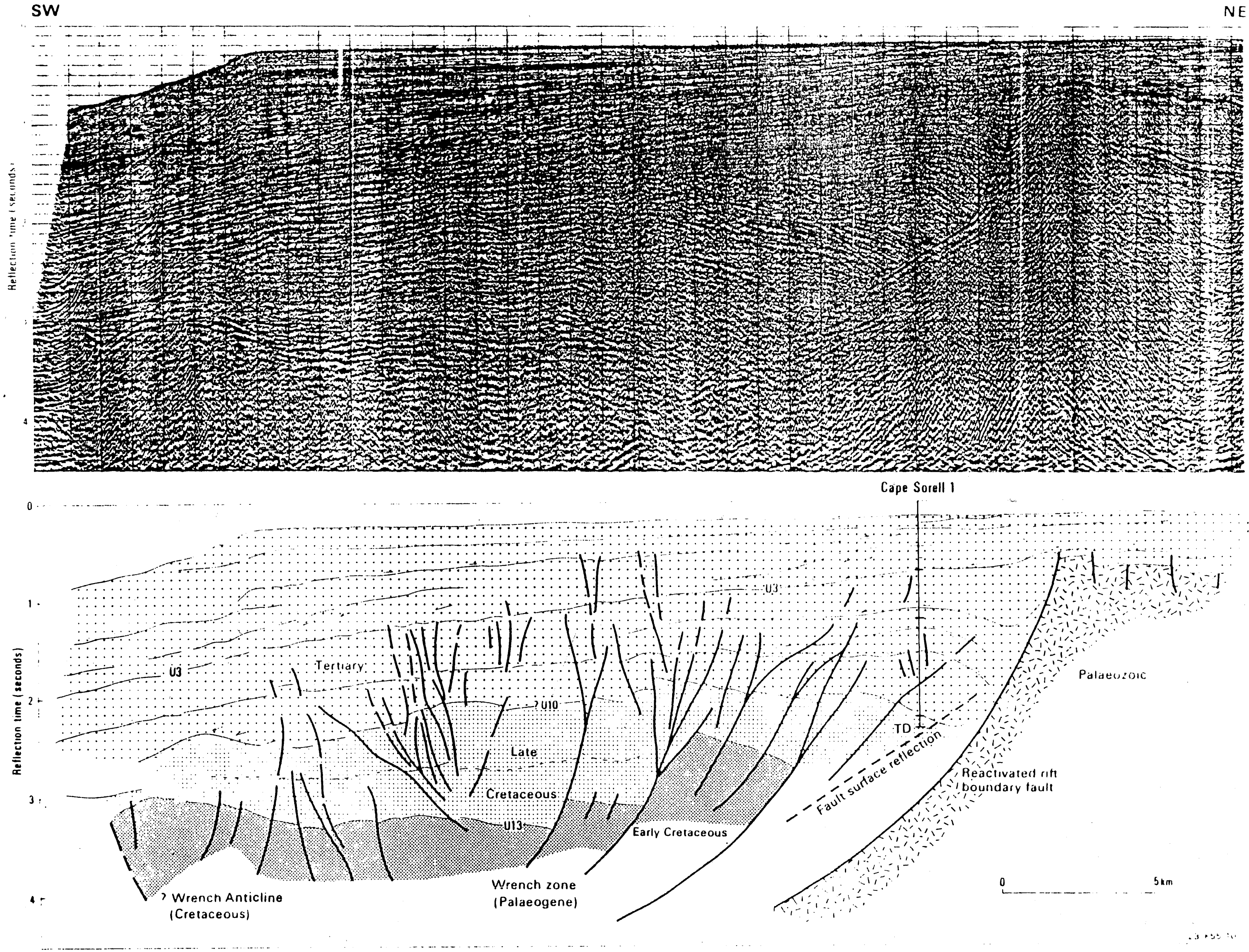


Figure 11 : Interpretation of AMOCO seismic profile W88-82 through Cape Sorell No. 1. After Hinz et al., 1986.

Table 1 : Regional stratigraphy, unconformities and seismic sequences. After Hinz et al. (1986)

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 Contorted fill in first stage rift	Lower rift-fill	Continental–? fluvial, lacustrine Alluvial fan and/or volcanics	1000 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) 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		?	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) 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			Nirranda Group (transgressive) — shallow marine	? Minor volcanism at U5 time
U3						35	13		
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		Southeast Indian Ocean spreading	Heytesbury Group (transgressive) marine carbonates	Main episode of seafloor spreading

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

an up-to-date regional structural interpretation of the major horizons, and digitizing of well logs clarified stratigraphic relationships.

In early 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 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. 2B and Table 2). A detailed cruise report was provided by Hinz et al. (1985). An interpretation of these seismic lines (Figs. 8 and 9), combined with those of a 1982 BMR line and an AMOCO line (Figs. 10 & 11), showed that up to 5 seconds (two-way time) of section was present and that up to 14 unconformities could be identified (Table 1 and Hinz et al., 1986). Sampling and well data indicated that unconformity U3 represented the regional Oligocene unconformity, U9 the basal Tertiary unconformity, and U12 the basal Upper Cretaceous unconformity. The relatively thin Tertiary sequences consist essentially of Neogene carbonates and Palaeogene terrigenous sediments. The Upper Cretaceous Cretaceous sequence appears to subcrop along the foot of the continental slope, along with continental basement which was sampled at three stations.

Table 2. Character and age of Sonne samples and their relationship to seismic sequences

Sequence	Station	Seismic character at station
Pleistocene-Recent oozes & turbidites	many	transparent; above U2 unconformity
L. Miocene-E. Pliocene chalk	19,26*	thinly layered; near U3 unconformity
L. Oligocene-E. Miocene marl	1,2,3,	character not known; near U3 unconformity
L. Oligocene soft bryozoan marl and limestone	31,32,33	character not known; reflectors obscured by slope
M. Eocene lithified deepwater limestone	32,34(?) 29(?)	character not known; reflectors obscured by slope
E. Eocene peaty sand	22*,30	thinly layered; beneath U3 unconformity
Quartz sandstone	4	near U10 unconformity
Basalt	4	near U10 unconformity; probably dykes or flows; well above volcanic basement
Lithified sandstone and grit	35,37	old sequence near basement
Schists and related rocks	28,29,36	basement

(?) not palaeontologically dated
* inconsistent with seismic interpretation of shipboard monitors

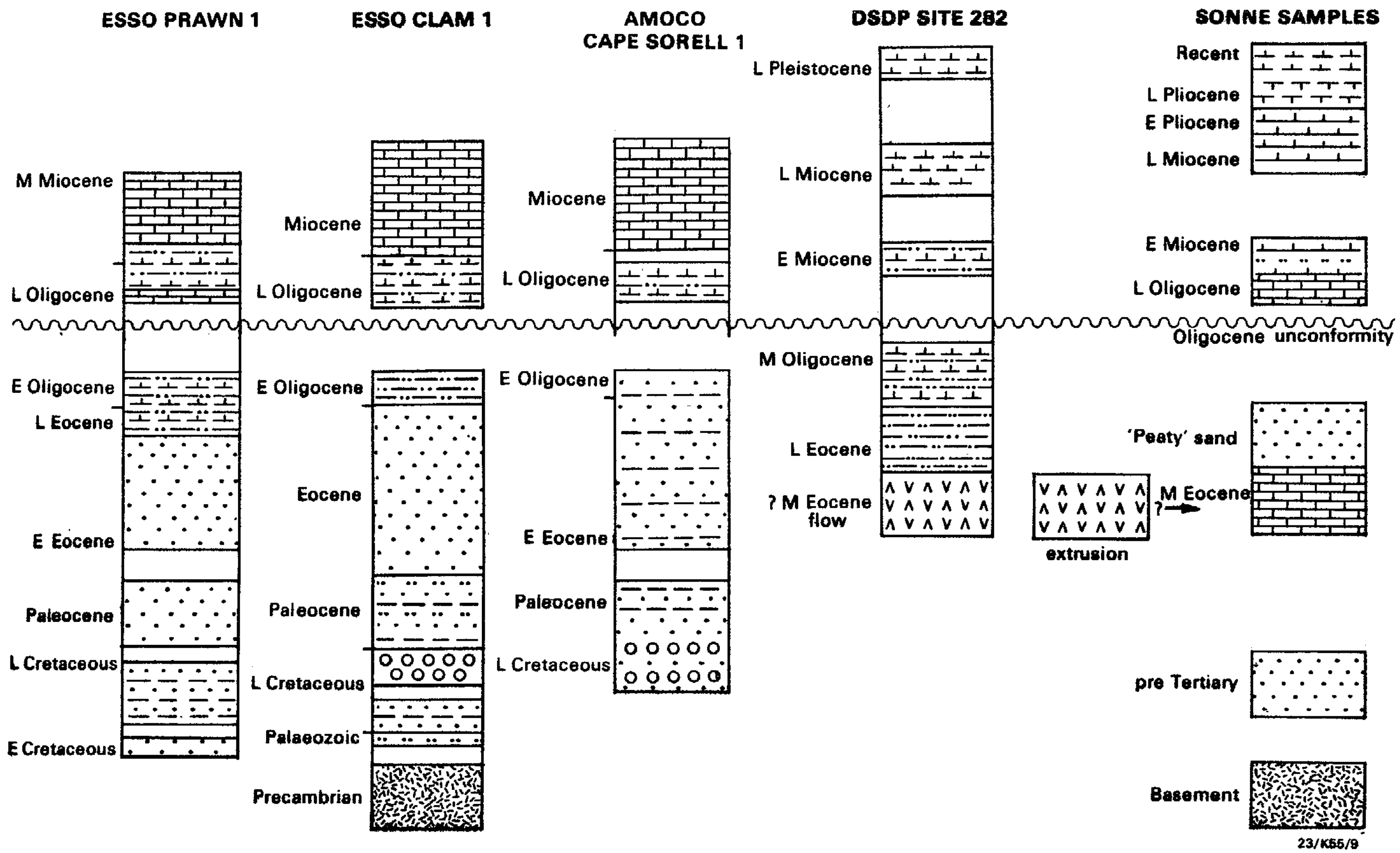


Figure 12 : Stratigraphic relationship of petroleum exploration wells, DSDP Site 282, and "Sonne" sample sites.

In mid 1985, BMR's new geoscience research vessel "Rig Seismic" carried out a regional study of northern Tasmania, Victorian and South Australian areas (BMR Survey 48) during which 3700 km of multichannel seismic data were gathered, including six regional lines which extended to the abyssal plain (Exon, Williamson et al., 1987). Teething problems with the geological winch confined sampling to six stations; the most interesting sampling result was the recovery of probably Palaeozoic metasediments from the outer margin on the edge of the abyssal plain. Tertiary samples indicated subsidence of 3500 m since the middle Eocene. On the geophysical side, there was the recognition that decollement surfaces on which stretching had occurred, as recognized in the east on BMR 40/22-23 (Willcox et al., 1985, was also present in some profiles in the west (Williamson et al., 1987). A regional reassessment of available multichannel seismic profiles by Williamson et al. (1987) has provided a series of structure contour maps of the region covered by the "Rig Seismic" cruise. These maps differ in detail from those prepared from company interpretations by Megallaa (1987), but show the same established picture of blocks bounded by coast-parallel faults and tilted landward.

Tectonic studies which have touched on the Otway Basin 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 (1977), and that of Deighton, Falvey & Taylor (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 m.y. ago, followed by more normal spreading rates until the present. Falvey & Mutter (1981) and Willcox (1982) included the Otway margin in general reviews of Australia's continental margins. Veevers (1985) has suggested that breakup started 95 m.y. ago.

Geochemical and source rock maturity studies commenced with work on coastal bitumen which was summarized by McKirdy & Horvath (1976). This study showed that bitumen from beaches along the western Otway Basin represents natural oil seepages, believed to be derived from submarine outcrops of Cretaceous freshwater and paralic rocks. More recent studies (McKirdy et al., 1986) show that the oils contain botryococcane, indicating that they were derived from lacustrine green algae, apparently of Cretaceous age. Studies of the source-rock potential of core material from the Otway Basin (Jackson et al., 1983; Felton & Jackson, 1985) indicate that the best source rocks may be in the Late Cretaceous and possibly the Early Tertiary sequences, and that maturity varies across the basin. Thermal geohistory studies by Williamson et al. (1987) suggest that the Voluta Trough in the west may be an important area for the generation of hydrocarbons.

On the west Tasmanian margin, Deep Sea Drilling Program (DSDP) Site 282 on the abyssal plain (Figs. 2 and 12) contained a sequence of organic-rich Eocene silty clays with considerable source rock potential (Hunt, 1975a). 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 (Hinz 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.

Leg 29 of DSDP drilled four partly cored holes in the Tasmanian region, including Site 282 some 310 metres deep in 4202 metres of water (Kennett, Houtz et al., 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. 8). The sequences drilled in it (Fig. 12) cover 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. Proposals for further drilling to resolve problems of breakup history under the Ocean Drilling Program have been made by Branson (1984) and Willcox et al. (1985), but have not been adopted into the program.

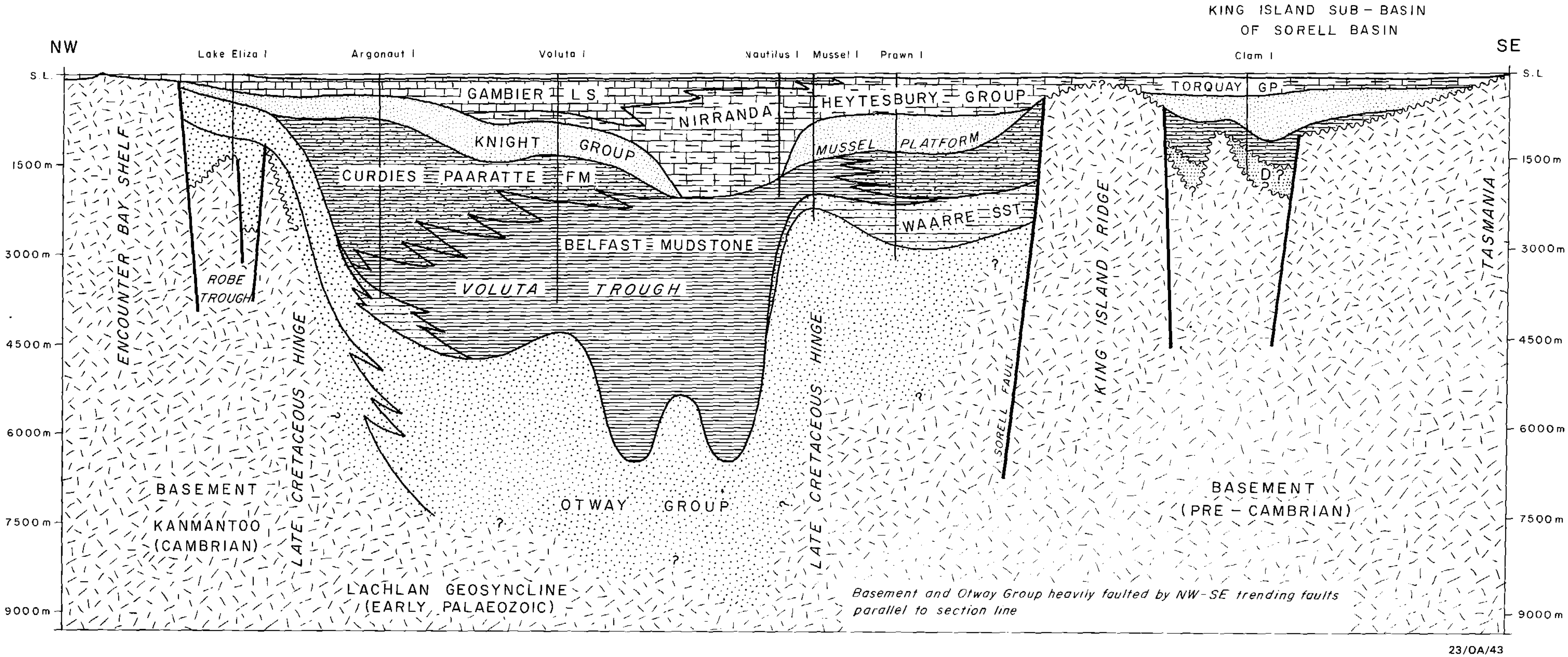
REGIONAL GEOLOGY

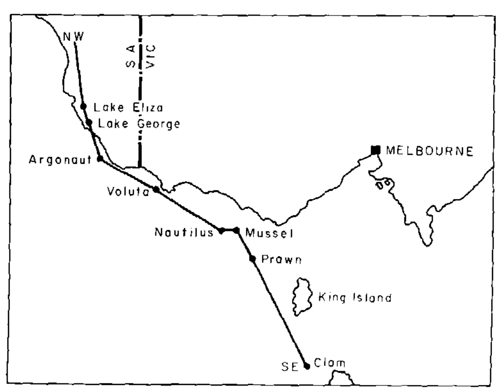
The Otway Basin is one of a series of extensional basins along the southern margin of Australia, which developed in Late Jurassic and Early Cretaceous times before the breakup of East Gondwanaland. These basins vary in character from predominantly rift related in the Great Australian Bight, to mixed rift and wrench related in the Otway Basin, to predominantly wrench related on the western margin of Tasmania. The abrupt terminations of most of the basins,and the accompanying offsets of the continental shelf, can be attributed to the development of major transform or transfer faults. The Otway Basin trends WNW overall, and is extensively faulted, with major movements terminating mostly in the earliest Tertiary, but is relatively little folded. Structural trends in the basin are either WNW or NNE (Fig. 7) and most structures formed in the Cretaceous.

The Otway Basin proper straddles the coastline for 500 km between the Mornington Peninsula in Victoria and Cape Jaffa in South Australia, and it has an average width of 200 km. Its northeastern margin is on land; its southwestern margin is the base of the continental rise at about 4500 m water depth. A related sedimentary basin continues SSE down the west coast of Tasmania for 500 km, where it averages 100 km in width. Typical cross-sections are shown in Figures 13 & 14.

Palaeozoic metasediments crop out north of the basin in Victoria, and Proterozoic metamorphics crop out east of the basin in Tasmania and King Island; both form economic basement beneath it. The maximum sedimentary thickness is 10 km, and the sediments consist of four major sequences (Fig. 3): Lower Cretaceous non-marine detrital sediments of the Otway Group; Upper Cretaceous transgressive-regressive detrital sediments of the Sherbrook Group; Palaeocene-Eocene transgressive-regressive, largely detrital sediments of the Wangerrip and Nirranda Groups; and Oligocene-Miocene shelf carbonates of the Heytesbury Group. Deposition was most widespread in the Early Cretaceous and Tertiary, and most restricted in the Late Cretaceous.

It is generally believed that before breakup East Antarctica and/or the South Tasmania Plateau adjoined the Otway Basin (Fig 15). Cande & Mutter (1982) revised the age identification of the east-west trending oceanic magnetic anomalies, and concluded that the margin started to form 90 m.y. ago (Turonian). The South Tasmania Plateau and East Antarctica apparently moved southward past Tasmania along a transform fault zone, leaving oceanic crust behind, with the plateau separating from Antarctica in the Oligocene according to Hinz et al., (1985). The Late Cretaceous age of breakup suggests that sediments of this age should rest on oceanic basement at the present southern edge of the Otway Basin. Most Otway Basin sequences thin toward basement ridges at the foot of the continental rise; the ridges were probably





NW-SE CROSS-SECTION
THROUGH OTWAY BASIN REGION

0 100 200km

Fig. 13. Northwest-southeast cross-section through the Otway basin. After Robertson et al., 1987.

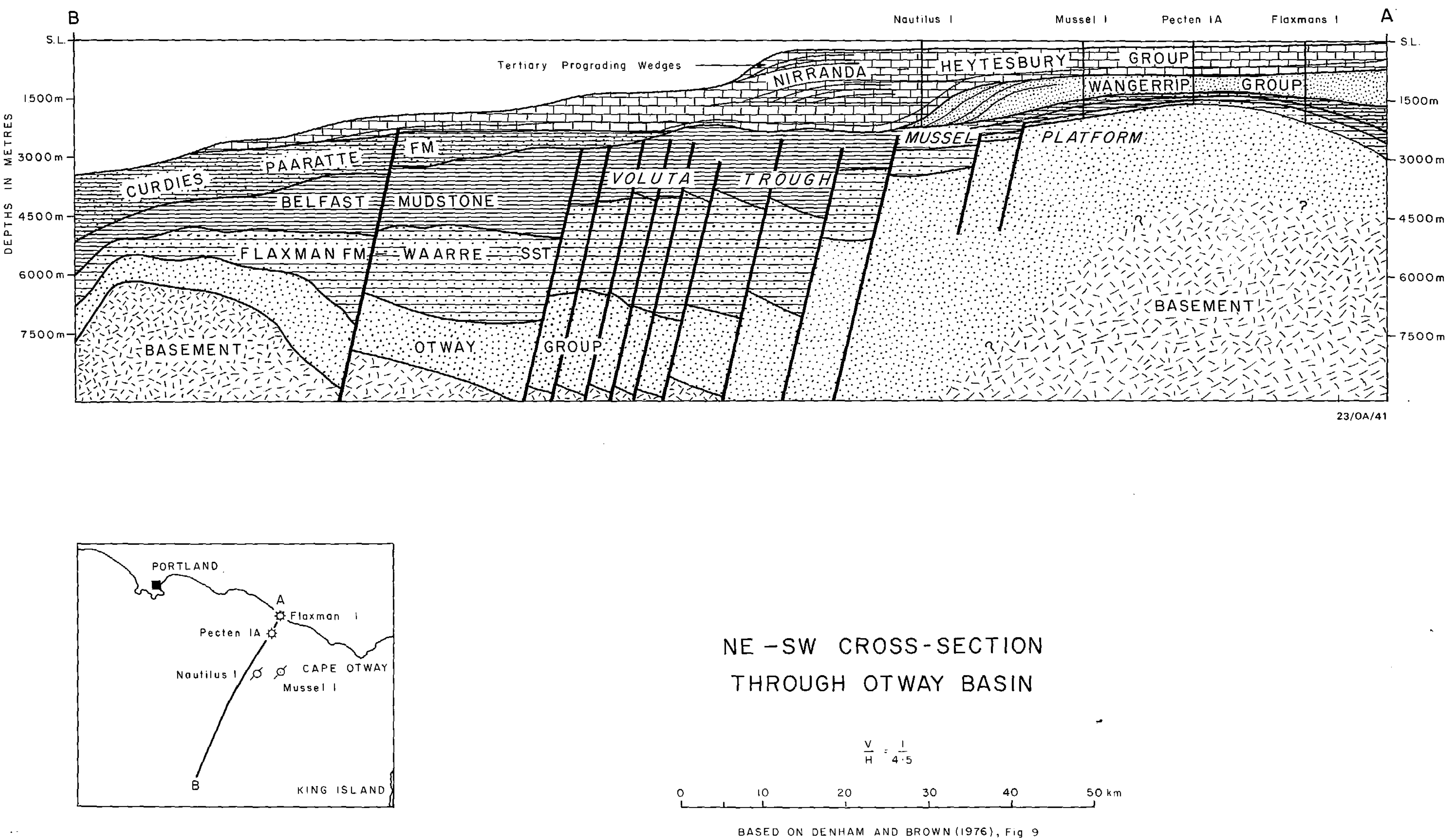


Fig. 14. Northeast-southwest cross-section through the Otway Basin. After Denham & Brown, 1976.

topographically high until breakup. Figure 6 shows a series of interpretations of seismic profiles from NW to SE along the margin.

The Otway Basin first formed in the latest Jurassic to earliest Cretaceous, in troughs caused by initial rifting. The oldest known sediments are of transitional Jurassic-Cretaceous age on floral and microfloral evidence (Dettmann & Douglas,1976). Much of the basin was part of the Bassian Rift, which continued eastward into the Bass and Gippsland Basins, and cut across the major Palaeozoic structures, which trend northwards. The basin filled with up to 5000m of volcaniclastic sediment of the essentially Lower Cretaceous Otway Group, derived from contemporaneous volcanism (Gleadow & Duddy,1981). Whether these sediments occur off western Tasmania is not proven by drilling, but seismic interpretation suggests a thick sequence in the Cape Sorell sub-basin, seaward of Cape Sorell No. 1, and elsewhere (Fig. 11). In South Australia (Morton & Cockshell, 1987) the earliest Cretaceous sediments (Otway Group) were deposited in the early phase of rifting in the east-west orientated Robe-Penola trough which is probably an aborted rift, and also to the south. The sequence consists of the lower Pretty Hill Sandstone (braided fluvial) and the upper Eumeralla Formation (fluvial-lacustrine). Palaeocurrent and isopach data indicate a probable broadly east to west transport direction.

In the Late Cretaceous, as rifting continued and then slow spreading started, the basin began to take up its present shape. In the east the Otway Basin proper terminated against the King Island-Mornington Peninsula Ridge (Fig. 16), the basin being separated from a smaller eastern portion, the Torquay Embayment, by the Otway Ranges High and Cape Otway-King Island High. The Torquay Embayment remained a non-marine sub-basin until late Eocene times, being filled by 3000m of Eastern View Formation coal measures. On the Tasmanian margin more than 3200 m of Late Cretaceous sediments were drilled in Cape Sorell No. 1 (AMOCO, 1982).

The western and southern parts of the basin were affected by a number of developing structures from early in the Late Cretaceous. Major NNE trending highs developed in the north (Fig. 16), where there are two Early Cretaceous troughs: the westerly trending Robe Trough, and the WNW trending Penola Trough adjoining it to the east. In the east the Sorell Fault transform separated the non-depositional Cape Otway-King Island High from the Mussel Platform (Fig. 16), which extended as far west as a Late Cretaceous hinge line associated with the Warrnambool High. South and west of the Mussel Platform, the basin was subsiding rapidly to form the WNW trending Voluta Trough (Fig. 16) as breakup occurred. East of the hinge line, WNW trending normal faults cut basement, the Otway Group and the lower Upper Cretaceous (Fig. 7). The structure of the Tasmanian margin is not well known, but it appears that a number of margin paralleling strike-slip faults developed at about this time (Hinz et al. 1987).

Upper Cretaceous transgressive-regressive detrital sediments of the Sherbrook Group were deposited in much of the basin as it sank, reaching a maximum thickness of 4000 m in the Voluta Trough (Fig. 13). They did not transgress far enough northward to cover the entire Otway Group, which was the source of much Sherbrook Group detritus. The initial transgression came from the west. In South Australia (Morton & Cockshell, 1987), the thick Late Cretaceous post-breakup sequence, (Sherbrook Group), contrasts in depositional style to the underlying Otway Group. The sequence where it is underlain by thinned continental crust or new oceanic basement, was deposited in a large,

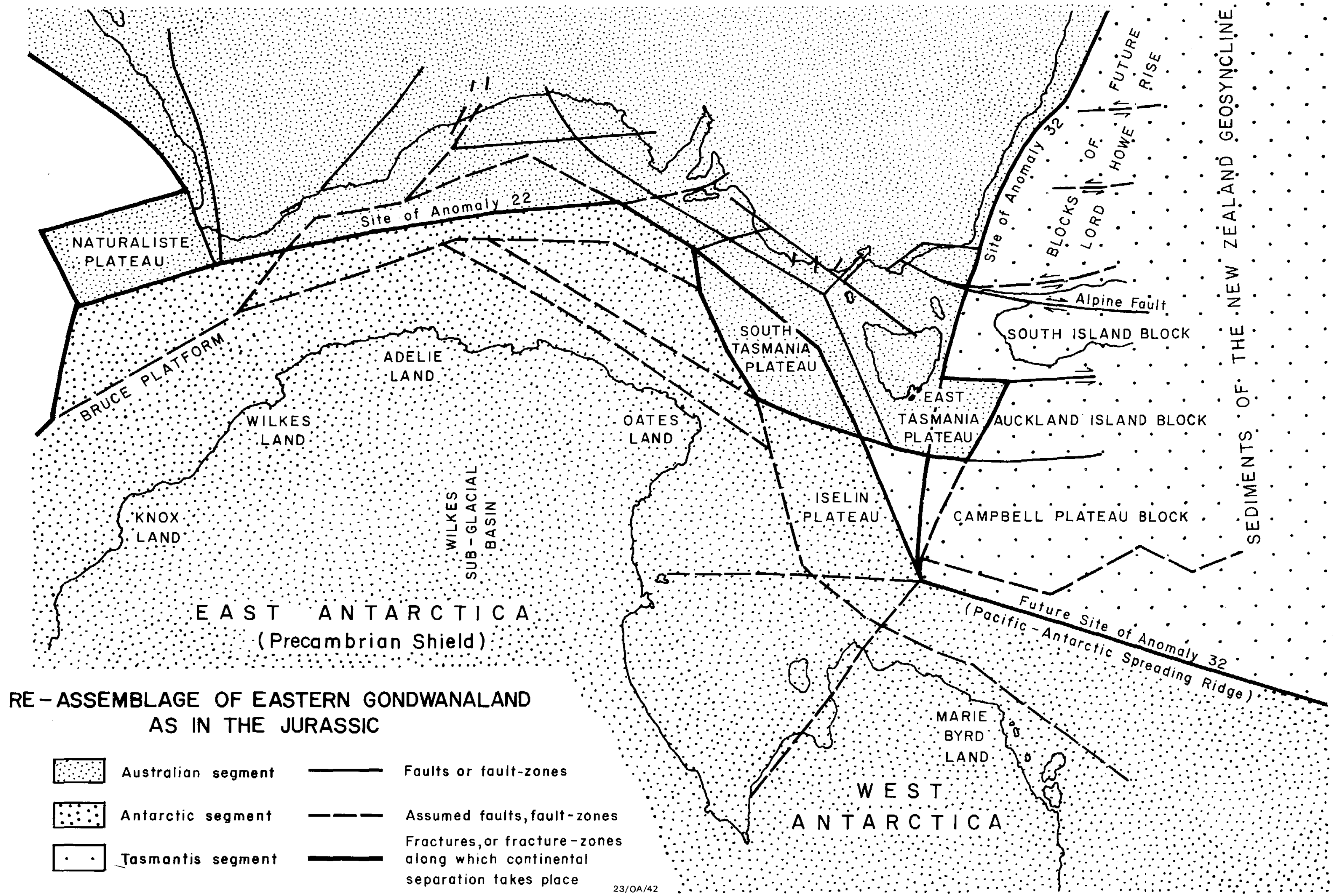


Fig. 15. Jurassic re-construction of eastern Gondwanaland
After Robertson et al., 1978.

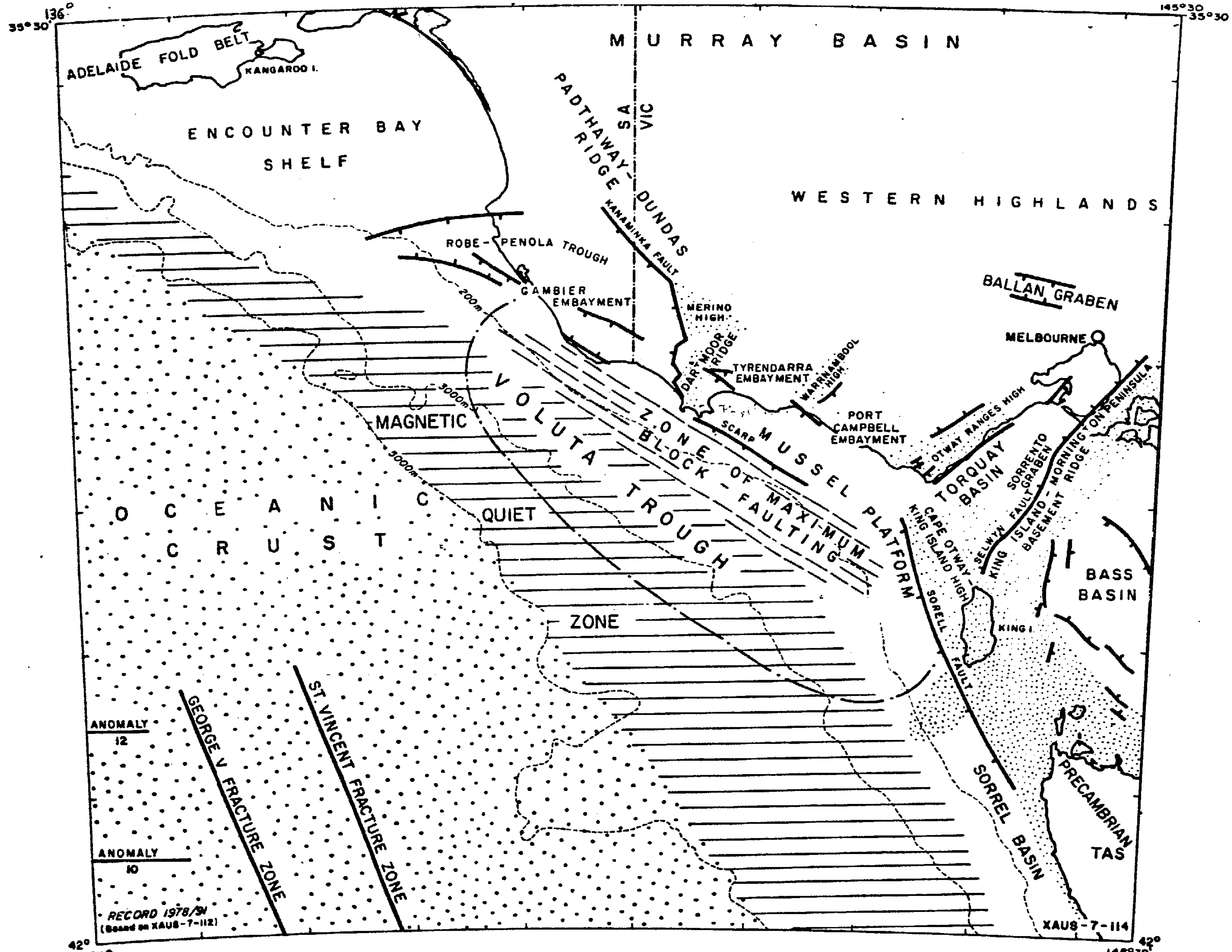


Figure 16 : Major structural elements of the Otway Basin. After Robertson et al. (1978).

southerly prograding delta complex, comparable in size to the Niger Delta. In the north there was no crustal thinning and a sandy condensed Sherbrook Group sequence is probably mostly of fluvial origin. Evidence of the fully marine conditions found in Victoria is absent, suggesting more restricted conditions in the South Australian portion of the basin.

Tertiary marine strata generally overlap all older Otway Basin sequences on the landward side, but are not extensive beyond the present continental shelf. They are separated by a major Oligocene unconformity, U3 (Table 1) which coincides with a change from terrigenous to carbonate deposition (Fig. 12). During the Paleocene, breakup was well advanced, the margin sank steadily, and a widespread transgressive-regressive detrital sequence, the Wangerrip Group,was deposited in the north. It prograded southwestward across the Mussel Platform and into the Voluta Trough where it reaches a maximum thickness of 1000 m; similar prograding is evident in Eocene sequences on the Tasmanian margin (Hinz et al., 1987). As the margin continued to subside, normal marine conditions were slowly established and, outside the Torquay Embayment, thin sandstones and marls of the Nirranda Group were overlain by marine carbonates of the late Oligocene and Miocene Heytesbury Group, which also prograded southwestward , more than keeping pace with subsidence on the shelf.

PETROLEUM EXPLORATION

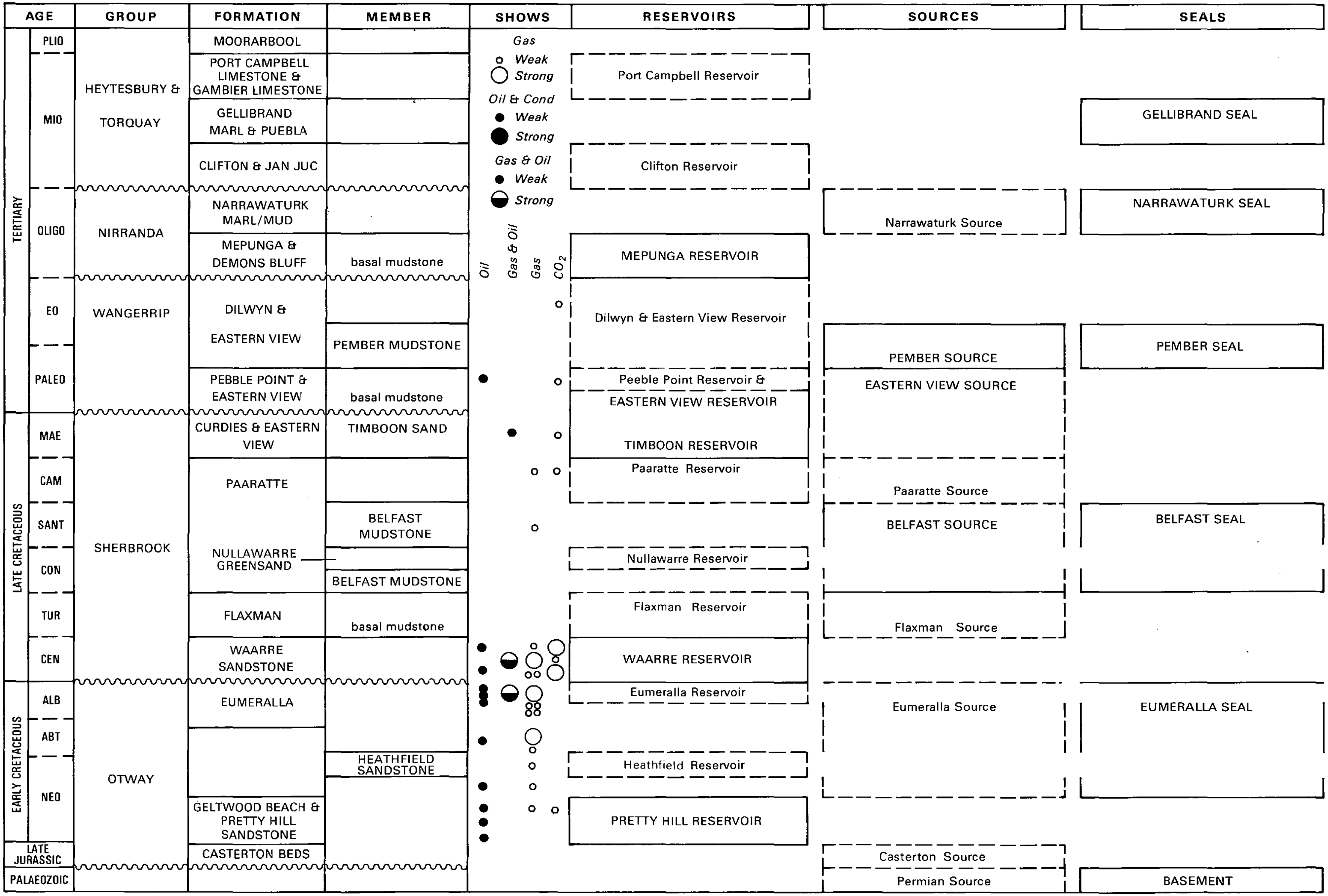
History

Alfred Flat bore was drilled near Kingston, South Australia to test for shallow oil following the observation of bitumen-like material on the surface. The well was dry and this 'bitumen' proved to be altered algal mat. Since the early 1960's, about 50 exploration wells have been drilled onshore and 12 offshore. The only viable hydrocarbon discoveries to date have been made in the Port Campbell area, where gas from the North Paaratte field is being piped to the town of Warrnambool. Several other small fields in the area are subeconomic. Carbon dioxide gas of possible volcanogenic origin is produced from Caroline No. 1 well in southeastern South Australia.

Oil, gas and condensate shows are widespread both on and offshore, having been found in about 20 wells. The shows occur throughout the Cretaceous and Tertiary sequences (Fig. 17). Drilling, especially in recent years, has concentrated on structural traps at Upper Cretaceous and Tertiary levels. Only three offshore petroleum exploration permits, all in the western Otway Basin, are current. Permit coverage onshore is extensive.

Potential Petroleum Source Rocks

Potential source and seal units in the Otway Basin sequence are indicated in Figure 17. Organic geochemical data from the basin are reported by Jackson and others (1983). Felton and Jackson (1985), from a limited suite of samples, identified the Tertiary Dilwyn Formation and intervals within the Otway Group as having the best oil potential, in terms of source rock richness and oil-prone organic matter, compared with other formations. The Belfast Mudstone, commonly regarded as a good petroleum source, was found to be gas-prone, although of moderate organic richness, as was much of the Otway Group. The considerable thickness of Otway Basin sediments and the reconnaissance nature of Felton and Jackson's (1985) sampling offer



23/OA/44

Fig. 17. Eastern Otway Basin stratigraphy related to hydrocarbon shows and to potential reservoirs, sources and seals.

encouragement for more detailed studies. McKirdy (1985) reported organic compounds apparently derived from the alga Botryococcus from within the Otway Group, and linked this occurrence with similar compounds from the inspissated oil strandings known from along the southern coast, which he suggested were derived from a mature Otway Group source offshore.

Potential Reservoirs and Seals

Both the Pretty Hill Sandstone and the Waarre Formation are fairly clean quartz sandstones, and have moderate to good porosity where drilled. Seals for both are fine-grained or otherwise tight sediments of the Eumeralla Formation and Belfast Mudstone respectively. Clay linings in pores, siliceous cement and, in places, carbonate cement and compacted lithic fragments, reduce reservoir potential in both these units and make regional reservoir evaluation difficult. Sands at the top of the Sherbrook Group are clean but are commonly freshwater-flushed where drilled on structural highs onshore; seals in this interval are poor.

Tertiary sands include the Dilwyn Formation, a regionally important highly porous and permeable aquifer onshore, which may be hydrocarbon- bearing in suitable traps both on and offshore. Other sands low in the Tertiary sequence have variable but often good reservoir potential. The Pember Mudstone may act as both seal and source for the Dilwyn Formation.

Traps and Timing

Exploration wells have tested mainly structural traps in the basin. The majority of these are rollovers associated with the north-northwest trending fault system which dominates basin structure. Such traps rely on sealing of the fault for their integrity. Because of the highly faulted nature of the Cretaceous sequence, rollover traps are numerous, but generally small. Simple anticlinal or domal traps are uncommon. Potential stratigraphic traps within the basin are numerous but almost completely untested. Pinchouts of coarse clastic detritus adjacent to rising basement blocks are certainly present at the base of the Otway Group and probably the Sherbrook Group. Potential unconformity traps exist at the tops of all the major sequences.

Published geohistory analyses (Middleton and Falvey,1983) of the offshore wells Voluta-No. 1 and Pecten No. 1A were used by Felton and Jackson (1985) to suggest relationships for hydrocarbon generation and trap formation in two structurally distinct parts of the basin. Major block faulting and down-to-basin normal faulting occurred during continental breakup in Mid- to Late Cretaceous time (100-65 Ma ago), with minor movement continuing until the end of the Palaeocene (65-55 Ma ago). Fault-related traps were thus fully developed 55 Ma ago. Peak oil generation (at Ro=1.0%) would have occurred in the Otway Group in the Voluta Trough between 80-60 Ma ago, permitting substantial hydrocarbon loss. The Upper Cretaceous section here is early mature at the present day. At Pecten-No. 1A on the Mussel Platform, the Otway Group is at present entirely within the 'oil window', its base having reached peak generation 60 Ma ago, so that there too most of its hydrocarbons would have been generated since fault trap development. The Upper Cretaceous at Pecten-No. 1A is still largely immature.

Prospectivity

The best prospects for oil and gas discoveries, in both structural and stratigraphic traps, are in areas where the underlying sedimentary section has reached maturity later than 55 Ma ago, given the amount of structural disturbance in the basin up to that time. The Otway and Wangerrip Groups appear to have the best oil source potential so oil plays might include:

1. Waarre/upper Otway reservoirs sourced by Otway Group and sealed by Otway/Belfast mudstones in the Mussel Platform area;

2. Pretty Hill Sandstone reservoirs sourced and sealed by Eumeralla Formation mudstones in the western part of the basin.

Gas prospects are more widespread but appear best onshore, particularly in the central and western areas of the basin, where a mature Belfast source may charge both Waarre and Tertiary reservoirs.

GEOLOGICAL RESULTS

The locations of all geological stations are shown in Figures 1 and 2. The scientific contributors to all this work were N.F. Exon, A. Felton, A. Stephenson, S. Shafik and C. Wilson. The names bracketed after each section heading are those who wrote the text.

DREDGE SAMPLING (A. Felton and A. Stephenson)

Twenty-two dredge stations were occupied (Figs. 1 and 2), fourteen yielding hard rock material. Most stations also yielded Recent foram-nannofossil ooze in the pipe dredge. A summary of dredging results is presented in Table 3.

Methods and techniques

Sites selected for dredging were located on the continental slope except for DR20. Seismic lines, particularly those run on BMR cruise 48 (July 1985), and echosounder profiles from that cruise gave good control on site selection. Sites included slopes of 8 degrees or more, and canyons, particularly in the western part of the basin. One site (DR18) was occupied after a 600 m high topographic feature was noted on the echosounder profile during a transit.

On arrival at a proposed dredge site, an echosounder profile was run downslope to define the target. The ship was then stopped and wire run out until the amount of wire out equalled the water depth. The ship was then got under way, heading up the slope at 1-2 knots, the wire being paid out exceeded the depth of water at the foot of the slope by 20-30%. Dredging continued to the top of the slope or a specified water depth. Tension on the wire was recorded on a chart recorder during dredging. On one occasion, the dredge had to be freed by reversing the ship's heading. One dredge was lost, at DR20, when the weak link, protecting the wire rope from excessive tension, gave way.

Equipment deployed was similar at all stations except DR01. A small pipe dredge was deployed ahead of a chain bag with a solid bridle. Weights were clamped to the wire rope several metres ahead of the pipe dredge to maximise sample recovery. At DR01, a large chain bag with a toothed leading edge and a chain bridle was deployed, together with a pipe dredge. When retrieved, the pipe dredge was empty and the bag mesh was entangled with the teeth. This dredge bag was not used again during the trip.

Samples obtained from the dredge were washed clean once on board and sorted into groups of similar rock types. Each rock type present was given a number prefixed by the station number (eg. DR07/1) and individual rocks from the sample given a letter suffix (DR07/1A,B etc). Mud from the pipe dredge was included in the listing. The proportion of each rock type present in the dredge haul was recorded, and the rocks described from hand specimen, using sawn faces where necessary. Smear slides were prepared from weakly lithified specimens and sedimentological and nannofossil descriptions made.

Station data and results

Station DR 01

This station was located at the base of the continental slope west of

TABLE 3 : DREDGE STATIONS

Station	Latitude	Longitude	Water depth (m)	Seismic profile	Recovery (hard rock)	Description or comments
DR01	37°49'	138°06'	5200	N409 67/002	None	not on bottom
DR02	37°40.3' 37°37.7'	138°16.8' 138°19.6'	4100- 3800	N409 67/002	5kg	L. Eocene & E. Oligocene gray sandy siltstone; gray Quaternary foram nanno ooze.
DR03	38°14.6' 38°14.0'	138°36.0' 138°38.4'	4500- 4000	48/041 67/004	40kg	Indurated ?Cretaceous dark brown to gray siltstone in Fe oxide crust; plastic dark brown mud to silty claystone.
DR04	38°26.7' 38°24.3'	138°49.6' 138°52.3'	4700- 4050	48/042 67/004	300kg	Dark gray ?Cretaceous laminated mudstone; mid gray siltstone in Fe oxide crust; pink Quaternary ooze.
DR05	38°25.4' 38°24.3'	138°54.7' 138°55.8'	3900- 3850	48/042	200kg	Dark gray ?Cretaceous siltstone, shale, claystone; pink Quaternary ooze.
DR06	38°45.4' 38°46.2'	139°8.9' 139°9.0'	4660- 4450	N410 67/005	1kg	Black ?Cretaceous non-fissile mudstone, Mn crusts to 4mm; gray Quaternary ooze.
DR07	38°47.4' 38°47.8'	139°12.4' 139°12.1'	4450- 4200	N410 67/005	0.1kg	Black ?Late Cretaceous slate, brown mudstone, 2mm Mn crust; light brown Quaternary ooze.
DR08	39°01.2' 39°02.7'	140°03.4' 140°00.9'	4350- 4050	48/043	2kg	Brown mudstone; brown pelagic mud.
DR09	39°26.9'	139°59.5'	4800	48/043	300kg	Metaquartzite; quartz veined felsic volcanics; metashale; coarse felsic tuff; light brown mud. ?Palaeozoic or Adelaidean.
DR10	38°05.2' 38°04.5'	139°45.2' 139°46.4'	1950- 1700	48/042	200kg	Fossilferous calcareous clay, white (L. Oligoc) and gray (M. Eocene; L. Eocene-E. Oligocene); chert concretions; L. Oligocene bryozoal calcarenite; limonitic concretions in quartzose host; light brown mud.

Table 3 (cont.)

Station	Latitude	Longitude	Water depth (m)	Seismic profile	Recovery (hard rock)	Description or comments
DR11	37°58.6' 37°58.4'	139°49.0' 139°49.5'	1400- 1200	16/085	-	Olive gray foram nanno ooze.
DR12	37°46.3' 37°46.7'	139°25.3' 139°25.6'	1350- 1150	16/045	40kg	E. Miocene chalk, L. Oligocene soft chalk, gray E-M. Oligocene and L. Oligocene chert or porcellanite, quartz-rich sandstone and sandy mudstone, gray sticky mud; pale gray foram nanno ooze.
DR13	38°30.2' 38°30.2'	140°52.0' 140°53.7'	1020 -500	16/033	-	Green mud, soft and firm.
DR14	38°50.0' 38°49.8'	140°35.4' 140°35.0'	3050 -2450	48/054	40kg	White L. Oligocene & E-M. Miocene chalk; brown siltstone; grey ?Palaeozoic hard tuff and volcanic sandstone; minor quartz granule conglomerate; gray ooze; white Miocene calcareous clay.
DR15	38°58.3' 38°56.8	140°51.8' 140°50.2'	3120- 2500	48/054	-	Gray and brown ooze.
DR16	38°53.5' 38°50.4'	141°29.2' 141°29.0'	1450 -800	16/039	-	Light olive gray ooze.
DR17	39°09.0' 39°09.0'	141°51.1' 141°53.0'	2270- 2060	16/029	-	Gray clay.
DR18	39°12.9' 39°11.8'	140°07.2' 142°11.5'	1950- 1650	16/029	2kg	White Middle Miocene chalk; brown L. Eocene-E. Oligocene and ?Miocene siltstone; gray mudstone; white calcareous mud; olive gray ooze and mud.
DR19	39°29.2' 39°29.5'	142°13.4' 142°16.2'	2600- 2100	16/027	2kg	White L. Oligocene chalk; brown mudstone; gray ooze; and brownish gray ooze (L. Oligocene).
DR20	39°05.8'	143°19.9'	66	16/029	-	Chain bag dredge broke off at weak link.

Table 3 (cont.)

Station	Latitude	Longitude	Water depth (m)	Seismic profile	Recovery (hard rock)	Description or comments
DR21	40°50.3' 40°49.5'	141°46.0' 141°49.0'	4580- 4155	40/024	20kg	Yellowish brown, f-m, well-sorted labile sandstone. Otway Group.
DR22	42°40.4' 42°42.2'	143°43.3' 143°43.2'	4200- 3900	16/008	1kg	Brown and gray v.f. micaceous sandstone and siltstone of Otway Group; tough dark gray mud; white and pale olive brown foram nanno ooze.
DR23	42°39.0' 42°41.6'	143°43.1' 143°42.8'	4257- 4000	16/008	-	Brown foram nanno ooze.

Beachport Terrace on a topographic ridge of 10 degree slope to the southwest. The ridge was interpreted from seismic evidence as either Otway Group or pre-Mesozoic basement. The dredge probably never reached water bottom due to a strong easterly and winch problems including loss of hydraulic pressure and wrong readings on the control panel.

Station DR 02

The station was on the lower slope west of Beachport Terrace, in 4100-3700 m water depth. Slope angle was less than 10 degrees, towards the southwest. The target was the Tertiary sequence.

Samples were recovered at 4100m-3900m from the pipe dredge only, and consisted of yellowish grey (Munsell colour 5Y7/2 foram/nannofossil ooze, dated from nannofossils as Late Quaternary, and lithified light olige grey sandy siltstone with some darker material (5Y5/2 - 10YR 4/2), dated from nannofossils as early Oligocene.

Station DR 03

The location was on the lower slope south of Beachport Terrace, near the abyssal plain, in 4800 m water. The echosounder profile showed a slope of 10-12 , to the southwest. About 40 kg of material was collected, from 4800-4100 m water depth.

DR03/1 - a boulder of dark brownish grey indurated siltstone, with joints and fractures coated by secondary iron minerals. This boulder comprised half of the 40 kg sample.

DR03/2 - dark brown mud with distinctive plastic texture, containing 'cores' of more indurated but still soft silty claystone with ferruginous coating. Two fractions:

DR03/2A - plastic mud with 'core' material
DR03/2B - 'cores' isolated by washing off mud. Comprises 50% of sample.

DR 03/3 - moderately indurated ferruginous material (?boxstone in part) on soft silty claystone as DR03/2. Comprises <1% of sample.

The dark brown mud lacked nannofossils and is probably from a non-marine or restricted marine environment.

All material tentatively assigned a Late Cretaceous age (Belfast Mudstone equivalent) on lithological grounds. An Early Cretaceous age (Otway Group equivalent) is also possible.

Station DR04

The target at station 4 was lower Otway Group, interpreted from seismic data. The site was located at the base of the continental slope in 4800 m water, on a 10 southwesterly dipping slope. A full bag (ca. 300 kg) of rocks was obtained from water depths of 4700-4050 metres, together with pinkish ooze in the pipe dredge.

DR04/1 - dark grey to brown soft to hard mudstone with incipient to distinct cleavage. Strongly fractured, with conchoidal fractures; ferruginous staining on fracture faces and cleavage planes. Indistinct lamination and occasional brecciated texture noted on sawn faces. This rock type comprises about 90% of haul. Probably Early or Late Cretaceous.

DR04/2A - medium grey-brown mudstone, laminated; small ?burrows parallel to lamination on sawn surface.

DR04/2B - as 2A, but hardened due to weathering/alteration; ferruginous crusts and boxworks surround central cores of mudstone. Probably Early or Late Cretaceous.

DR04/3 - carbonate rocks : ?dolomite breccia and microkarst with ferruginous rinds and boxworks. On lithological grounds possibly Tertiary in age.

DR04/4 - coarse quartzose sandstone : rounded quartz grains as framework in ferruginous matrix. On lithological grounds probably Tertiary in age.

DR04/5 - dark brown plastic mud with 'cores' of soft dark brown mudstone; similar to DR03/2. Probable Late Cretaceous age.

DR04/6 - light brown mud from pipe dredge. Recent age.

DR04/7 - light brown siliceous flattened concretions (perhaps related to rock type 2A). Probable Cretaceous age.

Station DR 05

This station was located near the base of the continental slope, in 3900 m water above station DR04. The target was upper Otway Group. About 200 kg of material was recovered.

DR05/1A - medium to dark grey, moderately indurated mudstone, conchoidal fractures with limonite staining. Indistinct bedding laminae, with incipient fracture cleavage oblique to bedding. Similar to DR 04/1.

DR05/1B - similar to 1A but with black coating, possibly manganese oxides.

DR05/1C - as 1A but containing macrofossils identified as ammonites.

Lithotype DR05/1 comprised 70% of dredge haul. Probable Late Cretaceous age (Belfast Mudstone or equivalent) on lithological grounds and presence of marine fossils.

DR05/2A - concretions developed in mudstone 1A above. Ferruginous skins with multiple concentric zones.

DR05/2A - weathered mudstone core of concretion. Age of 'core' material as for DR05/1 above. Age of concretion development unknown. About 25% of haul.

DR05/3 - black, dark grey and grey brown light grey mud, derived in part from rock type 1A. Light grey material probably Recent ooze. Age Late Cretaceous as above. About 5% of haul.

Station DR06

The station was located on the northern side of a topographic ridge on the abyssal plain southwest of Argonaut-1 well, in 4800 m water. Indurated brownish green quartz-veined silty mudstone was recovered from the south side of this ridge at 048-DR06 during BMR's 1985 Otway Basin cruise. Ten kilograms of material was recovered in the pipe dredge only, from a depth of 4450 m.

DR06/A - small pieces of black, non-fissile mudstone, about 90% of lithified material. Probable Palaeozoic basement; possibly Cretaceous age.

DR06/B - manganese crusts to 4 mm thick. Age unknown.

DR06/C - olive grey pelagic ooze with Quaternary nannofossils.

Station DR07

The target at this station was basement. The site was located in 4750 m water on the same ridge as DR06, but further up the slope to the south.

Recovery was about 5kg, from the pipe dredge only.

DR07A - light brown pelagic ooze with Quaternary nannofossils.

DR08B - 4 pieces black slate (to 4mm diameter).

DR07B/2 - 4 small dark brown mudstone fragments.

DR07/3 - 1 small light brown mudstone.

DR07B/4 - 1 manganese crust.

This material is similar to the range of rock types recoverd at DR03. The mudstones are probably of Cretaceous age on lithological grounds; the black slate, if a true slate, is probably Palaeozoic.

Station DR08

The station was located on the northeastern side of a small ridge near the base of the continental slope south of Argonaut - 1 well. The target was probably Otway Group. Recovery was 10 kg pelagic ooze and dark brown mud in the pipe dredge, from 4351 m to 4050 m water depth. The pelagic ooze yielded Quaternary nannofossils. The brown mud contained fragments of soft dark brown mudstone, similar to that described from DR03 and DR04. The age of the dark brown mud and mudstone is probably Late Cretaceous, on lithological grounds.

Station DR09

The target at this location was basement, on the southeastern end of the topographic ridge dredged at DR06 and DR07. The water depth was 4800-4530m. About 300 kg of hard rocks were recovered in the chain bag, and light brown ooze and some small rocks in the pipe dredge.

Pipe dredge material

DR09/1 - yellow-brown ooze with Quaternary nannofossils.

DR09/2 - yellow orange terrigenous clay, firm texture but easily deformable. Possibly Recent.

DR09/3 - about 1 kg rock fragments representative of material in chain bag. Fragments have manganeses oxide coating.

DR09/4 - two small fragments of coarse quartz and feldspar, possibly pegmatite.

DR09/9 - light brown ooze with Quaternary nanno-fossils.

Chain bag material

DR09/5 - light greenish grey felsic volcanic breccia: quartz and volcanic rock fragments in a fine-grained siliceous groundmass.

DR09/6 - coarse and fine-grained basic igneous rocks, greenish grey, fragments in a fine-grained siliceous groundmass.

DR09/6 - coarse and fine-grained basic igneous rocks, greenish grey, fractured and quartz veined. Coarse varieties contain phenocrysts of plagioclase and ?pyroxene to 3 mm long, in altered greenish groundmass. These rocks comprise 75% of hard rock sample.

DR09/7 - fine-grained metaquartzite, pyritic in part, possibly fine siliceous felsic volcanic, quartz-veined; ?metashale. Comprises 25% of haul.

DR09/8 - spotted siliceous metavolcanic or metasedimentary rock. Less than 1% of haul.

This suite is tentatively assigned as Early Palaeozoic or Precambrian (Adelaidean) age on lithological grounds. An early Mesozoic age (pre-Otway Group) is possible for part or all of the igneous rocks recovered: may have accompanied the earliest stages of the rifting event which culminated in the separation of Australia and Antarctica.

Station DR10

Early Tertiary rocks were the target at this site, located on a 15 degree slope to the southwest, in 1950-1700 m water. Two hundred kilograms of mixed carbonate rocks were obtained from the chain bag and light brown ooze with fragments of rock from the pipe dredge.

DR10/1 - soft white (5Y 8/1) fossiliferous calcareous claystone with poorly sorted, poorly rounded sand-sized quartz grains. Fossils are mainly bryozoan debris. The claystone is bioturbated, with burrows 2-7 mm in diameter, some with a manganese oxide lining. Yielded Late Oligocene coccoliths. Comprises 30% of dredge haul.

DR10/2 - chert concretions/nodules from both DR10/1 and DR10/3.

2A - early to middle Oligocene nannofossils.

2B - late Oligocene nannofossils. Comprises 30% of dredge haul.

DR10/3 - light brownish grey (2.5Y6/2) sparsely fossiliferous calcareous claystone, with minor poorly sorted, poorly rounded quartz sand grains, possibly bimodal; minor mica sparse borings, 2-4 mm diameter; comprises 25% of dredge haul.

DR10/3A - middle Eocene coccoliths.

DR10/3B - latest Eocene - early Oligocene coccoliths.

DR10/4 - highly fossiliferous bryozoal calcarenite, with chert concretion. Fossils 90% bryozoan debris, 10% mollusc and worm burrow fragments. Minor mica and well-rounded translucent to green quartz sand grains. Contains late Oligocene coccoliths.

DR10/5 - brownish yellow (10YR2/1) limonitic concretions in poorly sorted quartz sandstone host, with quartz grains similar to DR10/1 and 4. The concretions are manganese rich and may result from cementation/lithification on the sea floor. Comprises 5% of haul. Did not yield nannofossils.

DR10/6 - light brown ooze and fragments of rock types as above.

Station DR11

This site, on the middle continental slope in 1400 m water, west of Argonaut-1 well, had a target of lower Tertiary rocks on a southwest facing 10 slope. Only ooze without hard material was obtained in the pipe dredge. There was no recovery in the bag.

DR11 - light olive grey foram-nanno ooze.

Station DR12

The station was located southwest of Beachport with the target being a canyon on the middle slope running SW with water depths between 1350 m and 1150 m. The south side of the canyon was sampled, seeking late Cretaceous and early Tertiary rocks. Five rock types were collected in the 50 kg sample, plus mud in the pipe dredge.

DR12/1 - a sandy mudstone to ferruginous sandstone suite (25% of sample). The sandstone was fine to medium-grained, brown, and quartz rich. The sandy mudstone was dark grey, and is almost certainly a facies equivalent of the sandstone. Some rocks had cores of black sandy mudstone, surrounded by rims of ferruginous material 2-3 mm thick. This rock suite contained no nannofossils.

DR12/2 - White chalk, firm, and bored (25% of sample). This sediment contained early Miocene coccoliths, and graded to sample DR12/3.

DR12/3 - chert or porcellanite (30% of sample). This sample ranged from pale grey to greenish grey in colour, and was also bored. Some rocks consist of altered calcareous mudstone rather than chalk. All of lithotypes DR12/2 and DR12/3 apparently belonged to one assemblage; however, DR12/3 contained coccoliths of both early-middle Oligocene, and late Oligocene age (in contrast to the age determination in DR12/2 of early Miocene).

DR12/4 - a soft white chalk (10% of sample) dated as late Oligocene.

DR12/5 - Brown to grey mudstone (10% of sample), dated as Late Quaternary.

DR12/6 - Light grey foram-nanno ooze was recovered from the pipe dredge - no age determination available, but probably late Quaternary.

In addition, the pipe dredge brought up colonial deepwater corals (some living), solitary corals, worms, paper-thin bivalves, and one deep-sea fish. The soft organisms and corals were forwarded to Wolfgang Zeidler of South Australian Museum.

Station DR13

The station was located off Discovery Bay, west of Portland, with the target being a canyon cut into possible Oligocene sediments, in water depths of from 1020 m to 500 m. No hard rock was recovered from the chain bag, but the pipe dredge contained two buckets of mud. No age determinations are available.

DR13A - olive grey very soft foram-nanno ooze.

DR13B - olive grey firm mud, cohesive, sandy, foram-nanno ooze. Probably bioturbated, as a worm was recovered from within the sediment.

Station DR14

The station was located south of Port Macdonnel; the target was the western side of a SSW trending canyon in water depths of 3050 m to 2450 m. Six rock types were recovered in the 40 kg chain bag sample; in addition to 10 kg of ooze and day in the pipe dredge.

DR 14/1 - White, bored, and bioturbated fine-grained chalk, containing chert nodules, and with pale green weathering surfaces (?ferrous oxide). This comprised 70% of the sample, and contained two distinct boring types: one of 1 cm - 2 cm diameter, and the other of 1 cm - 3 cm diameter. The inside of these boring tubes was often lined with a coating of manganese oxide. The sample contained late Oligocene, and early to middle Miocene coccoliths.

DR14/2 - Brown, relatively weathered (green as DR 14/1), grading through manganese dioxide to limonite) siltstone and claystone. This comprised 15% of the sample, and was often weathered to concretions with a 1 cm ferruginous layered rim enveloping a claystone core. No age data available on this sediment.

DR14/3 - One small piece of white foram-rich chalk, with some borings, and containing some shelly fragments.

DR14/4 - Grey hard tuff suite (10% of sample), varying from quartz rich, vitreous tuff to volcanogenic sandstone. This sample was further subdivided into collapsed pumice (A), volcanic sandstone (B), and tuff (C).

DR14/5 - One piece of hard, dense, dark-grey rock, with sandsized texture.

Consists of quartz in a fine matrix containing some sulphides (probably pyrite).

DR14/6 - One piece of hard, grey conglomerate, consisting of vein quartz pebbles in a quartzose matrix.

Soft material from the pipe dredge included:

DR14/7 - Grey (pale) foram-nanno ooze.

DR14/8 - White, soft calcareous clay, containing Miocene coccoliths.

Station DR15

The station was located south of Port MacDonnell, the target was Oligocene or older rocks in a canyon with water depths of 3120 m to 2500 m; the canyon appears to be associated with a major near-vertical fault. No rocks were recovered in the chain bag, but 5 kg of mud was recovered from the pipe dredge.

DR 15 - Grey and brown foram-nanno ooze.

Station DR16

The station was located south of Portland; the target was Eocene rocks on the upper continental slope, in water depths of 1450 m to 800 m. No rocks were recovered from the chain bag, but the pipe dredge contained 20 kg of mud.

DR16 - Light olive grey foram-nanno ooze; cohesive, firm, but unconsolidated, and with a minor silt fraction.

Station DR17

This station was located south of Portland, with the target being Tertiary rocks forming a small scarp on the eastern side of an old, infilled canyon on the middle slope. Water depths ranged from 2270 to 2060 m. There was no recovery from the chain bag, and the pipe dredge recovered only a small amount of gray clay (sample DR17).

Station DR18

This station was located southwest of Portland, with the target being Oligocene and older rocks in the lower section of a canyon on the middle slope. Water depths ranged from 1950 m to 1650 m. There was no recovery from the chain bag, but the pipe dredge recovered 15 kg of sample, including 2 kg of lithified material.

DR18/1 - a small amount (<1% sample) of moderately lithified, foram-bearing white middle Miocene chalk.

DR18/2 - soft white calcareous semi-lithified mud (ca. 50% of sample), containing middle Miocene nannoplankton.

DR18/3 - Pale brown, non calcareous, weakly lithified siltstone (ca. 50% of sample), dated as late Eocene to early Oligocene.

DR 18/4* - Unconsolidated light olive grey foram-nanno ooze, possibly Miocene.

DR 18/5 - One piece of dark grey lithified mudstone (<1% of sample).

DR18/5* - Soft olive grey calcareous mud.

*These unconsolidated muds were intermixed, and have not been counted in the lithified percentages.

Station DR 19

This station was located southwest of Nautilus A-1 well, on the middle slope. The target was pre-Oligocene rocks on a fault scarp/canyon wall, in water depths of 2625 m to 2250 m. No rocks were recovered from the chain bag, but 2 kg of sediment was recovered from the pipe dredge.

DR 19/1 - off white semi-consolidated chalky material,recovered from the jaws of the chain bag, probably a composite. Contained late Oligocene nannoplankton.

DR 19/2 - a few small pebbles of apparently non-calcareous pale brown, finely bedded mudstone.

DR 19/3 - plastic, pale grey, foram-nanno ooze.

DR 19/4 - soft, pale brownish grey, foram-nanno ooze; contained late Oligocene nannofossils.

Station DR20

This station was located southwest of Cape Otway, on a basalt high between Cape Otway and King Island (Gill, 1986). Target was basalt in 66 m of water

The chain bag dredge became ensnared and broke off at the designed weak link, so there was no recovery of sample.

Station DR21

This station was located west of King Island, with the target being a ridge of apparent Otway Group sediment near the abyssal plain, in 4580 m to 4155 m of water. The western side of this ridge was dredged; it appears to be associated with a major normal fault. About 20 kg of rock was recovered from the chain bag.

DR 21/1 - Massive moderate yellowish brown sandstone (80% of sample). Well sorted, medium grained, weakly lithified, micaceous, feldspathic, labile quartzose sandstone. Contains 2 mm - 3 mm diameter borings, and 1 mm - 2 mm maganiferous crusts, and 1 mm flecks of muscovite throughout. Bedding exists, but is indistinct.

DR21/2 - Well-bedded, thinly bedded, fine-grained, micaceous labile sandstone with mud clasts (20% of sample). Contains dark yellowish brown 1 mm - 2 mm manganiferous crusts, particularly in 1 cm diameter borings, and on surfaces. Contains clay lenses (with bedding draped over some), and abundant carbonaceous debris.

Both lithotypes are highly leached and weathered, and contain no visible fossils. These sandstones are almost certainly part of the Otway Group.

Station DR22

This station was located southwest of Cape Sorell; the target was possible Otway Group sediments on the lower continental slope, in 4200 m to 3909 m of water. There were no rocks recovered from the chain bag, but 1 kg of sample was recovered from the dredge mouth, and from within ooze in the pipe dredge.

DR22/1 - Small pieces of brown and grey siltstone, and very fine-grained micaceous sandstone (5% of semi - and lithified sample); possibly Otway Group.

DR22/2 - Tough, dark grey mud, recovered from chain dredge lip (80% of semi- and lithified sample).

DR22/3 - White, sticky foram-nanno ooze (19% of semi- and lithified sample).

DR22/4 - Pale olive brown nanno-foram ooze (samples DR22/1 and DR22/3 were contained within this ooze).

Station DR 23

This station was located southwest of Cape Sorell, in water depths of 4275 m to 4000 m. The target was possible Otway Group, in a ridge just above the abyssal plain. This ridge was the same as that sampled in DR22. DR22 sampled the southern side of the ridge; DR23 sampled the northern side. There was no recovery from the chain bag, but some 5 kg of ooze was recovered from the pipe dredge.

DR 23 - Brown, recent fine-grained foram-nanno ooze, oxidized. Sifted, but no rock fragments present.

PRELIMINARY REPORT ON GRAVITY CORES (C. Wilson)

Objectives

Fifty four gravity cores (Figs. 1 and 2) were taken with the objectives of sampling unconsolidated Quaternary and Tertiary sediments, and older more consolidated sequences where possible. Cores were split aboard ship for initial lithological description, nannofossil study (see Shafik, this volume), and geochemical analysis (see Heggie and McKirdy, this volume). Conductivity experiments were undertaken on selected cores for calculation of heat flow values (see Lee, this volume).

Position, water depth, core length and a brief description are given in Tables 4 and 5. A key to all the figures showing core logs is given in Figure 18.

Sampling method and description

TABLE 4: CORE STATIONS

Station	Latitude	Longitude	Water depth (m)	Seismic profile	Recovery (cm)	Description or comments
GC01	37°10.2'	138°35.8'	425	16/049 67/001	220	Greenish gray foram ooze.
GC02	37°23.9'	138°34.7'	1270	16/049	54	Greenish gray foram nanno ooze.
GC03	37°33.0'	138°35.0'	1476	16/049	310	Olive gray to greenish gray foram nanno ooze.
GC04	37°35.0'	138°35.0'	1526	16/049	184	Greenish gray foram nanno ooze; claystone.
GC05	37°45.5'	138°34.9'	2235	16/049	80	Olive gray foram nanno ooze, L. Eocene semilithified mud.
GC06	39°30.8'	139°57.7'	4590	48/043	263	Olive gray foram nanno mud; minor calcareous turbidites.
GC07	39°20.1'	139°59.2'	4120	48/043	287	Olive gray foram nanno mud.
GC08	39°02.2'	140°02.9'	3980	48/043	294	Olive gray foram nanno ooze and mud; ashy horizon 34 cm.
GC09A	38°57.1'	140°06.6'	3615	48/043	203	Olive gray foram nanno ooze and mud; ashy horizon 27 cm.
GC10	38°51.7'	140°06.1'	3332	48/043	374	Light olive gray foram nanno ooze; minor turbite; ashy horizon 25 cm.
GC11	38°45.0'	140°07.4'	3214	48/043	308	Olive gray foram nanno ooze and mud; ashy horizon 30 cm.
GC12	38°42.6'	140°07.1'	3150	48/043	10	Peat, ?Eocene. Corer tipped, young material washed out.
GC12A	38°42.6'	140°07.1	3133	48/043	306	Olive gray foram nanno ooze and mud; ashy horizon 35 cm.
GC13	38°27.9'	140°10.0'	2525	48/043	364	Olive gray foram nanno ooze; minor turbidites.
GC14	38°25.4'	140°09.9	2250	48/043	357	Olive gray foram nanno ooze; one minor turbidite.
GC15	38°22.9'	140°10.6'	1964	48/043	291	Olive gray foram nanno ooze; one minor turbidite.

Table 4 (cont.)

Station	Latitude	Longitude	Water depth (m)	Seismic profile	Recovery (cm)	Description or comments
GC16	38°20.0'	140°10.9'	1650	48/043	196	Olive gray foram nanno ooze.
GC17	38°17.2'	140°11.1'	1490	48/043	326	Olive gray foram nanno ooze; one minor turbidite.
GC18	38°11.6'	140°11.5'	1035	48/043	233	Olive gray foram nanno ooze.
GC19	38°07.2'	140°13.0'	345	48/043	176	Olive gray bryozoal sand to 28cm; mud below.
GC20	38°05.0'	140°14.36'	166	48/043	-	No recovery. ?bottom contact.
GC20A	38°05.2'	140°14.4'	166	48/043	-	No recovery. Bent pipe suggests sand.
GC21	37°59.4'	140°03.6'	315	48/042	232	Shelly muddy foram sand.
GC22	38°02.3'	139°58.0'	1003	48/042	319	Olive gray foram nanno ooze; one minor turbidite.
GC23	38°03.2'	139°55.9'	1146	48/042	277	Olive gray foram nanno ooze; minor turbidites.
GC24	38°35.1'	141°09.6'	392	48/007	184	Olive gray sandy calcareous ooze.
GC25	39°36.5'	141°10.5'	450	48/007	184	Olive gray sandy calcareous ooze.
GC26	38°37.9'	141°11.1'	469	48/007	224	Olive gray sandy calcareous ooze, minor coarse bed.
GC27	38°38.9'	141°11.5'	506	48/007	225	Olive gray foram nanno ooze, minor coarse bed.
GC28	38°40.1'	141°12.5'	545	48/007	248	Olive gray foram nanno ooze, minor coarse bed.
GC29	39°34.0'	142°59.0'	240	40/022	364	Olive gray shelly carbonate ooze over olive shelly mud.
GC30	39°35.0'	142°57.4'	558	40/022	145	Olive calcareous ooze over greenish gray clay.

Table 4 (cont.)

Station	Latitude	Longitude	Water depth (m)	Seismic profile	Recovery (cm)	Description or comments
GC31	39°36.0'	142°57.0'	829	40/22	296	Gray foram nanno ooze over olive gray calcareous ooze.
GC32	39°40.1'	142°54.7'	1244	40/22	93	Olive gray muddy foram nanno ooze.
GC33	39°45.5'	142°52.0'	1433	40/22	270	Olive gray foram nanno ooze.
GC34	39°47.7'	142°48.8'	1630	40/22	287	Gray foram nanno ooze, with 2 carbonate sand turbidites.
GC35	39°54.8'	142°44.2'	2280	40/22	144	Light olive gray foram nanno ooze, containing E-M Miocene mudstone slump.
GC36	40°00.9'	142°40.1'	2182	40/22	259	Gray foram nanno ooze.
GC37	40°14.1'	142°25.2'	3090	40/23	275	Gray foram nanno ooze, with 3 carbonate sand turbidites.
GC38	40°27.9'	142°04.9'	3850	40/23	194	Gray foram nanno ooze, with 2 carbonate sand turbidites.
GC39	40°37.9'	141°50.1'	4300	40/23	135	Olive gray foram nanno ooze, with one sand turbidite, over L. Oligocene green clay.
GC40	40°41.5'	141°46.4'	4370	40/23	62	Gray foram nanno ooze over E. Miocene olive brown calcareous clay.
GC41	40°43.8'	141°42.4'	4645	40/23	190	Two thick calcareous turbidite sequences, above multi-coloured pre Quaternary clays.
GC42	40°49.6'	141°48.8'	4161	40/23	84	Light gray foram nanno ooze, over yellow to reddish mottled gypsiferous clay (soil profile).
GC43B	42°17.8'	142°51.7'	4830	Sonne 46	2	Light olive gray v.c. gritty bryozoal sand.
GC44	42°14.8'	142°31.6'	4103	Sonne 46	146	Greenish gray foram nanno ooze, with 4 carbonate sand turbidites.

Table 4 (cont.)

Station	Latitude	Longitude	Water depth (m)	Seismic profile	Recovery (cm)	Description or comments
GC45	42°13.6'	142°52.5'	3715	Sonne 46	360	Gray and greenish gray foram nanno ooze.
GC46	42°12.1'	144°24.8'	2360	Sonne 46	176	Greenish gray foram nanno ooze, over calcareous sand turbidite, over soft light gray chalk.
GC47	42°10.6'	144°40.9'	765	Sonne 46	134	Gray foram nanno ooze, with 4 carbonate sand turbidites.
GC48	42°10.8'	144°44.3'	377	Sonne 46	190	Olive gray mixed c. bryozoal sand and foram nanno ooze.
GC49	41°31.4'	144°20.3'	838	16/015	294	Olive gray bryozoal sand, foram sand and foram nanno ooze.
GC50A	41°30.5'	144°17.4'	1081	16/015	169	Gray foram nanno ooze.
GC51	41°31.2'	144°13.1'	1557	16/015	127	Greenish gray foram nanno ooze.
GC52	41°10.9'	143°57.5'	1145	16/017	175	Olive foram nanno ooze.
GC53	41°10.9'	143°55.4'	1367	16/017	166	Olive gray foram nanno ooze.
GC54	41°10.9'	143°50.2'	1634	16/017	97	Olive gray foram nanno ooze, over hard greyish olive mudstone.

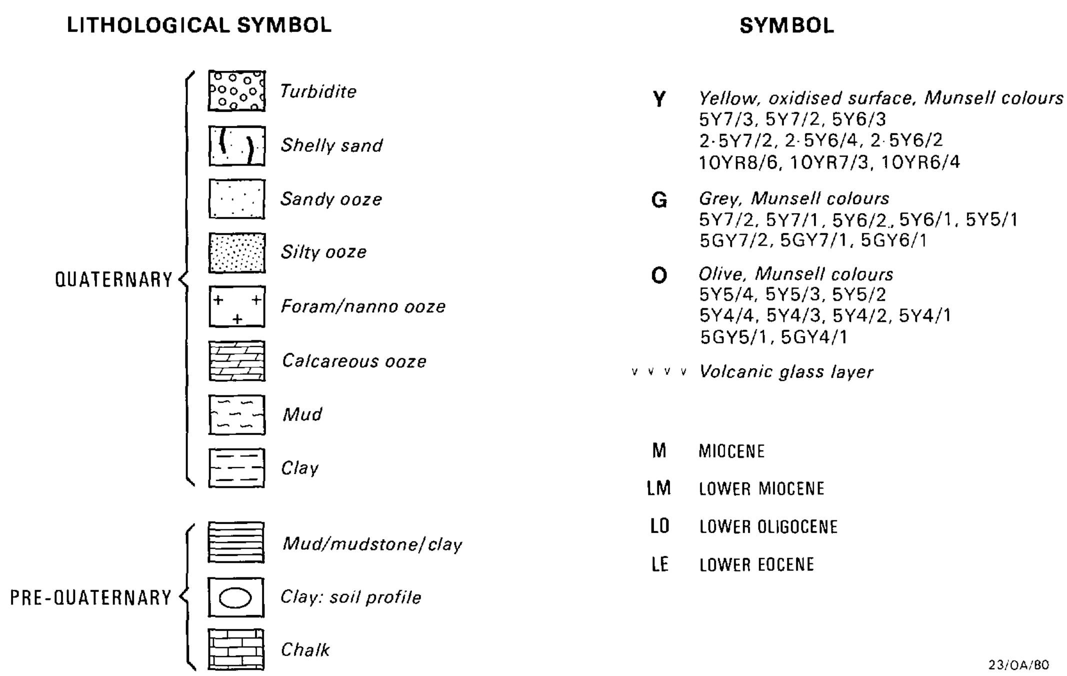


Fig. 18. Key to all core logs.

Table 5 : Core Descriptions

STATION	RECOVERY (CM)	COMMENTS
GC01	220	80 cm greenish grey foram/nanno ooze, over greenish grey fine sandy and silty muds.
GC02	54	Greenish grey muddy foram/nanno ooze.
GC03	310	Olive grey to greenish grey foram/nanno ooze.
GC04	184	130cm greenish grey foram/nanno ooze, over a blueish grey laminated claystone. Possible glass layer at 144-147cm.
GC05	80	Olive grey foram/nanno ooze over semi-lithified, olive grey, l. Eocene mud.
GC06	263	Olive grey nanno/foram mud. Minor calcareous turbidite. Possible glass layer at 111-112 cm.
GC07	287	Banded olive grey oozes and muds. Glass layer at 66-68cm.
GC08	294	Olive grey and greenish grey foram/nanno oozes and muds. Glass layer at 34cm.
GC09A	203	Olive grey and greenish grey foram/nanno oozes and muds. Minor calcareous turbidites. Glass layer at 27cm.
GC10	374	Light olive grey foram/nanno ooze. Minor calcareous turbidite. Glass layer at 25cm.
GC11	308	Light greenish grey and grey foram/nanno ooze and mud. Thin calcareous turbidites. Glass layer at 30cm.
GC12	10	Eocene peat.
GC12A	306	Olive grey and greenish grey foram/nanno ooze and mud. Glass horizon at 35cm.
GC13	364	Olive grey foram/nanno ooze. Minor calcareous turbidites.
GC14	357	Olive grey and greenish grey foram/nanno ooze. Minor calcareous turbidite.
GC15	291	Interbedded light olive grey and greenish grey foram/nanno ooze. Minor turbidite.
GC16	196	Olive grey and greenish grey foram/nanno ooze.
GC17	326	Olive grey and greenish grey foram/nanno ooze. Minor turbidite.
GC18	233	Olive grey foram/nanno ooze.
GC19	176	28cm olive grey brozoal sand over olive grey mud.
GC20		No recovery.
GC20A		No recovery.
GC21	232	Olive grey shelly, muddy, fine calcareous sand.
GC22	319	Olive grey foram/nanno ooze. One minor calcareous turbidite.
GC23	277	Olive grey foram/nanno ooze. Minor calcareous turbidites.
GC24	184	Olive grey sandy calcareous ooze.
GC25	184	Olive grey sandy calcareous ooze.
GC26	224	Olive grey sandy calcareous ooze. Thin coarse bioclastic bed at 114-117 cm.
GC27	225	Olive grey foram/nanno ooze. Minor bioclastic bed at 188-192cm.

GC28	248	Olive grey foram/nanno ooze. Coarse shelly unit at 178-190cm.
GC29	364	71cm olive grey shelly carbonate ooze over shelly mud.
GC30	145	28cm olive grey sandy calcareous ooze over a firm greenish grey clay.
GC31	296	Sandy olive grey foram/nanno ooze over olive grey calcareous ooze.
GC32	93	Olive grey muddy foram/nanno ooze.
GC33	276	Olive grey and greenish grey muddy foram/nanno mud.
GC34	287	Light olive grey and greenish grey foram/nanno mud. Two calcareous sand turbidites.
GC35	144	Light olive grey foram/nanno ooze containing Miocene mudstone slump.
GC36	259	Grey and greenish grey foram/nanno ooze.
GC37	275	Greenish grey foram/nanno ooze. Three carbonate sand turbidites.
GC38	194	Greenish grey foram/nanno ooze. Two carbonate sand turbidites.
GC39	135	Olive grey foram/nanno ooze with one sand turbidite.
GC40	62	Grey foram/nanno ooze over olive brown, Oligocene calcareous clay.
GC41	190	Two thick calcareous turbidites over multicoloured Miocene clays.
GC42		Light grey foram/nanno ooze, over yellow to reddish mottled gypsiferous clay (soil profile).
GC43B	2	Light olive grey, gritty bryozoal sand.
GC44	146	Greenish grey, muddy foram/nanno ooze. Four carbonate sand turbidites. Possible glass layer at 40cm.
GC45	360	Grey and greenish grey foram/nanno ooze.
GC46	176	93cm greenish grey foram/nanno ooze, over 7cm calcareous sand turbidite, over light greenish grey chalk.
GC47	134	Greenish grey foram/nanno ooze. Four carbonate sand turbidites.
GC48	190	Olive grey shelly, bryozoal sand.
GC49	294	Olive grey bryozoal sand, foram sand and foram/nanno ooze.
GC50A	169	Olive grey and greenish grey, foram/nanno ooze.
GC51	127	Greenish grey, foram/nanno ooze.
GC52	175	Olive foram/nanno ooze.
GC53	166	Olive grey, foram/nanno ooze.
GC54	97	Olive grey, foram/nanno ooze, over hard olive grey mudstone.

Unconsolidated sediment was recovered using a gravity corer consisting of a 1200kg weight, and 3-5m core barrels using 90mm liners. Penetration into semi-consolidated/consolidated sediment proved difficult, often resulting in poor penetration and bent core barrels. However, these sediments were usually pre Quaternary, such that even with limited recovery, the data collected were extremely important.

In some cases the core liner was fitted with a flapper valve to trap bottom waters for geochemical analysis.

Cores were divided into one metre lengths using a hand saw, and then split using a frame mounted power saw. Cores were labelled with a cruise number (67), a site number (i.e. GC08), a section interval measured in cm's from the top of the core (i.e. 100-134cm) and a core letter designating the sequence of the sections (i.e. CC or core catcher). In addition yellow tape was secured around the lower half of each section. Cores were stored in their liners in plastic bags at a temperature of 4 degrees C.

Cored material was described by lithological unit, following the sediment classification of the DSDP, (after JOIDES 1974), and colour variations were matched against a Munsell colour chart. The positions of nannofossil, geochemical and smear slide samples were recorded on the log.

Presentation of the data

A twofold approach was used in interpretation and presentation of the data. Cores from the same region (i.e. along the same or related seismic profiles) were arranged sequentially according to depth. Units wherever possible were correlated to give geological sections along a depth profile. This allowed general trends to be observed and interpreted.

The problems with this approach arise primarily from the different styles of shipboard interpretation of the various geologists describing the cores. Cross-sections were thus constructed in a broad sense. Obvious lithologies, such as the surface oxidised layer proved easy to separate. The oozes however, proved difficult to correlate as variation in colour and lithology were often slight. Distinction of units was therefore limited to a simple twofold division, primarily by colour. Colour units were chosen to separate the lighter bands (generally grey/greenish grey), from the darker (olive to dark greenish grey), and although this represents a somewhat artificial division, a more detailed approach would be unrealistic after such preliminary studies.

Cores figured show either a typical profile or some anomalous feature.

Northwest part of western Otway Basin

The north-western Otway region is represented by the five samples GC01-05, taken along the seismic profile 16/049. The geological cross-section (Fig. 19), represents a transition from outer shelf (GC01), to mid slope (GC05).

The outer shelf sample (GC01), is dominated by bioturbated greenish grey, calcareous silty muds and fine sands. Detrital mica grains are common. Moving southwards downslope the sand and silt fraction is rapidly lost, and the cores become dominated by calcareous oozes. There is an associated change from the

Fig. 19. Cores GC01-5, on BMR seismic line 16/049, west of Beachport. Refer to Fig. 18 for key.

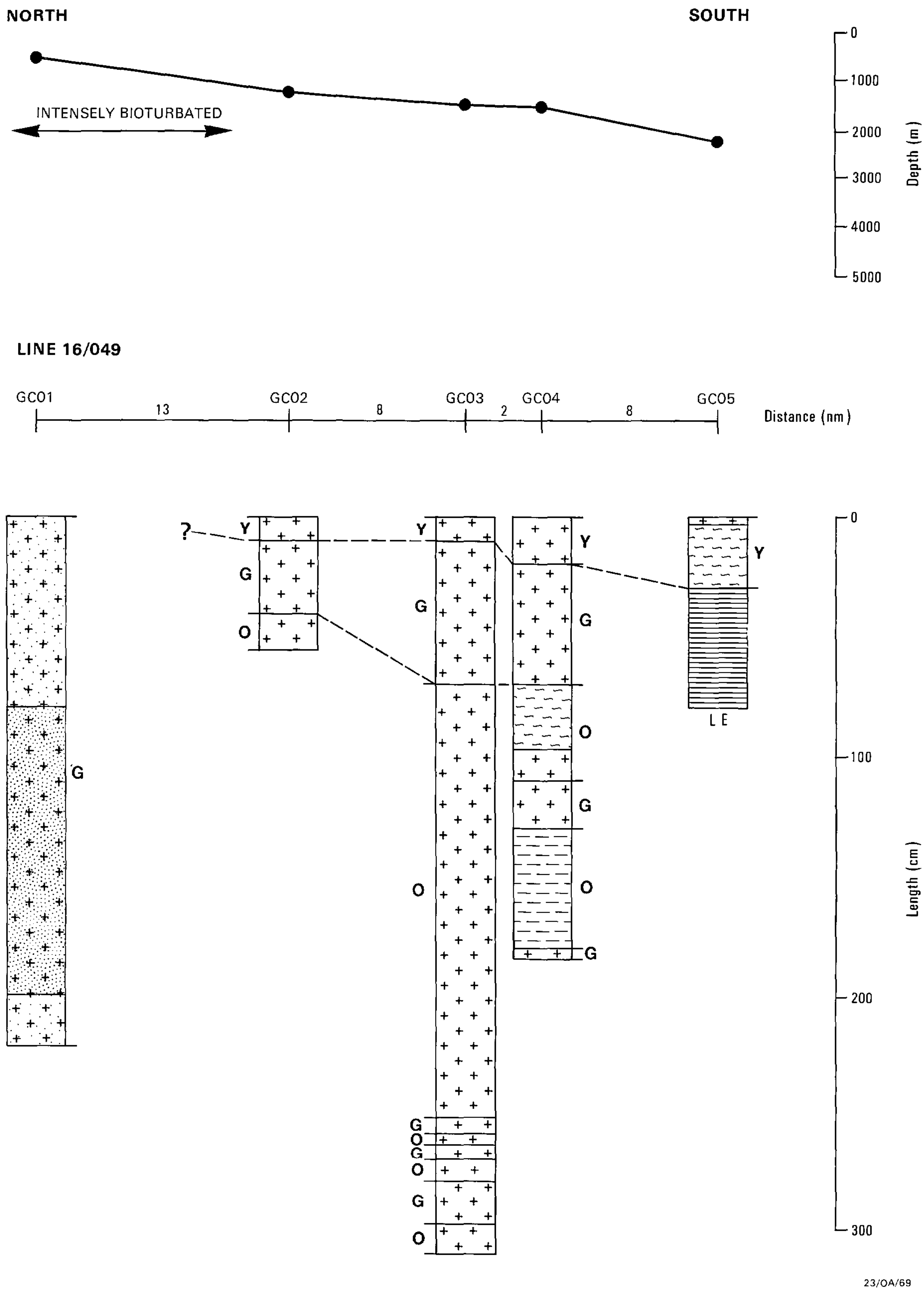
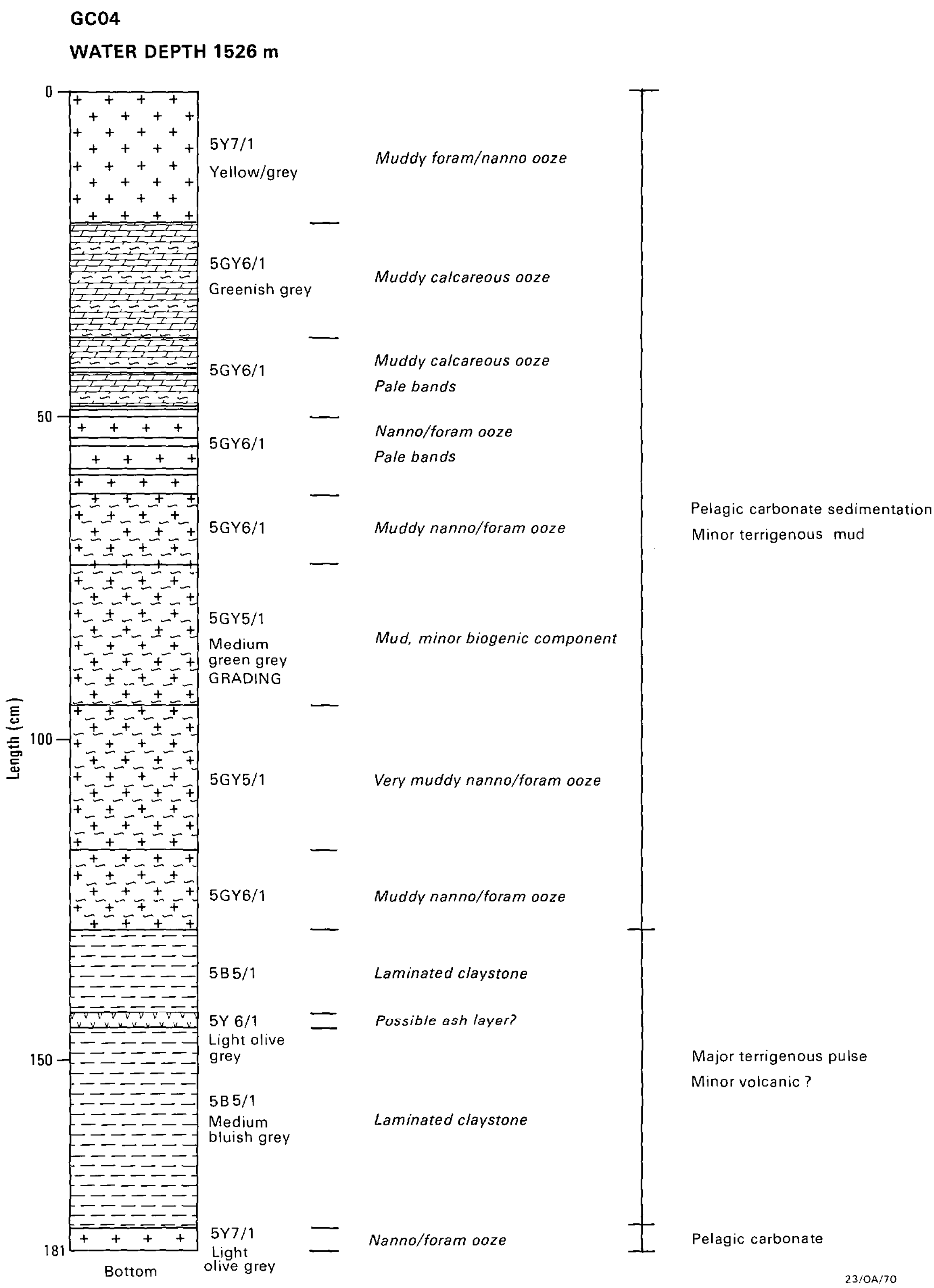


Fig. 20. Detail of upper slope Core GC04, west of Beachport.



intensly bioturbated, banded units of the slope. Typically the slope profiles show an alternation between lighter greenish grey and darker olive green units. Lithological variation is slight.

GC04 contains an atypical claystone (Fig. 20). The upper 130 cm is dominated by muddy foram/nanno oozes, showing typical colour banding. Variation is slight and preservation largely due to limited bioturbation. This overlies an anomalous olive grey claystone with a possible ash band. It is taken to represent a terrigenous dominated period of sedimentation, contrasting with a terrigenous free, pelagic carbonate phase, represented by foram/nanno oozes.

GC05, a light yellowish brown nanno/foram ooze, overlies a late Eocene, olive grey mud.

Western Otway Basin

The western Otway Basin region is represented by the samples GC06-GC19, along the seismic profile 48/043, and GC20-GC23, along the profile 48/042. The geological section, (Fig. 21, at back of report) records the transition from outer shelf (GC19, 21) to the abyssal plain (GC06).

The shelf samples are dominated by extensively bioturbated skeletal sands (bryozoal, foraminiferal and pelecypod). Rapid deposition and bioturbation have destroyed most internal structure resulting in thick homogenous, olive grey units (Fig. 22). South down the slope the sand fraction is rapidly lost and foram/nanno oozes dominate. Lithological change is accompanied by a change from intensely bioturbated units, to those displaying *Zoophycos* type and unidentified burrows, which give the sediment a mottled appearance. Bioturbation is lacking in the deepest cores (GC06-08), and internal banding is present. Lithological variation between the bands is slight (the darker bands appear to contain slightly more clay than the lighter bands), and recognition is primarily on alternation of colour. In the deepest cores banding is cyclic and may represent climatic or other long-term cycles.

A thin turbidite unit occurs at a similar depth in several cores and a tentative correlation is made. It may thus represent a chronostratigraphic unit. It is overlain by increasingly less sediment in the deeper water cores, reflecting slower rates of sedimentation towards the abyssal plain. Its absence in GC07 and GC08, but the presence of four turbidite events in GC06 from the base of the slope, suggest a different source area or the possible effect of contour currents.

A thin brown or green horizon, present in the upper parts of cores 06-12A may represent a volcanic glass horizon and is thus potentially dateable.

An oxidized surface layer appears first at a water depth of 1490m (GC19), and increases in thickness downslope. Its absence above 1500m may relate to the oxygen minimum zone.

The lower sections of GC06-GC08, and GC12A, GC13, are dominated by olive and greenish grey muds. This unit becomes more important in the deeper cores. It is suggested that the muds may represent a terrigenous dominated phase of sedimentation (see Fig. 20), in contrast to the overlying carbonate dominated phase, or may relate to leaching of carbonate below the CCD.

Fig. 22. Detail of homogenous outer shelf core GC021, from south of Beachport.

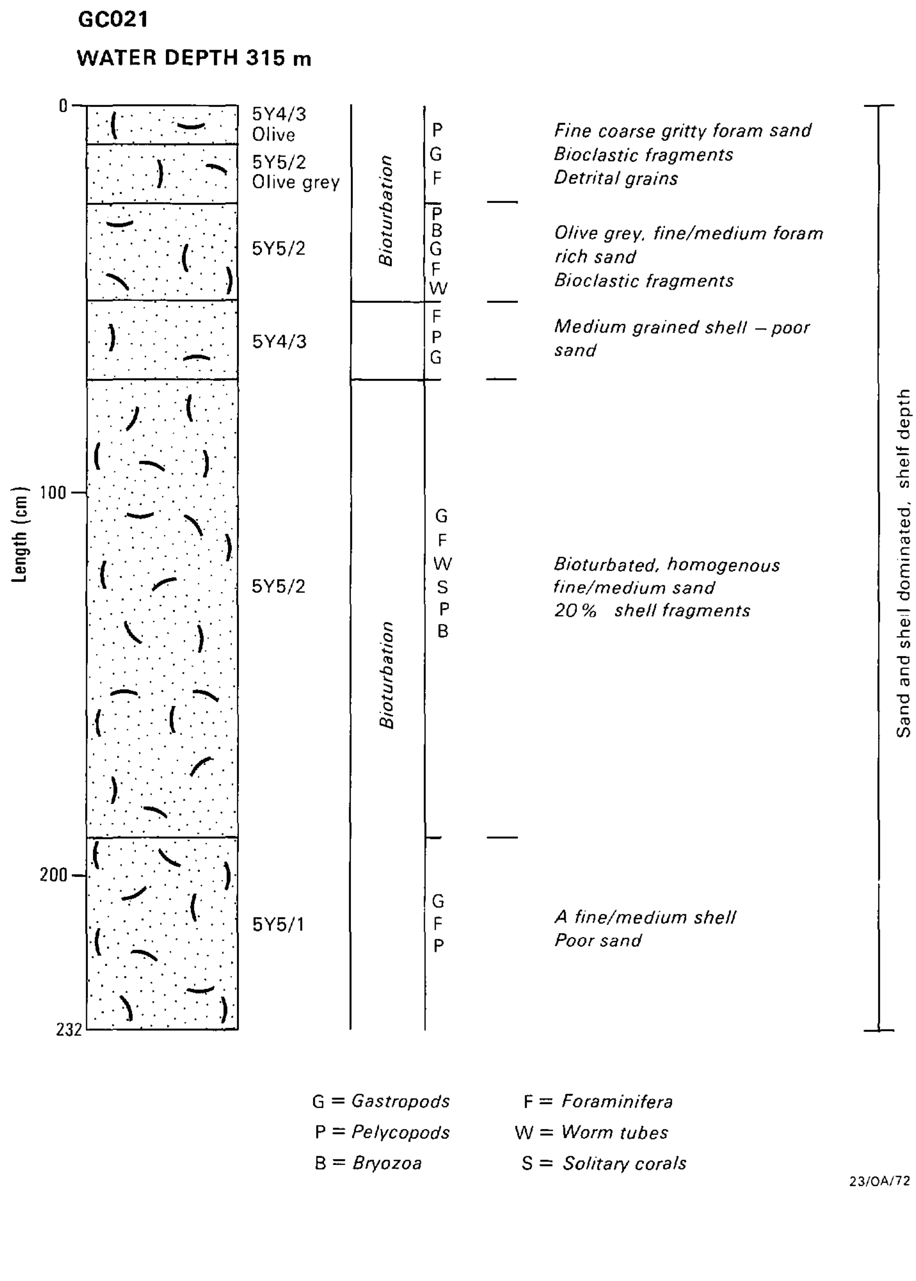
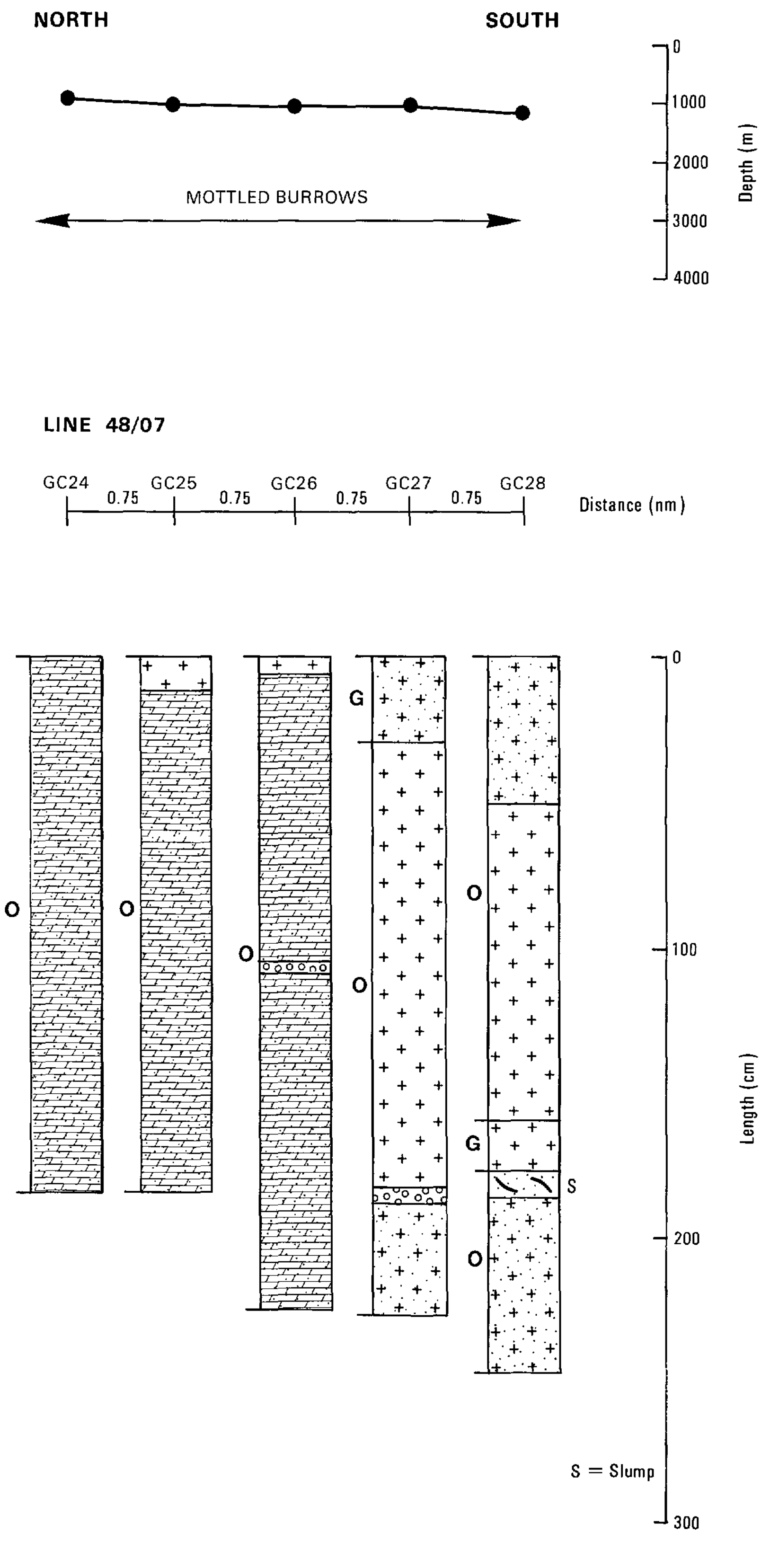


Fig. 23. Upper slope cores GC24-28 on BMR seismic line 48/007 south of Portland.



GC12 recovered 10cm of peat, of assumed Eocene age.

Mid Otway Basin

This region is represented by GC24-GC28, along the seismic line 48/007. All cores are from the region of the outer shelf (Fig 23). Sedimentation is dominated by fine sandy oozes and bioturbation is extensive, such that internal banding is rare. GC24 and GC25 contain a homogenous unit almost two metres thick.

The surface oxidized layer is absent, suggesting all cores exist within the oxygen minimum zone.

Eastern Otway Basin

The eastern Otway basin is represented by GC29-GC41, along the seismic profile 40/022-23, and GC42, along the line 40/024. The geological section (Fig. 25) shows a transition from outer shelf to abyssal plain.

The shallowest core (GC29), records a relatively high-energy style of sedimentation and is dominated by olive grey shelly muds and oozes. The shelly component is typically shelf derived bryozoal, coral, pelecypod, and gastropod fragments up to 1cm diameter, which together make up 20-30 percent of the unit. The shelly material rapidly decreases downslope and GC30-GC31 are typically olive and olive grey, fine sands and fine sandy calcareous oozes. These cores are extensively bioturbated, resulting in thick homogenous units. Further downslope (GC32-42) pelagic foram/nanno oozes dominate. Bioturbation changes to *Zoophycos* and mottled and small sulphide burrows below about 1000m, and this change is accompanied by an increase in the internal banding of the deeper cores. Variation between bands is slight and marked primarily by alternation between olive green and light greenish grey oozes. However, GC41 is unusual in that banding shows obvious lithological variation (see fig 25). Greenish grey pelagic clays alternate with foraminifera/nannofossil oozes and may be climatically controlled.

The volcanic glass layer recognized in profile 48/043 is generally absent, except for two thin bands close to the top of GC27 and at a depth of 110cm in GC41.

The oxidized surface layer, as with other profiles, thickens downslope into deeper water, and it's absence in GC31 relates to the position of the oxygen minimum zone.

GC30 (see fig 24, at back of report), consists of an upper olive grey, sandy calcareous ooze, which passes sharply downwards into a firm, dark, greenish grey clay. This contrasts with the calcareous dominated sedimentation of surrounding cores and represents a terrigenous-dominated phase. The clay is burrowed at its upper surface.

GC35 (see fig 24) contains a 20cm thick unit of a medium grey ooze in which grey, calcareous, e-m Miocene mudstone clasts were found. Glauconitic siltstone pebbles up to 3mm long suggest an original shelf origin.

GC39 (see fig 24) consists of an upper banded greenish grey and olive grey

Fig. 25. Detail of continental rise core GC041 taken west of King Island, showing unusual lithological variation.

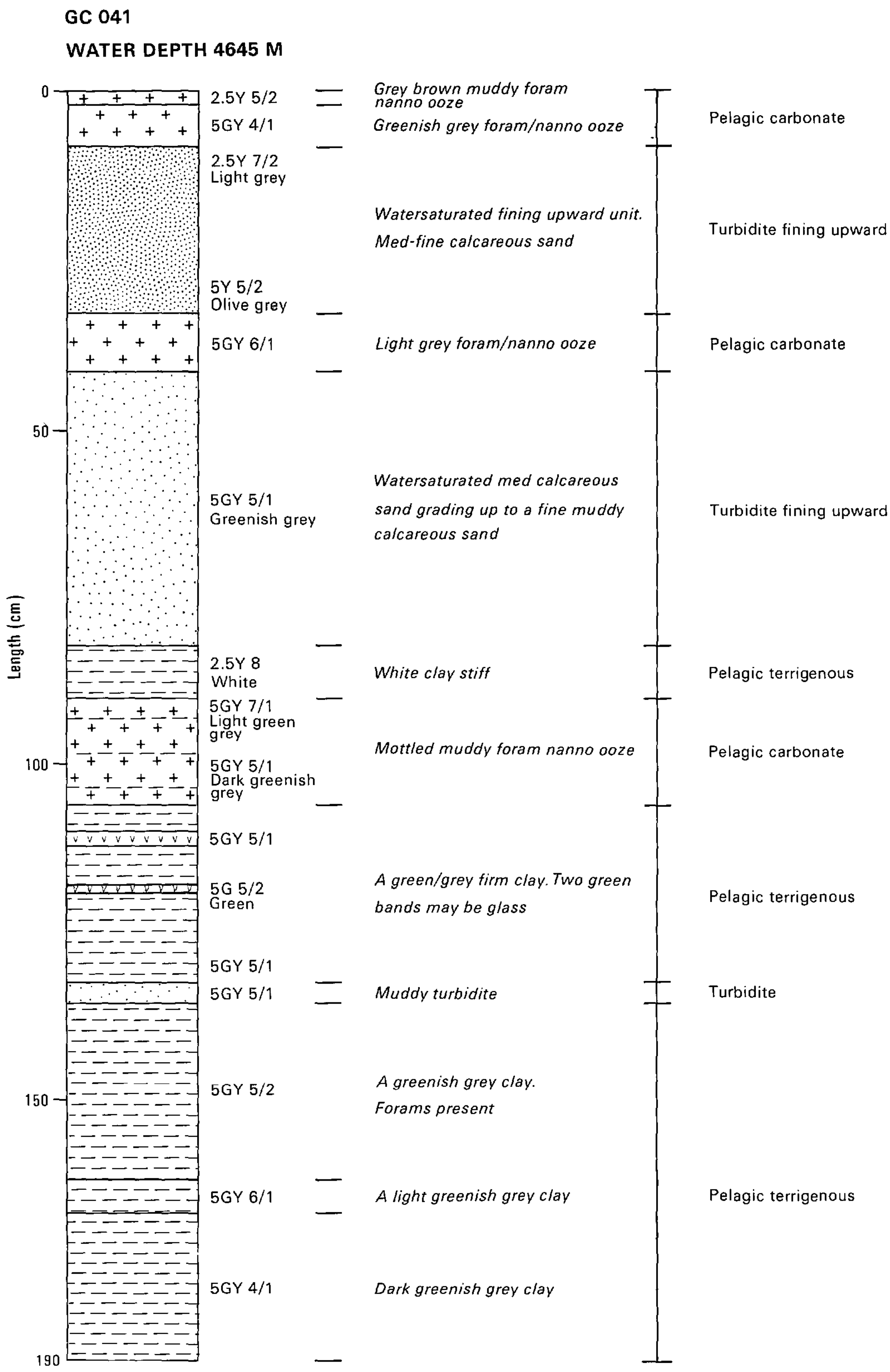
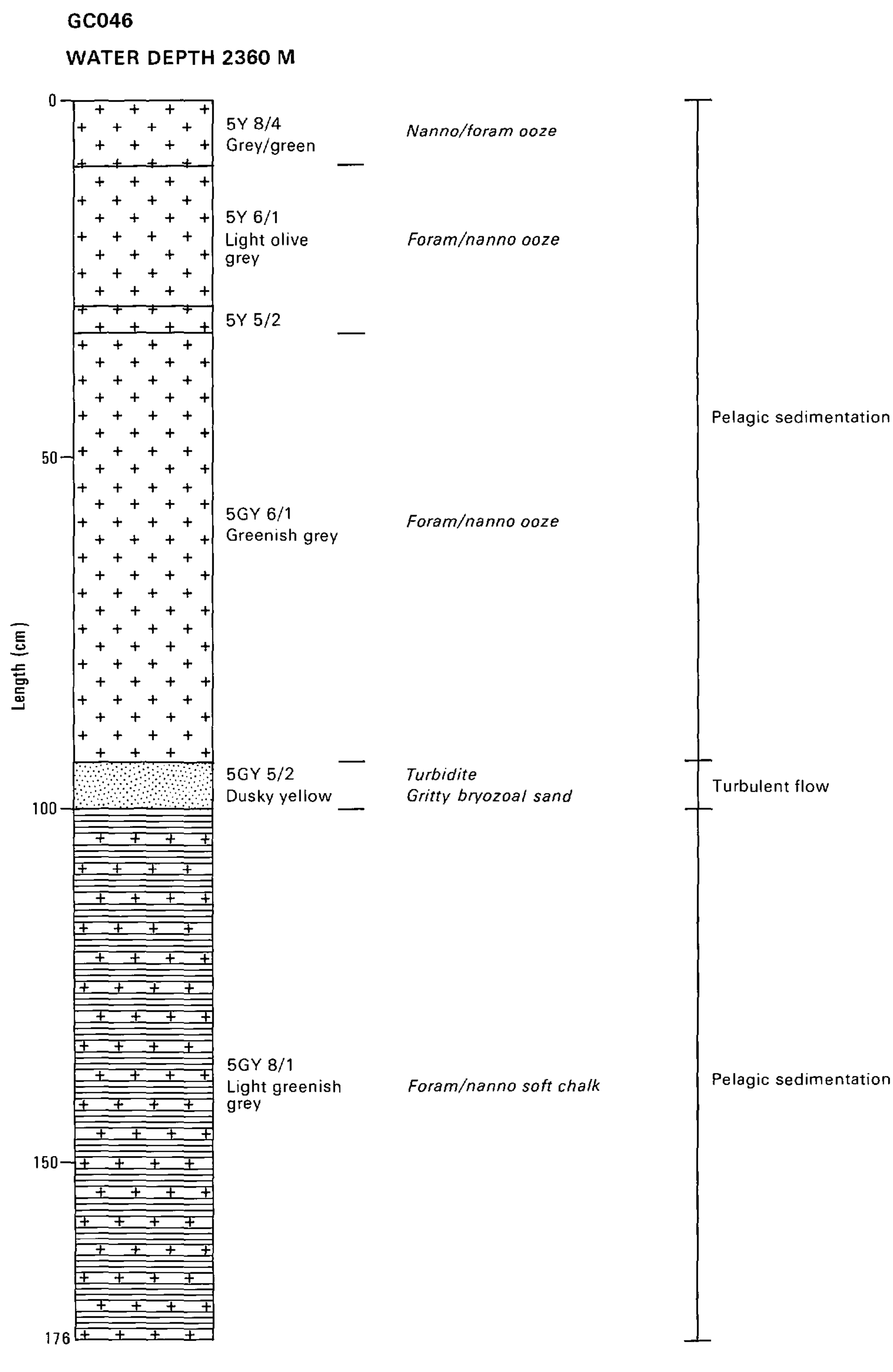


Fig. 27. Detail of Core GC046 from the mid-slope west of Cape Sorell.



foram/nanno ooze, overlying a coarse sand containing rounded basalt granules. This unit in turn overlies a stiff green clay of late Oligocene age. It seems likely that erosion of the slope exposed Miocene clays to Quaternary sedimentation.

GC41 (see fig 25). This core consists of two thick calcareous turbidite units which pass sharply into well bedded, multicoloured, possibly pre-Quaternary clays. Cyclic alternation of clays and calcareous oozes may be climatically related.

GC42 (see fig 24). A light grey, soft foram/nanno ooze overlies a yellow to reddish, mottled gypsiferous soil profile. Its presence in over 4000m of water has important implications for the subsidence of the margin.

West Tasmanian region

Three profiles were successfully cored off west Tasmania, and are dealt with individually as regions A, B and C.

Region A, is represented by cores 44-48, along the "Sonne" seismic profile 46. Fig 26 (at back of report) represents a section from mid shelf (GC48), to lower slope (GC44).

GC48, at a water depth of 377m, consists entirely of an olive grey, shelly sand, extensively bioturbated such that if forms a thick (190cm), homogenous unit. Pelecypod, coral and bryozoal fragments are the dominant components of the shelf fraction.

The shell and sand component rapidly disappear downslope, and the cores become dominated by foram/nanno oozes. Calcareous turbidite units up to 20cm thick are present, but are not correlateable. The deepest cores are poorly bioturbated and internal banding becomes more important. Lithological variation is slight and banding marked by alternation of light greenish grey and darker olive green units.

A weakly developed glass layer is present below a thin, calcareous turbidite in GC44.

The surface yellow brown, oxidized layer, as with other profiles, thickens downslope to reach a maximum of 30cm in GC44.

GC46 (see fig 27). 93cm of a greenish grey, foram/nanno ooze overlies a thin bryozoal sand turbidite, which in turn overlies a light greenish grey chalk.

Region B consists of GC49-GC51, samples along the seismic profile 16/015. The geological section, fig 28, shows a transition from outer shelf to mid slope. The outer shelf sample, GC49, consists of skeletal bryozoal sands and olive grey sandy oozes, typical of other outer shelf samples. It is extensively bioturbated and thick homogenous units dominate the core. The sand/shell fraction disappears rapidly downslope and greenish grey foram/nanno oozes dominate.

Region C is represented by GC52-GC54, along the profile 16/017. The cores are typical of the mid/upper slope region and are characteristically banded grey and olive grey oozes, (see fig 29).

SUMMARY AND CONCLUSION

Pre-Quaternary units.

Pre-Quaternary sediments were recovered from several cores.

Eocene sediment (GC5/GC12), represents a terrigenous dominated phase of sedimentation. The peat recovered from GC12 is inferred to be part of a mid Eocene to mid Oligocene unit recorded in DSDP holes 280/282, and "SONNE" cores SO36/22SL and SO36/30KL. Olive brown, calcareous clay of Oligocene age may be part of the same formation.

Miocene sediments are represented by multicoloured clays (GC41), and slumped glauconitic, mudstone clasts (GC35).

Quaternary

Quaternary sediments, dominated by calcareous sands and foram/nanno oozes, were deposited throughout the area. From plotted geological cross-sections, trends in shelf to abyssal plain sedimentation were established and a model of sedimentation along this margin is proposed.

Trend from shelf to abyssal plain

1). Lithology changes rapidly from outer shelf shelly sands and sandy oozes to slope and abyssal plain foram/nanno oozes.

2). Thin calcareous turbidites, generally absent on the shelf, are found in slope and abyssal plain cores. A thin turbidite is tentatively correlated in profile 48/043 (Fig 21), and is overlain by a decreasing amount of sediment downslope, suggesting slower rates of deposition towards the abyssal plain.

3). A yellow brown surface-oxidized layer, generally absent in the outer shelf cores, increases in thickness downslope. Its presence is related to oxygen-enriched cold bottom waters.

4). A thin green or brown band present in many cores is probably a volcanic glass layer and is thus potentially dateable.

5). Cores from the shelf consist of thick bioturbated, homogenous units. Internal banding becomes more important downslope, as bioturbation decreases. Lithological variation between bands is generally slight (except GC4), and is recognised by alternation between light greenish grey and darker olive green colours. The banding is probably cyclic and may be climatically related.

6). The style of bioturbation changes with water depth. Outer shelf cores are extensively bioturbated and preserve little internal structure. Below about 1000m bioturbation decreases and internal banding becomes increasingly preserved. Sediments are generally mottled with infilled horizontal *Zoophycos* type and unidentified burrows. *Zoophycos* seems restricted to 1000-2500m. Below about 4000m mottling is absent and the only evidence of bioturbation is the presence of small (1mm diameter), sulphide filled burrows.

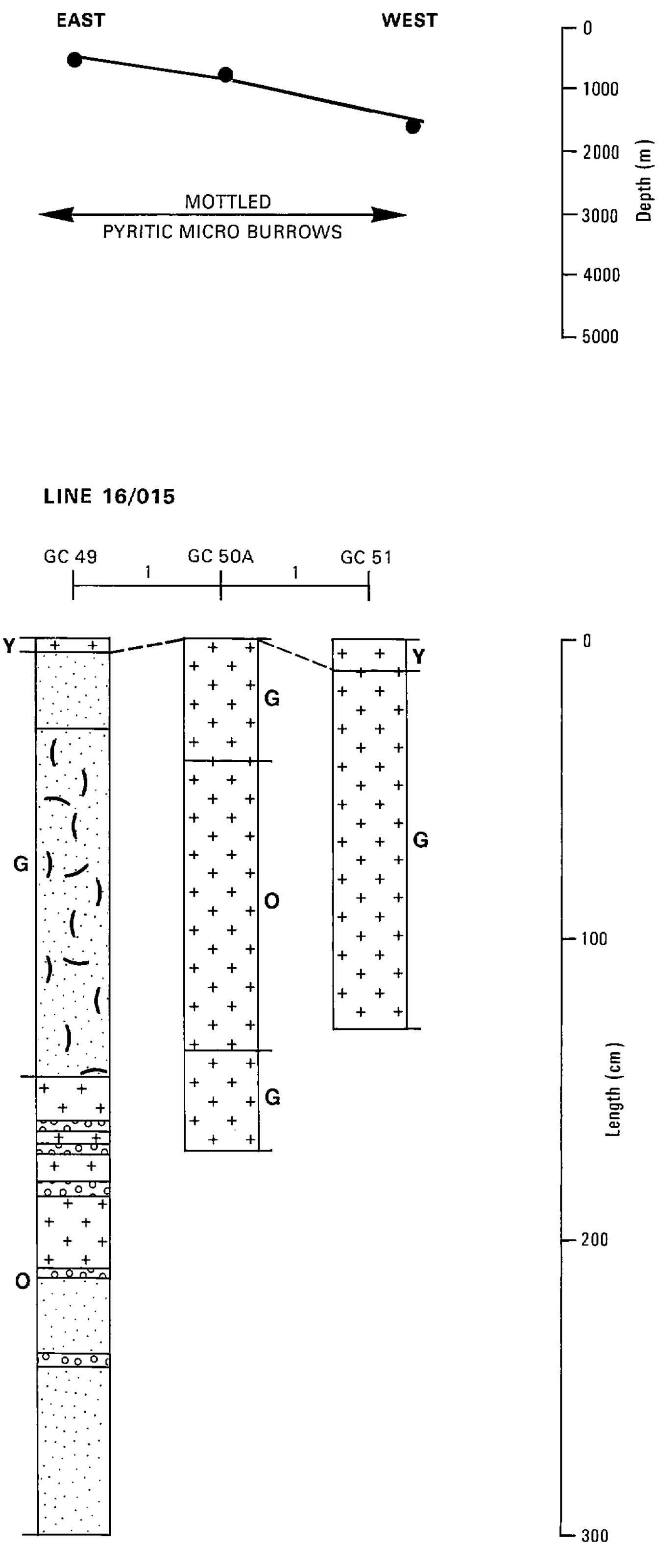


Fig. 28. Cores GC49-51 on BMR seismic line 16/015 off northwest Tasmania, on outer shelf and upper slope.

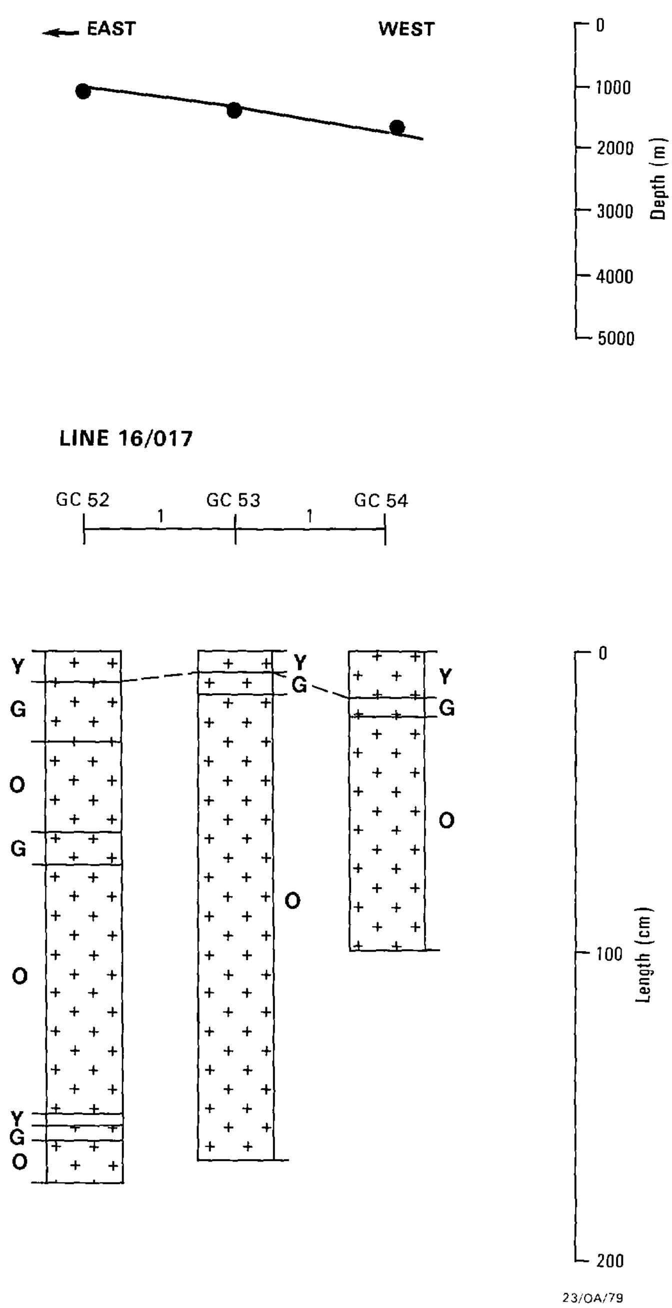


Fig. 29. Cores GC52-54 on BMR seismic line 16/017 off northwest Tasmania, on upper slope. GC54 is late Oligocene at base.

Model of sedimentation

Shelf areas are characterized by relatively high energy, shelly bryozoal sands and fine sandy oozes. These sediments are dominantly calcareous and are most likely sourced by a mid to outer shelf "carbonate factory", dominated by bryozoa, pelecypods, gastropods and benthic foraminifera. Bioturbation by a relatively large infauna is extensive, and thick homogenous units are common. Shelf sands periodically move downslope as turbiditity currents, but their contribution to overall slope and abyssal plain sedimentation is generally slight.

Slope and abyssal areas are dominated by pelagic carbonates, typically olive grey and greenish grey, foraminifera and nannofossil oozes. Terrigenous clays and muds, sourced from coastal areas, are present, but only in small amounts. Small variations in the terrigenous component appear cyclic, and may be climatically controlled. Bioturbation decreases downslope, and the cores are typically banded.

Recent volcanic eruptions, possibly in the Mount Gambier region, shed fine glass layers over the area of sedimentation sampled on this cruise.

GRAB SAMPLES (N.F. Exon)

It was important to have shelf samples, as part of the profiles from shelf to deep water, in the search for themogenic gas, and to a minor extent in the search for phosphate.

It had been hoped that the vibrocorer could be used at key shelf stations, but it proved too difficult to deploy. The gravity corer was used on the outer shelf at station GC20, where the water depth was 166 m, but got no penetration in sandy bottom. The corer was successfully deployed in water depths of more than 300 m, where sands were generally fine-grained or muddy. The dredge was used at one shelf station but was too cumbersome for widespread use in shallow water.

Because of the lack of reasonable alternatives the van Veen grab was deployed, from the hydrographic winch, at almost all shelf stations. It was successful at virtually all stations, only failing where there was hard outcrop at the sea bed. Altogether it was used at 33 stations, in water depths of 34 to 450 m, with the bulk of stations in depths of 60 to 200 m (Table 6). Their locations are shown in Figures 1 and 2, and a brief description of natural groups of samples follows.

Ten grab samples (GS2-10) were taken in shallow water (20-204 m) on seismic profiles 48/042 and 48/043, south and southwest of Lake Bonney near Argonaut No. 1 well off South Australia. Those in the shallowest water (5 & 6) showed that there was rocky bottom, covered in kelp and sponges - probably Miocene limestone. Beyond this, in water depths of 67-123m, was coarse brownish bryozoal sand and grit (3, 4, 7, 8, 9), containing various subordinate quantities of sponges, gastropods, pelecypods, algae, echinoids solitary corals, and encrusting serpulids. Quartz and rock fragments were virtually absent. The two deepest samples (2A, 10) are somewhat fine grained and consist of abraded fragments of the same organisms, with a smaller proportion of bryozoa.

Nine samples (GS15-23) were taken in water depths of 50-100 m south of Port MacDonnell, in an area where propane anomalies had been recorded in the wate column and gas plumes identified by sidescan sonar in 1980 (Shoreline Exploration, 1983). The shallowest stations (22,23), in water less than 75 m deep, recovered very little sediment and were probably sited on hard bottom. One contained abundant sponges and other organisms, and a little relatively fine grained sand consisting of abraded shell and bryozoal material. The others contained either coarse bryozoal sand or grit, or well-sorted, medium to coarse grained carbonate sand dominated by fragments of bryozoa and shells.

Four samples (GS11-14) were taken off Portland in the search for a possible shale diapir and a gas anomaly, both identified on seismic sections provided by Phillips Petroleum. Water depths were 45-70 m, and small quantities of sediment and abundant sponges suggest hard bottom. The sediment was coarse to gritty bryozoal sand containing forams, echinoid spines, large bivalves, encrusting serpulids and algal crusts.

Two samples (GS24,25) were taken from a submerged volcano off Cape Otway (Gill, 1986), consisting of fresh and weathered basalt.

Nine stations (GS26-33) were located off King Island and western Tasmania

TABLE 6 : GRAB STATIONS

Station	Latitude	Longitude	Water depth (m)	Seismic profile	Recovery (cm)	Description or comments
GS01	37°05.00'	138°34.8'	118	16/049	15	Yellow gray v.c. gritty carbonate sand.
GS2A	38°04.7'	140°13.5'	163	48/043	10	Brownish c. calcareous sand.
GS03	38°02.1'	140°16.0'	123	48/043	5	Brownish c. bryozoal sand.
GS04	37°59.1'	140°17.7'	69	48/043	20	Brownish bryozoal grit.
GS05	37°57.0'	140°20.3'	27	48/043	1	Lithified sand, kelp, sponges = rocky bottom.
GS06	37°54.8'	140°19.4'	20	48/043	-	Kelp only = rocky bottom.
GS07	37°55.7'	140°14.0'	67	48/042	10	Brownish c. bryozoal sand.
GS08	37°56.5'	140°08.8'	88	48/042	1	Brownish c. bryozoal sand.
GS09	37°56.4'	140°08.6'	100	48/042	20	Brownish bryozoal grit.
GS10	37°58.2'	140°05.3'	204	48/042	10	Olive brown f.c. carbonate sand.
GS11	38°27.05'	141°33.74'	45	OP80/51	1	Brown gritty bryozoal sand, abundant sponges.
GS12	38°28.23'	141°33.58'	60	OP80/53	1	Brown c. bryozoal sand, abundant sponges.
GS13	38°28.30'	141°32.68'	60	OP80/53	1	Brown gritty bryozoal sand, abundant sponges.
GS14	38°28.62'	141°32.40'	70	OP80/53	1	Brown gritty bryozoal sand, abundant sponges.
GS15	38°13.58'	140°37.96'	100		20	Light gray bryozoal grit.
GS16	38°13.5'	140°43.04'	95		30	Light olive gray carbonate sand.

Table 6 (cont.)

Station	Latitude	Longitude	Water depth (m)	Seismic profile	Recovery (cm)	Description or comments
GS17	38°13.5'	140°43.9'	94		30	Light brownish gray bryozoal grit.
GS18	38°13.75'	140°42.6'	95		30	Light brown c-v.c. carbonate sand, well sorted.
GS19	38°13.45'	140°43.2'	94		30	" " " " " " "
GS20	38°13.50'	140°43.5'	97		20	Light brown, well sorted m. carbonate sand.
GS21	38°13.8'	140°43.5'	89		15	Light gray f-m carbonate sand.
GS22	38°13.4'	140°47.3'	50		-	Probably hard bottom, two attempts.
GS23	38°13.3'	140°49.5'	74		1	Light brown f-m carbonate sand, abundant sponges.
GS24	39°05.84'	143°19.9'	34	16/029	100g	Black, fresh basalt.
GS25	39°06.3'	143°19.1'	38	16/029	10g	Weathered basalt.
GS26	39°30.0'	143°01.0'	110	40/22	200g	Light brown c. bryozoal sand.
GS27	39°32.0'	143°00.0'	180	40/22	5kg	Light brown m-c calcareous sand.
GS28	40°02.0'	143°13.2'	450		500g	Yellow m. calcareous sand.
GS29	42°10.0'	144°50.1'	156	Sonne 46	5kg	Light brown muddy, m-c bryozoal sand.
GS30	42°09.0'	144°55.0'	134	Sonne 46	500g	Ferruginous light brown ?phosphatic shelly concretions.
GS30A	42°08.9'	144°55.0'	135	Sonne 46	5kg	Light brown f-m. calcareous sand.
GS31	42°08.0'	145°01.0'	100	Sonne 46	8kg	Yellowish brown v.c. bryozoal sand and gravel.
GS32	41°30.8'	144°25.1'	294	16/015	6kg	Pale olive m-c bryozoal sand.
GS33	41°10.6'	144°08.1'	203	16/017	30kg	Olive brown muddy m-v.c. bryozoal sand.

in water depths of 110-450 m. Those in shallower water (26,31) were coarse brown bryozoal sands with some corals and pelecypods. The other samples were largely medium to coarse grained carbonate sands, with bryozoa generally dominant, and pelecypods, forams, brachiopods, and solitary corals making minor contributions. Several contained considerable mud, and one (30) contained ferruginous and possibly phosphatic concretions.

Overall the shelf sands could be readily matched with the sands in turbidites in deep water, which are predominantly of bryozoal origin.

TERTIARY NANNOFOSSILS FROM OFFSHORE OTWAY BASIN AND OFF WEST TASMANIA (S. Shafik)

ABSTRACT

Calcareous nannofossils from gravity cores and dredge samples recovered during BMR Cruise 67 were examined in order to date them and to elucidate their depositional paleaoenvironments. Forty nine gravity cores are entirely Quaternary in age, but another seven of these cores retrieved older levels. Sediments from several dredges are devoid of calcareous nannofossils, and the oldest dredged sediments containing these fossils, are assigned a mid middle Eocene age; the nannofossil-free sediments are probably older than the Eocene. This is consistent with results obtained during BMR Cruise 48 (Shafik, in press) and with the onshore sequence (Shafik, 1983). It suggests that open-marine conditions were well established by the mid middle Eocene in the Otway Basin, but probably not before.

Sediments obtained at six dredge stations were placed within high resolution Eocene and Oligocene biostratigraphic schemes, and correlated with those obtained during BMR Cruise 48. Abundant occurrence of *Chiasmolithus* and a paucity of *Discoaster* in most of the Eocene levels, suggest cold surface waters. However, a warm episode was detected within the middle Eocene. This is bracketed by the biostratigraphic interval (DI):**Reticulofenestra scissura*/+*Daktylethra punctulata* (corretable with the low-latitude planktic foraminiferal P.13 zone); * being lowest occurrence and + being highest occurrence. The evidence from the Oligocene indicates colder surface waters than during the Eocene: *Chiasmolithus altus* being abundant, rare discoasters, and almost total absence of the low-latitude sphenoliths in most Oligocene levels. Significantly, however, the low-latitude *Sphenolithus ciperoensis* was recorded from two dredges and from the bottom of a short gravity core; in these samples *Chiasmolithus altus* is missing. Similar record of the low-latitude *Sphenolithus ciperoensis* in onshore section in the western Otway Basin was noted previously by the writer. This suggests a short warm episode occurring during the late Oligocene in southern Australia.

Deposition during the Eocene and Oligocene was in nearshore or shallow-water environments. This is based on the presence of several hemipelagic nannofossil taxa (such as *Zygrhablithus bijugatus bijugatus* and *Pontosphaera multipora*) in most samples examined of these ages. Partial dissolution of few of the assemblages examined suggests deposition at deeper levels. However, in at least one of these assemblages the undeniable presence of few hemipelagic taxa (albeit being very poorly preserved) suggests deposition in shallow-water environment and a later prolonged exposure to cold bottom currents on the seabed. Based on evidence fom two dredge stations, a shoaling/fall in sea-level occurred progressively from the middle Eocene through into the early Oligocene.

Lower/middle Miocene were recovered at two dredge stations and in one of the gravity cores. The index species *Sphenolithus heteromorphus* was identified from several dredge samples. This together with records of the species from the onshore Victorian Tertiary support other evidence indicating a global warming event, very useful in biostratigraphic correlation at higher latitudes.

Upper Pliocene sediments were recovered in three gravity cores. Diversity

of the assemblages examined is low. Notable is the total lack of slim-rayed discoasters indicating cold surface waters during the late Pliocene in the Otway Basin.

INTRODUCTION

A major part of BMR Cruise 67 on the R/V Rig Seismic (January-Feburary, 1987) was devoted to samping Cretaceous, Paleogene and older outcropping sequence in the offshore Otway Basin and off west Tasmania (Figs. 1 and 2). Dredging and gravity coring were attempted at 76 stations (Tables 3 and 4). Although specific targets in the stratigraphic sequences could not always be sampled, rock/sediment recovery was high.

Light microscopy of smear slides was carried out on board ship to determine the age and palaeoenvironmental conditions, based on recovered calcareous nannofossil assemblages. Most gravity cores and dredge pipes recovered sediments containing Quaternary coccoliths; these are mostly not discussed here. This report deals with *in situ* Tertiary calcareous nannofossils extracted from many gravity cores and dredge samples.

Previously, Tertiary sediments from offshore Otway Basin were dredged during BMR Cruise 48 (June-July, 1985). Their calcareous nannofossils were studied by the writer (Shafik, in press).

ASSEMBLAGES: THEIR AGE AND PALAEOENVIRONMENTAL SIGNIFICANCE

Biostratigraphic assignment to any of the published calcareous nannofossil zonal schemes was not attempted. Instead, the concept of nannofossil datum interval (DI) was used and assemblages were related to a framework of calcareous nannofossil events (see, Tables 7 & 8); the symbols * and + are used in the biostratigraphic assignments made to denote lowest and highest occurrences of taxa.

I. GRAVITY CORES

A. Eocene in Gravity Core 67/GC 05.

This core was attempted on the lower slope of Beachport Terrace in a water depth of 2235 metres, at Lat. 37 45.46 S - Long. 138 34.40 E. It recovered 75 cm of mudstone. Two sharp colour changes are noted at the 26-cm and 2-cm levels in the core. Eight levels were sampled and examined by optical microscopy for their nannofossils.

Bottom of corecatcher (75 cm).

A well-preserved diversified assemblage was extracted from the bottom of the corecatcher. *Blackites spinulus*, *B. tenuis*, *Chiasmolithus expansus* (very rare), *C. oamaruensis*, *Coccolithus eopelagicus*, *C.* sp. cf. *C. pelagicus*, *Cyclicargolithus floridanus*, *C. reticulatus*, *Cyclococcolithus protoannulus*, *Discoaster nodifer*, *D. saipanensis*, *Helicosphaera seminulum*, *H.* sp. aff. *H. reticulata*, *Lanternithus minutus*, *Markalius inversus*, *Pontosphaera multipora*, *Reticulofenestra aragonensis*, *R. scissura*, *R. umbilica*, *R.* sp. cf. *R. hampdenensis*, *R. oamaruensis*, *Sphenolithus moriformis*, *Transversopontis obliquepons* and (dwarf) *Zygrhablithus bijugatus bijugatus* were identified.

Age and biostratigraphic assignment.

Chiasmolithus oamaruensis and *Cyclicargolithus reticulatus* are abundant. The overlap in the ranges of these two taxa, in the absence of *Isthmolithus recurvus*, indicates an early late Eocene age.

Table 7 gives the mid middle and late Eocene nannofossil biostratigraphic events recognised by Shafik (1983) in onshore Eocene sections in the Otway Basin. The Biostratigraphic span of core 67/GC 05 is shown in this table.

The biostratigraphic datum interval (DI) assignable to the corecatcher assemblage is the DI:**Chiasmolithus oamaruensis*/**Isthmolithus recurvus*, * being lowest occurrence.

Palaeoenvironment. The occurrence of several hemipelagic taxa including the holococcoliths *Lanternithus minutus* and *Zygrhablithus bijugatus bijugatus*, suggests that deposition occurred in a nearshore or shelf environment.

Samples from 60- & 47-cm levels.

Assemblages recovered are similar to that identified from 75 cm, suggesting similar palaeoenvironmental conditions. Forms referable to *Chiasmolithus expansus* are present at the 60-cm level, but absent from higher levels. *Corannulus germanicus* is noted at 60 cm, and *Neococcolithes dubius* and *Lapideacassis* sp. cf. *L. mariae* were encountered in Preparation 67/GC 05 (47 cm); these two taxa were not found at 75 cm.

Age and biostratigraphic assignment. The age of these assemblages is late Eocene, based on the overlap in the ranges of *Chiasmolithus oamaruensis* and *Cyclicargolithus reticulatus*. The occurrence of *Neococcolithes dubius* in Preparation 67/GC 05(47 cm) is positive evidence of early late Eocene age, prior to the appearance of *Isthmolithus recurvus*. The biostratigraphic datum interval assignable to this segment of the core is the DI:**Chiasmolithus oamaruensis*/+*Neococcolithes dubius*, * being lowest occurrence and + being highest occurrence (see Table 7).

Palaeoenvironment. There are less hemipelagic taxa than at 75 cm, suggesting possible rapid subsidence after the deposition of the corecatcher material.

Samples from the 30-, 27-, 26- & 2-cm levels.

Assemblages recovered from levels higher than 47 cm (except those from the top centimetre of the core) are similar to those from below: The taxa *Cyclicargolithus reticulatus*, *Discoaster saipanensis*, *D. nodifer*, *Chiasmolithus oamaruensis*, *Reticulofenestra aragonensis*, *R. scrippsae*, *R. scissura*, *R. umbilica*, *Coccolithus eopelagicus*, *Pontosphaera multipora*, *Transversopontis obliquepons*, *T.* sp., *Blackites spinulus*, *B. tenuis* and *Sphenolithus moriformis* were encountered at most levels; the key taxa *Cyclicargolithus reticulatus* and *Discoaster saipanensis* range up to the colour change at the top 2 centimetres of the core. *Cyclococcolithus formosus* and *C. protoannulus* appear at only few levels.

The key species *Isthmolithus recurvus* was encountered at most levels, its

Table 7. Mid middle to late Eocene calcareous nannofossil events, and their correlation with the foraminiferal P. zones.

Age	Biostratigraphic events	P. zone	Assignment
Late Eocene	+*Discoaster saipanensis*	P.16	67/DR 2-2b.
	+*Cyclicargolithus reticulatus*	P.16	
	**Isthmolithus recurvus*	P.15	
	+*Neococcolithes dubius*	P.15	
	**Chiasmolithus oamaruensis*	P.14	67/DR 10-3c.
	+*Chiasmolithus grandis*		
Middle Eocene			48/DR 7-3.
	+*Daktylethra punctulata*	P.13	48/DR 7-1.
	**Reticulofenestra scissura*	P.13	67/DR 10-3a.
	**Cyclicargolithus reticulatus*	P.12	

*Lowest occurrence +Highest occurrence

Span of core 67/GC 05.

lowest occurrence being at 30 cm.

Age and biostratigraphic assignment. Based on the overlap in the ranges of the key taxa *Isthmolithus recurvus*, *Cyclicargolithus reticulatus* and *Discoaster saipanensis*, the segment between 30 cm and 2 cm in the core is assigned to the biostratigraphic DI:**Isthmolithus recurvus/+Cyclicargolithus reticulatus*, * being lowest occurrence and + highest occurrence (see Table 7). The age is late Eocene.

Palaeoenvironment. Similar to that for the lower part of the core; seemingly deepening continued to occur during the deposition of the upper part of the core as indicated by a reduction in the abundance and diversity of the hemipelagic taxa.

Remarks. A comparison between the late Eocene nannofossil assemblages of core 67/GC 05 and coeval assemblages from onshore sections in the Otway Basin (Shafik, 1983) reveals some noteworthy points:

1. Some of the oceanic taxa, particularly *Reticulofenestra umbilica*, *R. scissura*, *Cyclicargolithus reticulatus* are substantially larger in size in offshore core 67/GC 05 than in the onshore material (e.g. Observation Bores #1 & #2: Shafik, 1983).

2. Other taxa, the hemipelagic ones, such as *Zygrhablithus bijugatus bijugatus*, *Pontosphaera multipora* are generally smaller in size in the offshore than in the onshore assemblages.

3. Some of the key taxa, particularly *Cyclococcolithus formosus*, are much rarer in the offshore than in the onshore material; these taxa are usually frequent to common in onshore material. This could have serious consequences if age determination of offshore material is based on the absence of such taxa.

Sample from the very top of core.

A Late Quaternary coccolith assemblage was identified from the top centimetre of core 67-GC 05, immediately above the sharp colour change. The assemblage included the taxa *Calcidiscus leptoporus*, *Coccolithus pelagicus*, *Emiliania huxleyi*, *Gephyrocapsa oceanica* and *Helicosphaera wallichii*.

B. Oligocene in Gravity Core 67/GC 39

Coring was attempted at Lat. 40 37.9 S - Long. 140 50.1 E, west of Tasmania and King Island, where water depth is 4300 metres. It recovered 135 cm of mainly grey foram nanno ooze with a thin layer of coarse sand overlying stiff green clays at the bottom.

Bottom of corecatcher (135 cm).

A very poorly-preserved nannofossil assemblage was recovered. The few taxa encountered show signs of severe dissolution, although the abundant *Discoaster deflandrei* is reasonably well preserved. Other species identified include *Coccolithus eopelagicus*, *C.* sp. *C. pelagicus*, *Coronocyclus nitescens*, *Cyclicargolithus floridanus*, *? C. abisectus*, *Helicosphaera obliqua*, *Reticulofenestra scissura* and *Sphenolithus moriformis*.

Cyclicargolithus floridanus and *Reticulofenestra scissura* are particularly abundant but the index species *Helicosphaera obliqua* is rare.

Age and biostratigraphic assignment. The co-occurrence of *Reticulofenestra scissura* and *Helicosphaera obliqua* suggests a late Oligocene age. The assemblage can be assigned to the DI:+*Chiasmolithus altus*/+*Reticulofenestra scissura* (see Table 8).

Palaeoenvironment. The low diversity of the assemblage is partly a result of differential dissolution. The absence of *Chiasmolithus altus* could be due to its total dissolution, or perhaps as a result of palaeoecological elimination. Warmer water conditions than those prevailed during most of the Oligocene (see most other Oligocene levels examined) could have been the cause. The apparent absence of the relatively resistent low-latitude sphenoliths could well be due to their extreme rarity.

Deposition was not far from the calcium compensation depth (CCD) as evinced by partial dissolution of most taxa identified. The absence of shallow-water indicators such as *Zygrhablithus bijugatus bijugatus* is in agreement with this conclusion; *Z. bijugatus bijugatus* is usually abundant in upper Oligocene sediments deposited under much shallower conditions in the Otway Basin.

Samples from 125-level and top of core.

Late Quaternary assemblages were recovered. Taxa identified include *Calcidiscus leptoporus*, *Coccolithus pelagicus*, ?*Emiliania huxleyi*, *Gephyrocapsa oceanica*, small *Gephrocapsa* spp., *Helicosphaera wallichii* and *Rhabdosphaera stylifer*.

C. Oligocene in Gravity Core 67/GC 54

A short core of 97 cm of olive grey foram nanno ooze, over hard greyish olive mudstone was recovered at Lat. 41 10.9 S - Long. 143 50.2 E, where water depth is 1634 metres; corecatcher was retrieved empty. Four samples were examined. The two samples from the ooze at 7- and 70-cm levels yielded Quaternary coccoliths, with rare displaced Tertiary specimens. The other two samples came from the hard mudstone, at the 85- and 97-cm levels. These yielded *in situ* older taxa.

Samples from 97- and 85-cm levels.

Abundant moderately well-preserved calcareous nannofossils were examined. Taxa identified include *Coccolithus eopelagicus*, *Cyclicargolithus abisectus*, *C. floridanus*, *Discoaster deflandrei*, *Helicosphaera euphratis*, *H. obliqua*, *P. multipora*, *Reticulofenestra aragonensis*, *R. scissura*, *Sphenolithus ciperoensis*, *S. moriformis* and *Zygrhablithus bijugatus bijugatus*. In addition, rare specimens of small *Gephrocapsa* spp. were noted, but these are thought to be contaminant from the overlying Quaternary soft ooze.

Age and biostratigraphic assignment. Based on the overlap in the ranges of the key taxa *Helicosphaera obliqua*, *H. euphratis*, *Reticulofenestra scissura* and *Zygrhablithus bijugatus*, the age is late Oligocene. The presence of the *Sphenolithus ciperoensis* supports this age determination.

Table 8. Latest Eocene to late Oligocene nannofossil events.

Age	Biostratigraphic events	Sample assignment
	+*Helicosphaera recta*	
Late	+*Reticulofenestra scissura*	
	interval with *Sphenolithus ciperoensis*	DR 14-1c; DR 19-4. GC 54 (85 cm).
Oligocne		DR 19-1; GC 39cc.
	+*Chiasmolithus altus*	
		DR 10-1, 10-2b,10-4; DR 12-4, 12-3a; DR 14-1a. @
	*H. recta; H. obliqua	
		48/DR 7-7;48/DR 5-1
	+*Reticulofenestra umbilica*	
Early		DR 10-2a; DR 12-3.
	+*Isthmolithus recurvus*	
Oligocene		DR 10-3b; DR 18-3b; DR 2-2.
	+*Cyclococcolithus formosus*#	
		DR 10-3d; 48/DR 7-1.
	+*Discoaster saipanensis*#	
Late Eocene	+*Cyclicargolitus reticulatus*	

*Lowest occurrence   +Highest occurrence

this event is unreliable because the species is usually rare and inconsistent in the onshore material (see text).

@ indicates two dredge samples from BMR Cruise 48 (48/DR 7-2 & 48/DR 5-2); unless specified all samples in the table were obltained during BMR Cruise 67.

Palaeoenvironment. The presence of the low-latitude *Sphenolithus ciperoensis* suggests an episode of warming during the late Oliogocene in the Otway Basin (see also Remarks on p.). The exclusion of the cold-temperature indicator *Chiasmolithus altus* could be due to the same warming event which brought *S. ciperoensis* into the Otway Basin.

Deposition was in nearshore or shallow-water environment as evidenced by the abundance occurrence of *Zygrhablithus bijugatus bijugatus*.

D. Miocene in Gravity Core 67/GC 40

This core was attempted at Lat. 40 41.5 S - Long. 141 46.4 E, west of Tasmania and King Island, where water depth is 4370 metres. It was targeted to sample Cretaceous and younger sediments. A short section of 65 cm of brown foram nanno ooze over a light olive brown calcareous clay unit was recovered. The contact between the ooze and the clay units is sharp, at the 22-cm level.

Bottom of corecatcher (65 cm).

The assemblage recoverd contains mixed moderately well-preserved and badly corroded specimens. Taxa identified include *Calcidiscus leptoporus*, *Cyclicargolithus floridanus*, *?C. abisectus*, *Discoaster deflandrei*, *?D. druggii*, *?D. exilis*, *Helicosphaera euphratis*, *H. kamptneri*, *H. obliqua*, *?H. granulata*, *Pontosphaera multipora*, *Sphenolithus abies*, *S. conicus*, *S.* sp. aff *S. belemnos* and *S. moriformis*. *Discoaster deflandrei* is common, probably having been concentrated through elimination of dissolution-prone taxa. Specimens of *Calcidiscus leptoporus* encountered are particularly better preserved than most specimens of *Cyclicargolithus* spp..

Age. The overlap in the range of *Helicosphaera kamptneri*, *H. obliqua*, *H. euphratis* and *Calcidiscus leptoporus* suggests early Miocene age. The absence of *Reticulofenestra scissura* supports this age assignment.

Palaeoenvironment. Deposition probably occurred at relatively shallow depth (continental shelf) because of the presence of *Pontosphaera multipora*. Partial dissolution of taxa probably is the result of prolonged exposure to cold water currents at the seabed.

Samples from 62-, 49- and 22-cm levels.

Assemblages are similar to that recorded from the corecatcher. The presence of *Calcidiscus leptoporus*, *Helicosphaera obliqua*, *H. kamptneri*, and *Pontosphaera multipora* is confirmed up to and including the sample from 22 cm.

Helicosphaera intermedia and *Coronocyclus nitescens* were identified at 22 cm, in addition to other taxa found in the corecatcher.

Age and Palaeoenvironment. Similar to the corecatcher assemblage: An early Miocene age, and a relatively shallow-water environment on the continental shelf are concluded for the levels immediately above the corecatcher up to and including the 22-cm level.

Sample from 18-cm level.

A Quaternary coccolith assemblage is identified, including the taxa

Calcidiscus leptoporus, *Coccolithus pelagicus*, *?Emiliania huxleyi*, small *Gephyrocapsa* spp. and *Helicosphaera wallichii*. In addition, the displaced nannofossil taxa *Calcidiscus macintyrei*, *Chiasmolithus altus*, *Coccolithus eopelagicus*, *Cyclicargolithus floridanus*, *Discoaster deflandrei* and *Reticulofenestra pseudoumbilica* were also recorded. These displaced taxa suggest Paleogene and Neogene sources.

E. Pliocene in Gravity Cores 67/GC 36, 67/GC 45 and 67/GC 46

Gravity Core 67/GC 36.

This core recovered 244 cm of mainly grey foram nanno ooze at Long. 40 00.88 S - Long. 142 40.11 E, where water depth is 2182 metres.

Assemblages recovered from the lower part of this core, at 244 and 195 cm, contain *Calcidiscus leptoporus*, *C. macintyrei*, *Coccolithus pelagicus*, *Helicosphaera kamptneri*, *Pontosphaera japonica*, *Pseudoemiliania lacunosa* and *Rhabdosphaera stylifer*. Small bridged *Gephyracapsa* were found at 117 cm but not at lower levels.

The presence of *Calcidiscus macintyrei* and *Pseudoemiliania lacunosa* and the absence of bridged *Gephyrocapsa* spp. suggest late Pliocene age.

Gravity Core 67/GC 45.

This core recovered 360 cm of grey and greenish grey foram oozes at Lat. 42 13.6 S - Long. 142 52.5 E, where water depth is 3715 metres. Assemblages examined from the lower part of this core, at 360 and 198 cm, contain *Calcidiscus leptoporus*, *C. macintyrei*, *Coccolithus pelagicus*, *Crenalithus doronicoides*, *Helicosphaera kamptneri* and *Pseudoemiliania lacunosa*. Rare displaced taxa such as *Cyclicargolithus abisectus* and *Reticulofenestra scissura* were also recorded. No bridged *Gephyrocapsa* spp. were found at 198 cm and the bottom of the core, in contrast with the late Quaternary assemblages identified from the the top of the core. The absence of these *Gephyrocapsa* spp. and the presence of both *Calcidiscus macintyrei* and *Pseudoemiliania lacunosa* suggest a late Pliocene age. The exclusion of discoasters is attributed to cold surface waters and is not considered as reliable biostratigraphic evidence; the abundant occurrence of *Coccolithus pelagicus* indicates cold surface waters.

Gravity Core 67/GC 46.

This core recovered 176 cm of greenish grey foram nanno ooze, over calcareous sand turbidite, over soft light grey chalk, at Lat. 42 12.1 S - Long. 144 24.8 E where water depth is 2360 metres. Assemblages retrieved from the grey chalk include *Calcidiscus leptoporus*, *C. macintyrei*, *Coccolithus pelagicus*, *Crenalithus doronicoides*, *Helicosphaera kamptneri*, *Pontosphaera japonica*, *Pseudoemiliania lacunosa* and *Rhabdosphaera stylifer*; rare reworked taxa were noted. The age is late Pliocene on account of the presence of *Calcidiscus macintyrei* and *Pseudoemiliania lacunosa*. The absence of bridged *Gephyrocapsa* spp. is in line with this age determination. The absence of slim-rayed discoasters is regarded as a response of the cold temperatures which seemed to have prevailed during the late Pliocene and Quaternary in the Otway Basin, rather than be used as a reliable biostratigraphic criterion; the extinction of the last slim-rayed discoasters is usually used in the low-latitude sections to mark the Pliocene/Pleistocene boundary.

Deposition occurred in shallow-water environment. This is based on the occurrence of *Pontosphaera japonica*. Surface waters were cold as attested to by the abundant occurrence of *Coccolithus pelgicus*.

II. DREDGE SAMPLES

Dredge Station 2

Dredging was attempted along a slope off SE South Australia, Beachport Terrace, between Lat. 37 40 S - Long. 138 20 E and Lat. 37 37.6 S - Long. 138 19.6 E. Water depth ranges between 4100 and 3700 metres. Two types of sediments were recovered: a yellowish grey foram nanno ooze (67/DR2-1), and semi-lithified light olive grey sandy siltstone with some darker material (67/DR2-2).

Preparation 67/DR 2-2b.

A subsample of the semi-lithified olive grey sandy siltstone was examined. Abundant poorly-preserved calcareous nannofossils were recovered. Poor preservation is mainly due to partial dissolution of most taxa, particularly chiasmoliths. The assemblage includes *Chiasmolithus altus*, *C. oamaruensis*, *Coccolithus eopelagicus*, *Discoaster saipanensis*, *Helicosphaera compacta*, *?Isthmolithus recurvus* (side view only), *Reticulofenestra aragonensis*, *R. hampdenensis*, *R. scissura*, *R. umbilica* and *Sphenolithus moriformis*. The presence of siliceous microfossils together with coagulation of the taxa into lumps on the slide, limited identification to the more freer specimens; treatment of the sample ultrasonically and the use of settling method together with adding a few drops of ammonia to the preparation may overcome these problems and more taxa may then could be identified. Most taxa named above are abundant in the assemblage except *Diascoaster saipanensis*, *Helicosphaera compacta* and *?Isthmolithus recurvus* which are very rare.

Age and biostratigraphic assignment. The co-occurrence of *Discoaster saipanensis* and *?Isthmolithus recurvus* in the absence of the index species *Cyclicargolithus reticulatus* suggests latest Eocene age. The absence of *C. reticulatus* is considered a reliable biostratigraphic criterion because the species is usually frequent to common in the upper Eocene of the Otway Basin prior to its extinction. In contrast *Discoaster saipanensis* (which is very rare in Preparation 67/DR 2-2b) is usually rare above the extinction datum of *C. reticulatus* (Shafik, 1983). The abundant occurrence of *Chiasmolithus altus* and *C. oamaruensis* in the presence of *Discoaster saipanensis* indicates late Eocene age.

The assemblage of Preparation 67/DR 2-2b is probably assignable to the DI:+*Cyclicargolithus reticulatus*/+*Discoaster saipanensis*, + being highest occurrence (see Table 7).

Palaeoenvironment. Surface waters were cold as attested to by the extreme rarity of discoasters and the abundance occurrence of chiasmoliths and *Reticulofenestra hampdenensis*.

Deposition occurred not too far from the calcium compensation depth (CCD) as suggested by the total absence of hemipelagic indicators and the partial dissolution of most taxa.

Preparation 67/DR 2-2c.

A subsample of the semi-lithified olive grey sandy siltstone was examined. A poorly preserved assemblage was recovered. Nannofossils are common to abundant, but most specimens show signs of dissolution. Large specimens of chiasmoliths are without their crosses, and small placoliths are reduced to the central tubes with only parts of the shields protruding from them. The taxa identified include *Chiasmolithus altus*, *Clausicoccus cribellum*, *Coccolithus eopelagicus*, *C.* sp. cf. *C. pelagicus*, *Cyclicargolithus floridanus*, *Discoaster tani*, *Helicosphaera compacta*, *Isthmolithus recurvus*, *Reticulofenestra aragonensis*, *R. hampdenensis*, *R. scissura*, *R. umbilica*, *Sphenolithus moriformis* and *Transversopontis pulcheroides*. The assemblage is dominated by the chiasmoliths and the reticulofenestras; *Reticulofenestra hampdenensis* is notably abundant. *Discoaster tani* and *Transversopontis pulcheroides* are particularly very rare. The rarity of *Transversopontis pulcheroides* is thought to be due to dissolution, but the rarity of *Discoaster tani* is attributed to palaeoenvironmental causes: *Transversopontis pulcheroides* is prone to dissolution and would have been among the taxa which were first destroyed (mostly beyond recognition); *Discoaster tani* is among the taxa most resistent to dissolution.

Age and biostratigraphic assignment. The presence of *Isthmolithus recurvus* suggests late Eocene to early Oligocene age. The absence of the Eocene index taxa *Cyclicargolithus reticulatus* and *Discoaster saipanensis* favours the younger age. However, *Discoaster saipanenensis* is usually rare in the uppermost Eocene of the onshore Otway Basin (Shafik, 1983) and its absence from Preparation 67/DR 2-2c may not be biostratigraphically important. *Cyclicargolitus reticulatus*, although is usually common in the later part of the Eocene of the Otway Basin and its exclusion should be biostratigraphically significant (Shafik, 1983), partial dissolution of the assemblage of Preparation 67/DR 2-2c could have destroyed its delicate central structure rendering its identification impossible: Indeed some circular placoliths (identified as *Cyclicargolithus floridanus*), being with open central area, mimick *Cyclicargolithus reticulatus* with a destroyed central structure.

The assemblage is assigned to the calcareous nannofossil DI:**Isthmolithus recurvus*/+*I. recurvus*; * being lowest occurrence, and + being highest occurrence.

Palaeoenvironment. Specimens of the genus *Chiasmolithus* are overwhelmingly more abundant than those of the genus *Discoaster*, indicating cold surface waters. The great abundance of *Reticulofenestra hampdenensis*, and the the presence of *Isthmolithus recurvus* support this conclusion.

Deposition is thought to have occurred not too much above the calcite compensation depth (CCD), because of the severity of dissolution as indicated by the absence of the crosses in most chiasmoliths and by a general paucity of species (reduced diversity resulting from selective dissolution).

Preparation 67/DR 2-2a.

This preparation is from a third fragment of the semi-lithified grey silstone. It is almost barren of calcareous nannofossils except for a few specimens of *Reticulofenestra umbilica* reduced to narrow rings and some pieces of *?Reticulofenestra scissura*.

On the basis of available evidence the age of Preparation 67/DR 2-2b could range from mid Eocene to mid Oligocene. This is equates with the DI:**Reticulofenestra scissura/+Reticulofenestra umbilica*.

Deposition occurred very near (or even slightly below) the calcium compensation depth.

Remarks. Preservational differences between the assemblages extracted from subsamples 67/DR 2-2a, 67/DR 2-2b and 67/DR 2-2c are mostly manifestations of differences in depositional depth: 67/DR 2-2a evidently was deposited at deeper levels than the other two, and 67/DR 2-2c was deposited at shallower depth than the other two: Subsample 67/DR 2-2a contains a residual assemblage left over after severe dissolution at depth not too far from the CCD, whereas the assemblage of 67/DR 2-2c includes evidence of deposition at much shallower depth; the shallow-water indicator *Transversopontis pulcheroides* occurs in subsample 67/DR 2-2c but not in subsample 67/DR 2-2b. It is very likely that these three subsamples came from very closeby outcrops or even from the same outcrop. The age-ranges given to these subsamples permit considering 67/DR 2-2a as middle Eocene, 67/DR 2-2b as latest Eocene, and 67/DR 2-2c as earliest Oligocene. Assuming these age assignments to be correct, it may be concluded that shoaling/sea-level fall occurred progressively from the middle Eocene into the early Oligocene. This is consistent with the evidence from coeval onshore sections in the same basin (Shafik, 1983).

Preparation DR 2-1.

A late Quaternary abundant moderately well-preserved coccoliths were identified. These included *Calcidiscus leptoporus*, *C.* sp. aff. *C. macintyrei*, *Ceratolithus cristatus*, *Coccolithus pelagicus*, *Emiliania huxleyi*, *Gephyrocapsa caribbeanica*, *G. oceanica* and *Helicosphaera wallichii*. *Ceratolithus cristatus* is very rare whereas *Coccolithus pelagicus* is abundant suggesting cold surface waters.

Dredge Station 3

This station lies beyond Beachport Terrace between Lat. 38 14.56 S - Long. 13 E8 34.66 E and Lat. 38 14.13 - Long. 138 35.22 E, near the abyssal plain on the outer continental margin. The water depth dredged ranges between 4800 and 4100 metres. The target aimed for was basement and/or Cretaceous Rocks.

Two main types of sediments were collected at this station: indurated siltstone (partly coated with secondary iron oxides) (67/DR 3-1) and dark brown silty claystone with Fe/Mn coating (67/DR 3-2b).

No calcareous nannofosssils were found in both dredge samples 67/DR 3-1 and 67/DR 3-2b. This may suggest that these dredges are probably older than the Eocene, judging from the sequence onshore.

The sediment recovered from the dredge pipe yielded poorly preserved coccoliths indicating late Quaternary age. Poor preservation is mainly because of partial dissolution of the taxa. These included *Calcidiscus leptoporus, Coccolithus pelagicus, Gephyrocapsa oceanica* and questionable *Emiliania huxleyi*.

Dredge Station 4

This station lies between Lat. 38 26.3 S - Long. 138 49.6 E and Lat. 38 24.3 S - Long. 138 52.3 E, where water depth ranges between 4700 and 4050 metres. The sampling target was the base of the Otway Group. Several types of hard rock/sediment were recovered. Four types were examined. A preparation from the dominant type 67/DR 4-1 (a dark grey to brown argillite, incipient to distinct slaty cleavage, strongly fractured) is devoid of calcareous nannofossils. Also preparations from types 67/DR 4-2 (a grey brown mudrock) and 67/DR 4-5 lacked calcareous nannofossils.

In the absence of calcareous nannofossils, the age of sediment types 67/DR 4-1, 67/DR 4-2 and 67/DR 4-5 could not be resolved.

Dredge Station 5

Dredging was attempted along the lower slope of BMR 48/42 Seismic Profile, to recover the upper Otway Group. Positions dredged are between Lat. 38 25.4 S - Long. 138 54.7 E and Lat. 38 24.8 S - Long. 138 56.8 E. Water depth ranges between 3900 and 3400 metres. Recovered sediments included grey mudstone (dominant type) and black mud. Both types lacked calcareous nannofossils; their age could not be determined.

Dredge Station 6

Dredging was attempted along a ridge on the abyssal plain SW of Argonaut well between Lat. 38 46.5 S - Long. 139 39.0 E and Lat. 38 46.2 S - Long. 139 9.0 E. Water depths dredged range between 4750 and 4780 metres. The target was Paleozoic rocks similar to those recovered during BMR 48 Cruise (48/DR 6). Only the dredge pipe retrieved material: The dominant lithology is a black mudstone (67/DR 6a) which lack calcareous nannofossils. Also, olive grey pelagic ooze (67- DR 6b) was recovered. This yielded Quaternary coccoliths.

Dredge Station 7

Dredging at this station was targeted to sample basement rocks of the continental crust. This was attempted along a ridge outcrop on the abyssal plain between Lat. 38 47.4 S - Long. 139 12.4 E and Lat. 38 47.8 S - Long. 139 12.1 E. Water depth ranges between 4450 and 4200 metres. Only the dredge pipe retreived material: light brown ooze (67/DR 7a) and several small black mudstone pebbles (67/DR 7b).

Quaternary coccoliths were recovered from the brown ooze (67/DR 7A). In contrast, none of the mudstone pebbles examined yielded calcareous nannofossils. The age of these mudstone pebbles could not therefore be determined.

Dredge Station 8

Dredging was attempted along a ridge near the base of the continental slope between Lat. 39 01.2 S - Long. 140 03.4 E and Lat. 39 02.7 - Long. 140 00.9 E, to sample the Otway Group in waters ranging in depth between 4351 and 4050 metres. The dredge chain bag was retrieved empty but the dredge pipe contained pelagic mud (67/DR 8-1) and fragments of brown mudstone (67/DR 8-?). Calcareous nannofossils indicating late Quaternary age were extracted from the pelagic mud 67/DR 8-1, but the brown mudstone lacked nannofossils. The age of the brown mudstone fragments could not be determined.

Dredge Station 9

Dredging along the continental slope at the edge of the abyssal plain at Lat. 39 26.9 S - Long. 139 59.5 E where water depth is 4800 metres was planned to probably recover basement. Hard siliceous cherts and fine grained igneous rocks were obtained in the dredge chain bag, in addition to yellowish brown calcareous ooze (67/DR 9-9) in the dredge pipe. Calcareous nannofossils indicating late Quaternary age were identified from the ooze.

Dredge Station 10

Dredging along a relatively steep slope SW of Argonaut well, between Lat. 38 05.2 S - Long. 139 45.2 E and Lat. 38 04.5 S - Long. 139 46.4 E, resulted in the recovery of five rock types (dredge chain bag) plus Quaternary light brown mud (dredge pipe). Water depth dredged ranges between 1950 and 1700 metres. Dominant rock types are white fossiliferous calcareous claystone with poorly sorted, poorly rounded quartz grains (DR 10-1), light brownish grey sparsely fossiliferous calcareous clay with poorly sorted minor quartz and also minor mica (DR 10-3), and chert concretions (DR 10-2) from types 67/DR 10-1 and 67/DR-3. Other types include bryozoal calcarenite, with concretion, very highly fossiliferous (90% of bryzoans) with well rounded minor quartz (DR 10-4), and limonitic concretions (DR 10-5).

Preparation 67/DR 10-3a.
A subsample of the brownish grey calcareous clay was examined. Assemblage recovered is moderately well-preserved. Dilution by siliceous microfossils rendered low nannnofossil abundance in the preparation. (Some onshore laboratory processing of the preparation, including treatment by ultrasonic, should improve the nannofossil abundance.) Nevertheless, the assemblage includes several key species.

The taxa identified are *Blackites spinulus*, *B. tenuis*, *Chiasmolithus grandis/C. expansus*, *Coccolithus eopelagicus*, *C.* sp. cf. *C. pelagicus*, *Cyclicargolityhus floridanus*, *C. reticulatus*, *Discoaser saipanensis*, *Helicosphaera reticulata*, *?Neococcolithes dubius* (rare, only side views), *Reticulofenestra oamaruensis* (rare), *R. scrippsae* (rare), *R.* sp. cf. *R. scissura*, *R. umbilica* and *Zygrhablithus bijugatus bijugatus* (very rare). *Thoracosphaera* sp. was also identified.

Age and biostratigraphic assignment. The co-occurrence of *Chiasmolithus expansus/C. grandis* and *Cyclicargolithus reticulatus* in the absence of typical *Reticulofenestra scissura* indicates an assignment to the biostratigraphic DI:**Cyclicargolithus reticulatus/*Reticulofenestra scissura* (see Table 7); * being lowest occurrence. This suggests a correlation with the low-latitude planktic foaminiferal zonal interval P.12 to P.13. The age is mid middle Eocene. The presence of *Discoaster saipenensis* supports the Eocene age, but the occurrence of the taxa *Helicosphaera reticulata* (though rare), *Reticulofenestra scrippsae* and atypical *R. scissura* confirms the biostratigraphic assignment and narrows the correlation with the low-latitude planktic foraminiferal scheme to early P.13 zone.

Palaeoenvironment. Based on the relative abundance of specimens of *Chiasmolithus* to *Discoaster*, surface water temperatures were temperate.

Deposition occurred in relatively shallow waters, on the continental shelf. This is based on the occurrence of *Blackites spinulus* and *Zygrhablithus bijugatus bijugatus*. Coeval assemblages from onshore material in the Otway and Perth Basins (Shafik, 1978, 1983) include more abundant and diversified nearshore nannofossil indicators (e.g. *Lanternithus minutus*).

Preparation 67/DR 10-3c.

Abundant moderately well-preserved calcareous nannofossils were recovered. However, the presence of siliceous microfossils coagulated the preparation and limited identification to the rare free specimens; onshore treatment could overcome this problem. The assemblage recorded must be considered as incomplete. Taxa identified are *Blackites spinulus*, *Chiasmolithus oamaruensis*, *?C. grandis*, *Coccolithus* sp. cf. *C. pelagicus*, *Cyclicargolithus reticulatus*, *Neococcolithus dubius*, *Reticulofenestra scrippsae*, *R. umbilica* and *Sphenolithus moriformis*. *Cyclicargolithus reticulatus* is particularly abundant.

Age and biostratigraphic assignment. The overlap in the ranges of *Chiasmolithus oamaruensis* and *Neococcolithes dubius* suggests a late Eocene age.

The assemblage is assigned to the DI:**Chiasmolithus oamaruensis/+Neococcolithes dubius*. This interval correlates within the planktic foraminiferal zonal interval P.14-early P.15 (see Table 7).

Palaeoenvironment. Deposition occurred on the continental shelf as evidenced by the presence of *Blackites spinulus*.

Preparation 67/DR 10-3d.

A subsample of the brownish grey calcareous clay was examined. Abundant moderately well-preserved calcareous nannofossils were recovered. The assemblage includes *Blackites spinulus*, *B. tenuis*, *Chiasmolithus altus*, *C. oamaruensis*, *Clausicoccus cribellum*, *Cyclococcolithus formosus*, *Cyclicargolithus floridanus*, *Diascoaster tani*, *Helicosphaera compacta*, *H.* sp. aff. *H. seminulum*, *Isthmolithus recurvus*, *Lanternithus minutus*, *Pontosphaera multipora*, *Reticulofenestra hampdenensis*, *R. hilae*, *R. oamaruensis*, *R. scrippsae*, *R. scissura*, *Sphenolithus moriformis*, *Transversopontis obliquipons*, *T. pulcheroides*, *T.* spp. and *Zygrhablithus bijugatus bijugatus*. Notable in this assemblage is the extreme rarity of the taxa *Cyclococcolithus formosus*, *Discoaster tani* and *Reticulofenestra oamaruensis*, and the abundance of *Reticulofenestra hampdenensis*.

Age and biostratigraphic assignment. The co-occurrence of *Isthmolithus recurvus* and *Cyclococcolithus formosus* in the absence of the Eocene index taxa *Cyclicargolithus reticulatus* and *Discoaster saipanensis* suggests earliest Oligocene age. However, the usual rarity of *D. saipanensis* within the uppermost Eocene of the Otway Basin sections (Shafik, 1983), makes its absence from the assemblage of Preparation 67/DR 10-3d unreliable, and the age of this assemblage could be latest Eocene or earliest Oligocene.

The assemblage is assigned to the DI:**Cyclicargolithus reticulatus*/+*Cyclococcolithus formosus* (see Table 8).

Palaeoenvironment. The occurrence of several hemipelagic taxa including *Lanternithus minutus* and *Zygrhablithus bijugatus bijugatus* suggests nearshore or shallow-water environment of the continental shelf. Surface waters were cold as evidenced by the abundant occurrence of chiasmoliths and the rarity of discoasters, as well as the great abundance of *Reticulofenestra hampdenensis*.

Preparation 67/DR 10-3b.

A subsample of the brownish grey calcareous clay was examined. Assemblage contains abundant moderately well-preserved nannofossils; although nannofossil debris abounds. Species diversity is relatively high. Taxa identified include *Blackites spinulus*, *B. tenuis*, *Chiasmolithus oamaruensis*, *Helicosphaera lophota*, *Isthmolithus recurvus*, *Lanternithus minutus* (rare), *Pontosphaera multipora* (rare), *Rhabdosphaera* sp. cf. *R. pseudomorionum*, *Reticulofenestra aragonensis*, *R. hampdenensis*, *R. oamaruensis (rare)*, *R. scissura*, *R. umbilica*, *Sphenolithus moriformis*, *Transversopontis obliquipons* and *Zygrhablithus bijugatus bijugatus*. *Thoracosphaera* sp. was also identified.

Age and biostratigraphic assignment. The assemblage includes species suggesting an age range of latest Eocene to early Oligocene: For example, *Isthmolithus recurvus* ranges from late Eocene (planktic foraminiferal zone P.15) to within the early Oligocene (planktic foaminiferal zone P.19); and *Chiasmolithus oamaruensis* has a longer range, from late Eocene (planktic foraminiferal zone P.14) to mid Oligocene (planktic foraminiferal zone P.20). The Eocene/Oligocene boundary is usually drawn at the extinction of the key species *Discoaster saipanensis*. This species is usually rare in the latest Eocene of the Otway Basin, above the extinction of the other index species *Cyclicargolithus reticulatus* (Shafik, 1983); the late Eocene assemblages of Gravity Core 67/GC 05 contains common *C. reticulatus* and frequent *D. saipanensis*.

Table 8 shows the nannofossil biostratigraphic events across the Eocene/Oligocene boundary and for the Oligocene. Biostratigraphic placement of the samples examined from Dredge Station 10 is indicated in this table.

The assemblage of Preparation 67/DR 10-3b is assigned to the biostratigraphic DI:+*Cyclicargolithus reticulatus*/+*Isthmolithus recurvus*; + being highest occurrence. The biostratigraphic evidence based on the absence of *Cyclococcolithus formosus* is usually unreliable in offshore Otway Basin material.

Palaeoenvironment. Based on abundant *Chiasmolithus oamaruensis* and virtual absence of discoasters, it is suggested that surface waters were cold. The presence of both *Isthmolithus recurvus* and *Reticulofenestra hampdenensis* supports this conclusion.

Deposition was in relatively shallow-water environment as attested to by the occurrence of *Zygrhablithus bijugatus bijugatus*, *Pontosphaera multipora*, *Transversopontis obliquipons*, *Blackites spinulus* and *B. tenuis*. These taxa are usually absent or very rare in deep ocean sediments.

Remarks. The assemblages of subsamples 67/DR 10-3a, 67/DR 10-3b, 67/DR 10 3c, 67/DR 10-3d include taxa indicative of shallow-water deposition, but in varying proportion and abundance. This suggests varying depositional depth; these subsamples are likely to have been dredged from very closeby outcrops or from different levels in the same outcrop. The middle Eocene assemblage of subsample 67/DR 10-3a suggests deeper depositional depth compared with the others - only the shallow-water indicator *Zygrhablithus bijugatus bijugatus* was found among this assemblage and in small numbers. In contrast, several shallow-water indicators, including *Z. bijugatus bijugatus*, *Lanternithus minutus*, *Pontosphaera multipora* and *Transversopontis* spp., were found in the younger assemblages of subsamples 67/DR 10-3b and 67/DR 10-3d - indicating shallower depositional depth; these assemblages are likely to be early Oligocene in age. The late Eocene assemblage of subsample 67/DR 10-3c contains rarer and less diversified shallow-water nannofossil indicators than in the early Oligocene assemblage.

Based on the nannofossil evidence in the subsamples of 67/DR 10-3 (discussed above), it is not unreasonable to conclude that shoaling/sea-level fall occurred progressively from the middle Eocene through into the early Oligocene. A very similar conclusion was reached based on sediments dredged at the deeper Station 2 (where water depth is 4100-3700 metres compared with 1950-1700 metres at Station 10) Km to the southwest.

Preparation 67/DR 10-2a.

A subsample of sediments enclosing the chert concretions (DR 10-2) was examined. Abundant moderately well-preserved calcareous nannofossils were studied among common nannofossil debris in this preparation. Species diversity is, however, relatively low. The taxa identified include *Chiasmolithus altus* (2 sizes), *Coccolithus* sp. cf. *C. pelagicus*, *Cyclicargolithus floridanus*, *Pontosphaera multipora*, *Reticulofenestra hampdenensis*, *R. scissura*, *R. umbilica*, *Sphenolithus moriformis* and *Zygrhablithus bijugatus bijugatus*.

Age and biostratigraphic assignment. The presence of *Reticulofenestra umbilica* in the absence of the index Eocene taxa *Cyclicargolithus reticulatus* and *Discoaster saipanensis* suggests an early to mid Oligocene age. The absence of *Isthmolithus recurvus* favours the younger age assignment.

The assemblage is assigned to the calcareous nannofossil DI:+*Isthmolithus recurvus*/+*Reticulofenetra umbilica* (see Table 8).

Palaeoenvironment. The low diversity of the assemblage (compared with coeval low-latitudes ones) suggests cold surface waters.

Deposition was on the continental shelf as evinced by the presence of *Pontosphaera multipora* and *Zygrhablithus bijugatus bijugatus*; these taxa are usually absent from deep oceanic sediments.

Preparation 67/DR 10-1.

A subsample of the white calcareous claystone was examined. The assemblage contains abundant moderately well-preserved calcareous nannofossils.

The taxa identified include *Chiasmolitus altus* (2 sizes), *Coccolitus* sp. cf. *Coccolithus pelagicus*, *Coronocyclus nitescens*, *Cyclicargolithus floridanus* (the large form), *C.* sp. aff. *C. abisectus*, *Helicosphaera euphratis*, *H. recta*, *Pontosphaera plana*, *P. multipora*, *P.* spp., *Reticulofenestra scissura*, *Sphenolithus moriformis* and *Zygrhablithus bijugatus bijugatus*.

Age and biostratigraphic assignment. On account of the overlap in the ranges of *Zygrhablithus bijugatus bijugatus*, *Reticulofenestra scissura*, *Helicosphaera euphratis*, *H. recta* and *Chiasmolithus altus*, the age is suggested as late Oligocene. The absence of *Reticulofenestra umbilica* is in agreement with this age determination.

The assemblage is assigned to the calcareous nannofossil DI:**Helicosphaera recta*/+*Chiasmolithus altus* (see Table 8).

Palaeoenvironment. The absence of the low-latitude sphenoliths, and the presence of abundant *Chiasmolithus altus* suggest cold surface waters.

Deposition occurred in nearshore or shallow-water environment on the continental shelf as attested to by the presence of *Pontosphaera* spp. and *Zygrhablithus bijugatus bijugatus*.

Prepartion 67/DR 10-2b.

A subsample of the sediments enclosing the chert concretions was examined. Assemblage recovered is similar to that studied from Preparation 67/DR 10-1. The taxa recovered are poorly preserved, evidently as a result of diagenesis. Those identified include *Chismolithus altus*, *Coccolithus eopelagicus*, *Clausicoccus cribellum*, *Cyclicargolithus floridanus*, *Discoaster deflandrei*, *Helicosphaera recta*, *Pontosphaera* sp., *Reticulofenestra lockeri*, *R. scissura*, *Sphenolithus moriformis* and *Zygrhablithus bijugatus bijugatus*.

Age and biostratigraphic assignment. Like Preparation 67/DR 10-1, the age is late Oligocene - based on the co-occurrence of *Chiasmolithus altus*, *Helicosphaera recta* and *Reticulofenestra scissura*. The assemblage is assigned to the DI:**Helicosphaera recta*/+*Chiasmolithus altus* (see Table 8).

Palaeoenvironment. Similar to that deduced for Preparation 67/DR 10-1. Diagenestic processes (e.g. recrystallzation) is probably responsible for the reduced diversity of the hemipelgic taxa.

Preparation 67/DR 10-4.

A subsample of the bryozoal calcarenite was examined. Assemblage recovered is similar to that studied from Preparation 67/DR 10-1. However, because of coagulation on the slide, identification was limited to the few freer specimens; examination of the assemblage after onshore treatment of the preparation may reveal more taxa than recorded here. Taxa identified include *Chiasmolithus altus*, *Coccolithus eopelagicus*, *C.* sp. cf. *C. pelagicus*, *Cyclicargolithus floridanus* (2 sizes), *Discoaster deflandrei* "group", *H. euphratis*, *H. recta*, *Pontosphaera multipora*, *Reticulofenestra lockeri*, *R. scissura*, *Sphenolitus moriformis* and *Zygrhablithus bijugatus bijugatus*.

Age and biostratigraphic assignment. The age is late Oligocene based on the co-occurrence of the taxa *Chiasmolithus altus*, *Helicosphaera euphratis*, *H.*

recta and *Reticulofenestra scissura*. The assemblage is assignable to the DI:**Helicosphaera recta/+Chiasmolithus altus* (see Table 8).

Palaeoenvironment. Cold surface waters in a relatively shallow-water environment on the continental shelf, similar to the environment deduced for Preparation 67/DR 10-1.

Dredge Station 12

Preparation 67/DR 12-3.

Abundant and moderately well-preserved calcareous nannofossils were encountered in this preparation. The assemblage identified includes *Blackites spinulus*, *B. tenuis*, *Chiasmolithus altus* (2 sizes), *Clausicoccus cribellum*, *Coccolithus eopelagicus*, *Cyclicargolithus floridanus*, *Lanternithus minutus*, *Micrantholithus* sp., *Pontosphaera multipora*, *P.* sp., *Reticulofenestra hampdenensis*, *R. hillae*, *R. scissura*, *R. umbilica*, *Sphenolithus moriformis*, *Transversopontis obliquipons* and *Zygrhablithus bijugatus bijugatus*.

Age and biostratigraphic assignment. The presence of *Reticulofenestra umbillica* and *R. hillae* in the absence of the key Eocene taxa *Cyclicargolithus reticulatus* and *Discoaster saipanensis* suggests early to mid Oligocene age. The absence of *Isthmolithus recurvus* favours the younger age assignment.

The assemblage is assigned to the calcareous nannofossil DI:+*Isthmolithus recurvus/+Reticulofenestra umbilica* (see Table 8).

Palaeoenvironment. The occurrence of several hemipelagic taxa (nearshore/shallow-water indicators) such as *Lanternithus minutus*, *Micrantholithus* sp., *Zygrhablithus bijugatus bijugatus*, *Blackites spinulus* and *B. tenuis* suggests that deposition was in the shallow waters of the continental shelf.

The great abundance of *Chiasmolithus altus*, and the total absence of low-latitude sphenoliths (e.g. *Sphenolithus predistentus*) suggests cold surface water temperatures.

Preparation 67/DR 12-4.

Calcareous nannofossils recovered are abundant and moderately well-preserved. The assemblage contains *Braarudosphaera bigelowii*, *Chiasmolithus altus*, *Clausicoccus cribellum*, *Coccolithus eopelagicus*, *Cyclicargolithus floridanus*, *Discoaster deflandrei* "group", *Helicosphaera euphratis*, *H. obliqua*, *H. recta*, *Reticulofenestra scissura*, *Sphenolithus moriformis*, *Zygrhablithus bijugatus bijugatus* and *Z. bijugatus crassus*.

Age and biostratigraphic assignment. The overlap in the ranges of *Chiasmolithus altus*, *Helicosphaera recta*, *H. euphratis*, *H. obliqua*, *Reticulofenestra scissura* and *Zygrhablithus bijugatus bijugatus* suggests a late Oligocene age. Coeval low-latitude assemblages (e.g. from Ashmore Reef, NNW of Australia: Shafik & Chaproniere, 1978) contain the index species *Sphenolithus ciperoensis*.

The assemblage is assigned to the calcareous nannofossil DI:**Helicosphaera recta/+Chismolithus altus* (see Table 8).

Palaeoenvironment. Cold surface waters are indicated by the absence of the low-latitude sphenoliths. Deposition occurred in nearshore or shallow-water environment on the continental shelf as evidenced by the presence of *Braarudosphaera bigelowii*, *Zygrhablithus bijugatus bijugatus* and *Z. bijugatus crassus*.

Preparation 67/DR 12-2c.

Moderately well-preserved nannofossils among abundant fine debris were examined. Identification was hampered to some extent by coagulation on the slide; this requires onshore treatment. Taxa identified included *Braarudosphaera bigelowii*, *Chiasmolithus altus*, *Coccolithus* sp. cf. *C. pelagicus*, *Cyclicargolithus abisectus*, *C. floridanus*, corroded *Pontosphaera multipora*, *Reticulofenestra aragonensis*, *R. scissura*, *Zyygrhablithus bijugatus bijugatus* and *Z. bijugatus crassus*.

Preparation 67/DR 12-3a.

Abundant moderately well-preserved nannofossils were recovered. Taxa identified include *Braarudosphaera bigelowii* (corroded with rounded edges resembling *B. discula*), *Chiasmolithus altus* (2 sizes), *Coccolithus eopelagicus*, *C.* sp. cf. *C. pelagicus*, *Cyclicargolithus abisectus*, *C. floridanus*, *Discoaster deflandrei*, *Helicosphaera recta*, *H. obliqua*, very poorly preserved *Pontosphaera multipora* and *P. plana*, *Rhabdosphaera* sp., *Reticulofenestra scissura*, *Sphenolithus moriformis*, *Triquetrorhabdulus carinatus*, *Zygrhablithus bijugatus bijugatus* and *Z. bijugatus crassus*. Also identified very rare *Reticulofenestra umbilica* which is thought to be reworked or a contaminant from other associated 67/DR 12-3 sediment.

Age and biostratigraphic assignment. The overlap in the ranges of *Triquetrorhabdulus carinatus*, *Helicosphaera recta*, *Chiasmolithus altus* and *Reticulofenestra scissura* indicates late Oligocene age.

The assemblage is assigned to the DI:**Helicosphaera recta*/+*Chiasmolithus altus* (see Table 8).

Palaeoenvironment. The presence of the taxa *Zygrhablithus bijugatus bijugatus*, *Z. bijugatus crassus*, *Braarudosphaera bigelowii*, *Pontosphaera multipora* and *P. plana* suggests that deposition occurred in nearshore or shallow-water environment on the continental shelf. Poor preservation of the latter three species may indicate some exposure to cold water currents on the seabed.

The abundant occurrence of *Chiasmolitus altus* suggests cold surface waters.

Preparation 67/DR 12-2.

Abundant moderately well-preserved nannofossils were examined in a smear slide. Coagulation on the slide limited proper recording of the individual species, because only the free specimens could be identified with confidence; ultrasonic treatment and addition of a few drops of ammonia to the preparation may overcome the problem of coagulation. The assemblage identified is dominated by *Cyclicargolithus floridanus*, *C. abisectus*, *Coccolithus eopelagicus*, and *C.* sp. cf. *C. pelagicus*, also present are *Sphenolithus* *moriformis* (frequent), *Helicosphaera kamptneri* (frequent to rare), *Discoaster deflandrei* "group" (frequent to rare), and rare *Calcidiscus leptoporus*, *Pontosphaera multipora* and *P. plana*.

Age. The co-occurrence of *Helicosphaera kamptneri*, *Calcidiscus leptoporus* and *Cyclicargolithus abisectus* suggests an early (possibly earliest) Miocene age. The absence of *Reticulofenestra scissura*, *Helicosphaera recta* and *Zygrhablithus bijugatus bijugatus* supports this age assignment. These taxa are known to disappear near or at the Oligocene/Miocene boundary, and are also known to abundantly occur in the upper Oligocene of the Otway Basin (e.g. 67/DR 10-1).

Palaeoenvironment. Low species diversity suggests cold water temperatures. Deposition was at intermediate depths as attested to by the rare occurrence of *Pontosphaera* spp.

Preparation 67/DR 12-5.

A late Quaternary moderately well-preserved coccolith assemblage was extracted. Coccoliths were few, nevertheless. Older taxa encountered were very rare. The late Quaternary taxa included *Calcidiscus leptoporus*, *C.* sp. cf. *C. macintyrei*, *Coccolithus pelagicus*, *Emiliania huxleyi*, *Gephyrocapa oceanica* and *Helicosphaera wallichiii*. The older taxa are *Cyclicargolithus floridanus* (few specimens), and a single specimen of *Sphenolithus predistentus/S. distentus*.

Preparation 67/DR 12-1.

No calcareous nannofossils were found in this preparation; the age of the sample could not be determined.

Dredge Station 14.

Dredging was attempted along the western side of a SSW trending canyon, south of Port Macdonnell, between Lat. 38 50.00S - Long. 140 35.4 E and Lat. 38 49.8 S - Long. 140 35.0 E. Water depth ranges between 3050 and 3100 metres. Several types of sediment/rock were recovered: White bored and bioturbated fine grained chalks containing chert nodules, with pale green weathering surface (DR 14-1). Also recovered a small piece of white foram-rich clay, with some shelly fragments (DR 14-7) and grey foram nanno ooze (DR14-8).

Preparation 67/DR 14-1a.

A subsample of the white chalks was examined. Abundant moderately well-preserved calcareous nannofossils were encountered in this preparation. Diversity of the assemblage is relatively low, consisting mainly of *Cyclicargolithus floridanus* (2 sizes), *Chiasmolityhus altus*, *Coccolithus eopelagicus*, *C.* sp. cf. *C. pelagicus*, *Reticulofenestra scissura*, *Sphenolithus moriformis* and *Zygrhablithus bijugatus bijugatus*.

Preparation 67/DR 14-1c.

A subsample of the white chalks was examined. A rich assemblage of moderately well-preserved calcareous nannofossils was recovered from this preparation. The taxa identified include *Coccolithus* sp. *C. pelagicus*, *Cyclicargolithus floridanus*, *C.* sp. aff. *C. abisectus*, *Discoaster deflandrei* "group", *Helicosphaera euphratis*, *H. perch-neilseni*, *?Pontosphaera plana*, *Reticulofenestra aragonensis*, *R. scissura*, *Sphenolithus ciperoensis*, *S. moriformis* and *Zygrhablitus bijugatus bijugatus*.

Age and biostratigraphic assignment. The overlap in the ranges of the taxa *Reticulofenestra scissura*, *Helicosphaera euphratis* and *H. perch-neilseni* suggests a late Oligocene age. The presence of the low-latitude *Sphenolithus ciperoensis* supports this age determination.

The assemblage is assigned to the interval with *Spenolithus ciperoensis* (see Table 8) which is bracketted by the DI:+*Chiasmolithus altus*/+*Reticulofenestra scissura*.

Remarks. Most of the late Oligocene assemblages examined from the Otway Basin are considered typical of higher latitudes because they contain abundant *Chiasmolithus altus*, and lack the low-latitude index sphenoliths; the genus *Chiasmolithus* is thought to have flourished particularly well at high latitudes. However, occasionally *Spenolithus ciperoensis* is found in the southern Australian Oligocene (e.g. Kingston #1 Bore in the Gambier Embayment: Shafik, unpublished data; BMR core 67/GC 54cc), suggesting episode(s) of warming.

The assemblage of Preparation 67/DR 14-1c evidently represents a short warming episode. The absence of cold-water indicator *Chiasmolithus altus* from the assemblage strongly supports this conclusion.

Preparation 67/DR 14-1b.

A subsample of the white chalks was examined. Assemblage recovered is dominated by two species even though the diversity is reasonably high. Preservation is moderate, but calcareous nannofossil debris is abundant. The dominant species are *Cyclicargolithus abisectus* and *C. floridanus*. Other taxa included *Calcidiscus leptoporus*, *Coccolithus miopelagicus*, *C.* sp. cf. *C. pelagicus*, *Diascoaster deflandrei* "group", *D. variabilis* "group", *Helicosphaera granulata*, *Reticulofenestra pseudoumbilica*, *Sphenolithus heteromorphus* and *S. moriformis*. Poor preservation of the discoasters made their finer differentiatin difficult.

Age. The presence of the index species *Sphenolithus heteromorphus* suggests late early to early middle Miocene. The vertical range of this species straddles the boundary between the early and middle Miocene according to many authors (e.g. Martini, 1971). Biostratigraphic distinction of this boundary is usually drawn at the extinction of *Helicosphaera ampliaperta* (see, e.g. Martini, 1971). *H. ampliaperta* has yet to be found in southern Australia. In contrast, *Sphenolithus heteromorphus* has a wide geographic range, and has been recorded from several Victorian sections (e.g. Sorento Bore, and Fossil Beach section: Shafik, unpublished data); in core 67/DR 35, displaced coeval mudstone containing abundant *Sphenolithus heteromorphus*, is bounded by Quaternary clays.

The absence of the *Helicosphaera ampliaperta* from Preparation 67/DR 14-1b and the Victorian Tertiary may not be biostratigraphically correlatable with this species extinction elsewhere.

Preparation 67/DR 14-1e.

A subsample of the white chalks was examined. Abundant moderately well-preserved calcareous nannofossils were extracted. Diversity is similar to the assemblage of Preparation 67/DR 14-1b. The taxa identified include *Calcidiscus leptoporus*, *Coccolithus miopelagicus*, *C.* sp. cf. *C. pelagicus*, *Discoaster deflandrei* "group", *D. variabilis* "group", *Helicosphaera kamptnerii*, *Sphenolithus heteromorphus* and *S. moriformis*.

Age. On account of the presence of *Sphenolithus heteromorphus*, the age is late early to early middle Miocene (see above remarks on age of 67/DR 14-1b).

Preparation 67/DR 14-1d.

A subsample of the white chalks was examined. Abundant and moderately well-preserved calcareous nannofossils were recovered. The assemblage is reasonably diversified, including the taxa *Calcidiscus leptoporus*, *Coccolithus* sp. cf. *C. pelagicus*, *Coronocyclus nitescens*, *Cyclicargolithus abisectus*, *C. floridanus*, *Discoaster deflandrei* "group", *D. variabilis* "group", *Helicosphaera granulata*, *H. kamptneri*, *Pontosphaera multipora*, *Sphenolithus abies* and *S. moriformis*.

Age. Based on the presence of *Calcidiscus leptoporus* and *Helicosphaera kamptneri* the age is tentatively considered as early to mid Miocene.

Preparation 67/DR 14-7.

A subsample of white soft calcareous clay recovered in the dredge pipe was examined. Abundant moderately well-preserved calcareous nannofossils were extracted. Taxa identified include *Calcidiscus leptoporus*, *C. macintyrei*, *Coccolithus* sp. *C. pelagicus*, *Coronocyclus nitescens*, *Cyclicargolithus floridanus*, *Discoaster variabilis* "group", *Helicosphaera granulata*, *H. kamptneri* and small *Reticulofenestra pseudoumbilica*.

Preparation 67/DR 14-8.

A subsample of the pale grey foram nanno ooze. Coccoliths extracted are abundant and moderately well-preserved. The identified include abundant *Gephyrocapsa oceanica* and *Emiliania huxleyi*. Other taxa identified are *Calcidiscus leptoporus*, *Coccolithus pelagicus*, *Gephyrocapsa caribbeanica*, small *Gephyrocapsa* spp., *Helicosphaera wallichii* and *Rhabdosphaera stylifer*.

Age. Late Quaternary on account of the presence of *Emiliania huxleyi* and *Gephyrocapsa oceanica*. The absence of the key species *Pseudoemiliania lacunosa* supports this age assignment.

Palaeoenvironment. Low species diversity of the assemblage coupled with the occurrence of common *Coccolithus pelagicus* suggest cold surface waters.

Dredge Station 15

This station lies south of Port Macdonnell in a canyon at Lat. 38 57.7 S - Long. 140 51.5 E where water depth is 3000 metres. No Tertiary coccoliths were found in the samples examined from this station.

Dredge Station 16

This station lies south of Portland between Lat. 38 54.17 S - Long. 141 29.32 E and Lat. 38 53.5 S - Long. 141 29.2 E where water depth ranges between 1733 and 1450 metres. The target was the Eocene sequence. Only the pipe dredge recovered material: light olive grey mud from which calcareous nannofossils indicative of late Quaternary age were extracted.

Dredge Station 17

Dredging was atempted between Lat. 39 09 S - Long. 141 51.1 E and Lat. 39 09 S - Long. 141 53.0 E, where water depth ranges between 2270 and 2060 metres. No Tertiary coccoliths were found in the samples examined from this station.

Dredge Station 18

This station lies SW of Portland between Lat. 39 12.9 S - Long. 142 7.2 E and Lat. 39 11.8 S - Long. 142 11.5 E, where water depth is between 1950 and 1650 metres. The target was Oligocene and older rocks. The dredge chain bag was recovered empty, but the pipe contained about 15 Kg of brown mud which after washing yielded a few pieces of sediments. These pieces could be sorted into six types of sediments: Moderately lithified foram- bearing white chalk (67/DR 18-1), soft white calcareous mud (67/DR 18-2), pale brown mostly non calcareous, weakly lithified siltstone (67/DR 18-3), light olive grey foram nanno ooze (67/DR 18-4), one piece of dark grey lithified mudstone (67/DR 18-5), and soft olive grey calcareous mud (67/DR 18-6).

Preparation 67/DR 18-3b.

Calcareous nannofossils are rare but diversified. The moderately well-preserved assemblage includes *Blackites ampulus*, *B. spinulus*, *B. tenuis*, *Chiasmolithus oamaruensis/C. altus*, *Clausicoccus cribellum*, *Coccolithus* sp. cf. *C. pelagicus*, *Cylicargolithus floridanus*, *Isthmolithus recurvus*, *Lanternithus minutus*, *Reticulofenestra hampdenensis*, *R. scrippae*, *R. scissura*, *R. umbilica*, *Trannsversopontis pulcher*, *T. pulcheroides*, *T. zigzag* and *Zygrhablithus bijugatus bijugatus*. Species of *Transversopontis* and *Reticulofenestra hampdenensis* are particularly abundant.

Age and biostratigraphic assignement. The co-occurrance of *Isthmolithus recurvus* and *Reticulofenestra umbilica* in the absence of the Eocene index taxa *Cyclicargolithus reticulatus* and *Discoaster saipanensis* suggests an early Oligocene age. However, the absence of particularly *Discoaster saipanensis* (indicative of latest Eocene) may not be bioastratigraphcally significant, the age is considered latest Eocene to early Oligocene.

Palaeoenvironment. The abundance occurrance of *Transversopontis* spp., *Zygrhablithus bijugatus bijugatus* and *Lanternithus minutus* suggests that deposition occurred in nearshore or in shallow waters of the continental shelf. The temperature of the surface waters must have been cold on account of the total absence of discoasters and the abundant occurrence of chiasmoliths. The presence of *Isthmolithus recurvus* agrees with this conclusion.

Remarks.The nannofossil assemblage of 67/DR 18-3b is coeval with the assemblage from 67/DR 10-3b dredged from Km to the. The two assemblages are very similar, and came from similar water depth range; dredging at Stations 10 and 18 was successfull where water depth ranges between 1950 and 1650 metres.

Preparation 67/DR 18-1.

Abundant poorly preserved calcareous nannofossils were extracted. Poor preservation is evidently caused by partial dissolution. The taxa identified include *Calcidiscus leptoporus, C. macintyrei, ?Cyclicargolithus abisectus, ?C. floridanus, Coccolithus* sp. cf. *C. pelagicus, Discoaster variabilis, Helicosphaera euphratis, H. granulata, H. kamptnerii, ?Pontosphaera multipora, Reticulofenestra gelida, R. pseudoumbilica* and *Sphenolithus abies.*

Age. The overlap in the ranges of several taxa such as *Helicosphaera euphratis, H. kamptnerii, Calcidiscus macintyrei, Cyclicargolithus floridanus, and Reticulofenestra pseudoumbilica* suggests a middle Miocene age.

Palaeoenvironment. The very low diversity of discoasters suggests cold surface waters. The presence of the higher latitude species *Reticulofenestra gelida* supports this conclusion.

Preparation 67/DR 18-2.

Preservation of the abundant calcareous nannofossils recovered in this preparation is better than in 67/DR 18-1. The assemblage includes *Calcidiscus leptoporus, C. macintyrei, Coccolithus miopelagicus, C.* sp. cf. *C. pelagicus, Cyclicargolithus abisectus, Discoaster exilis, Helicosphaera granulata, H. kamptnerii, Reticulofenestra gelida, R. pseudoumbilica, Scapholithus fossilis* and *Sphenolithus abies.*

Age. On account of the occurrence of *Reticulofenestra pseudoumbilica, Cyclicargolithus abisectus, Discoaster exilis* and *Calcidiscus macintyrei* the age is middle Miocene.

Palaeoenvironment. Low diversity of the discoasters and the abundant occurrence of *Reticulofenestra gelida* suggest cold surface waters.

Preparation DR 18-3a.

Almost non-fossiliferous, but with very rare specimens of *Spenolithus abies, Reticulofenestra gelida*, small *Calcidiscus leptoporus* and a corroded *Cyclicargolithus abisectus* suggesting a "middle" Miocene age.

Preparation 67/DR 18-4.

A late Quaternary coccolith assemblage was identified. This included *Calcidiscus leptoporus, C. macintyrei, Coccolithus pelagicus, Emiliania huxleyi, Gephyrocapsa caribbeanica, G. oceanica, Helicosphaera wallichii* and *Pontosphaera plana.* The low species diversity and the high abundance of *Coccolithus pelagicus* suggest cold surface waters.

Preparation 67/DR 18-6.

A late Quaternary assemblage was identified similar to that recorded from 67/DR 18-4. Additional taxa present included *Braarudosphaera bigelowii* which may suggest deposition in shallow water or nearshore environment on the continental shelf. Older taxa were encountered but as a very minor component of the assemblage. These included *Cyclicargolithus abisectus* and *C. floridanus* suggesting a mid Tertiary source.

Dredge Station 19

Dredging was attempted on mid slope, SW of Nautilus #A-1 well, between Lat. 39 29.2 S - Long. 142 13.4 E and Lat. 39 29.5 S - Long. 142 16. 2 E where water depth ranges between 2600 and 2100 metres. The target was pre-Oligocene rocks on fault scarp/canyon wall. Off white semi-consolidated chalky material (67/DR 19-1) was recovered from the jaws of the chain bag dredge. Others material recovered came from the dredge pipe: A few small pebbles of pale brown finely bored mudstone (67/DR 19-2), plastic pale grey foram nanno ooze (67/DR 19-3), and soft pale brownish grey foram nanno ooze (67/DR 19-4).

<u>Preparation 67/DR 19-1</u>.

Moderately well-preserved calcareous nannofossil assemblage was extracted. Main elements identified include *Coccolithus* sp. cf. *C. pelagicus*, *Cyclicargolithus floridanus*, *Discoaster deflandrei*, *Helicosphaera euphratis*, *H. obliqua*, *Pontosphaera multipora*, *Reticulofenestra aragonensis*, *R. lockeri*, *R. scissura*, *Sphenolithus moriformis* and *Zygrhablithus bijugatus bijugatus*.

<u>Age and biostratigraphic assignment</u>. The overlap in the ranges of *Reticulofenestra scissura*, *Helicosphaera euphratis* and *H. obliqua* suggests a late Oligocene age.

The absence of *Chiasmolithus altus* is considered biostratigraphically significant. The assemblage is assigned to the DI:+*Chismolithus altus* +*Reticulofenestra scissura* (see Table 8). The evidence from elsewhere in the Otway Basin suggests the occurrence of short warming episode during this late Oligocene biostratigraphic interval.

<u>Palaeoenvironment</u>. Temperate conditions probably prevailed. This is based on the absence of the cold temperature indicator *Chiasmolithus altus*.

Deposition occurred in shallow-water or nearshore environment on the continental shelf as attested to by the presence of *Zygrhablithus bijugatus bijugatus* and *Pontosphaera multipora*.

<u>Preparation 67/DR 19-4</u>.

Common moderately well-preserved calcareous nannofossils were recovered. The assemblage includes *Coccolithus* sp. cf. *C. pelagicus*, *Cyclicargolithus abisectus*, *C. floridanus*, *Discoaster deflandrei*, *Helicosphaera euphratis*, *H. intermedia*, *H. obliqua*, *Rhabdosphaera* sp. *Reticulofenestra aragonensis*, *R. lockeri*, *R. scissura*, *Sphenolithus abies*, *S. ciperoensis* and *S. moriformis*. Also identified were *Helicosphaera* sp. aff. *H. kamptnerii* and small *Gephyrocapsa* spp., which thought to be contaminants of the associated upper Quaternary sediments (67/DR 19-2 & 67/DR 19-3).

<u>Age and biostratigraphic assignment</u>. Based on the co-occurrence of several key taxa such as *Helicosphaera euphratis*, *H. obliqua*, *Reticulofenestra scissura* and *Cyclicargolithus abisectus*, a late Oligocene is suggested. The presence of *Sphenolithus ciperoensis* supports this age determination.

The assemblage is assigned to the interval with *Sphenolithus ciperoensis* (see Table 8). This interval is bracketted by the DI:+*Chiasmolithus altus*/+*Reticulofenestra scissura*.

Palaeoenvironment. The presence of the low-latitude *Sphenolithus ciperoensis* suggests a short peroid of warming during the late Oligocene in the Otway Basin.

The lack of hemipelagic taxa such as *Zygrhablithus bijugatus bijugatus* and *Pontosphaera multipora* (encountered in Preparation 67/DR 19-1) suggests that deposition occurred at deeper levels than 67/DR 19-1.

Preparation 67/DR 19-2.

Late Quaternary assemblage was recovered, including *Emiliania huxleyi, Calcidiscus leptoporus, ?C. macintyrei, Coccolithus pelagicus, Gephyrocapsa oceanica, G. caribbeanica, Helicosphaera wallichii, Rhabdosphaera stylifer* and *Scapholithus fossilis*. In addition large number of late Oligocene calcareous nannofossils were identified, but these could be contaminant from the associated upper Oligocene sediments (67/DR 19-1 & 67/DR 19-4).

Preparation 67/DR 19-3.

Assemblage recovered is similar to the late Quaternary assemblage of Preparation 67/DR 19-2, without the association of the late Oligocene taxa.

CORRELATION WITH EOCENE AND OLIGOCENE DREDGES RECOVERED DURING BMR 48 CRUISE

Middle Eocene

Two middle Eocene assemblages were identified from material dredged during BMR 48 Cruise from the continental slope WSW of Portland (48/DR 7) (see Figs. 1 & 2): an assemblage characterised by the overlap in the ranges of *Chiasmolithus solitus*, *Daktylethra punctulata* and *Reticulofenestra scissura*, and another characterised by the presence of *Reticulofenestra scissura* and the absence of both *Daktylethra punctulata* and *Chiasmolithus solitus*. calcareous mud (48/DR 7-3). The middle Eocene assemblage recorded in this report was dredged from a steep slope south of Argonaut well (67/DR 10) some Km to the N of 48/DR 7, does not correlate with either of the middle Eocene of 48/DR 7, on account that it predates the appearance of typical *Reticulofenestra scissura*. Thus the recovered middle Eocene sequence in the offshore Otway Basin during both BMR cruises, arranged chronologically (starting with the older), is:

1. Assemblage found in a brownish grey calcareous clay (67/DR 10-3a) containing the taxa *Chiasmolithus grandis/C. expansus, Cyclicargolithus reticulatus, Discoaster saipanensis, Helicosphaera reticulata, Neococcolithes dubius* and *Reticulofenestra* sp. cf. *R. scissura*.

2. Assemblage recovered from brown sandy siltstone (48/DR 7-1) including the key taxa *Chiasmolithus grandis/C. expansus, Cyclicargolithus reticulatus, Daktylethra punctulata, Discoaster barbadiensis, D. saipanensis, Helicosphaera reticulata, Neococcolithes dubius* and rare *Reticulofenestra scissura*.

3. Assemblage extracted from a white semi-consolidated calcareous mud (48/DR 7-3) containing *Chiasmolitus grandis/C. expansus*, *Cyclicargolithus retculatus*, *Discoaster saipanensis*, *Neococcolithes dubius* and *Reticulofenestra scissura*.

The middle assemblage is more diversified than the other two, and may represent a warmer period. It correlates with the low-latitude planktic foraminiferal zone (probably middle) P. 13. *Discoaster barbadiensis* is known to disappear above this level in the Otway Basin. But, in low latitude areas (e.g. Italy: Roth & others, 1971; Blake Plateau: Gartner, 1971) this species ranges to near the top of the Eocene.

Late Eocene

Sediments recovered during BMR Cruise 48 did not yield calcareous nannofossil of definite late Eocene. A gravity core (67/GC 05) and two dredge samples obtained during BMR Cruise 67 contained several late Eocene nannofossil assemblages. These can be summarised as follows (in an ascending order):

1. Assemblages identified from the lower part of core 67/GC 05, and from the brownish grey calcareous clay of the dredge subsample 67/DR 10-3c. These assemblages are characterised by the overlap in the ranges of the key taxa *Neococcolithes dubius* and *Chiasmolithus oamaruensis*. The index taxa *Cyclicargolithus reticulatus* and *Discoaster saipanensis* are present, and *Isthmolithus recurvus* is absent. Forms similar to *Chiasmolithus grandis* without its teeth were noted in the assemblage of 67/DR 10-3c.

2. Assemblages recorded from the mudstone of core 67/GC 05 between 30- and 2-cm levels. These assemblages are characterised by the overlap in the ranges of the index taxa *Isthmolithus recurvus*, *Discoaster saipanensis* and *Cyclicargolithus reticulatus*.

3. Assemblage extracted from the semi-lithified olive grey sandy siltstone of the dredge subsample 67/DR 2-2b. This assemblage can be characterised by the overlap in the ranges of the index taxa *Isthmolithus recurvus* and *Discoaster saipanensis* in the absence of *Cyclicargolithus reticulatus*.

Latest Eocene to early Oligocene

Two groups of assemblages assignable to the latest Eocene - early Oligocene age range are distinguished. One group with *Cyclococcolithus formosus*, possibly the older, and another without the same species. *C. formosus* is usually rare in the upper Eocene - Lower Oligocene sediments of the Otway Basin, and therefore its absence in this interval is considered as biostratigraphically unreliable.

Assemblages containing *Isthmolithus recurvus*, *Lanternithus minutus*, *Cyclococcolithus formosus* and *Reticulofenestra umbilica* without the association of the key taxa *Cyclicargolithus reticulatus* and *Discoaster saipanensis* were recovered during both BMR Cruises 48 and 67, from dredge subsamples 48/DR 7-1a and 67/DR 10-3d respectively. These assemblages were assigned a latest Eocene or early Oligocene age. Although the top of the range of *D. saipanensis* has been used by most investigators to delineate the Eocene/Oligocene boundary (see, e.g., Perth-Nielsen, 1985), nannofossil distribution in onshore Otway Basin material (Shafik, 1983) suggests that the absence of this species above the (usually reliable) extinction datum of *Cyclicargolithus reticulatus* is not always reliable as a biostratigraphic evidence.

Assemblages containing *Isthmolithus recurvus* and *Reticulofenestra umbilica* but seemingly lacking *Cyclococcolithus formosus* were recorded from three dredge stations occupied during BMR 67 (see Table 8); similar assemblages were not identified during BMR Cruise 48.

Early to mid Oligocene

Assemblages predating the appearance of the late Oligocene index taxa *Helicosphaera recta* and *H. obliqua*, and postdating the extinction of *Isthmolithus recurvus* were identified from dredge material obtained during BMR Cruises 48 and 67. However, those assemblages are not correlatable (see Table 8) and can be differentiated by the presence or absence of *Reticulofenestra umbilica*.

Assemblages characterised by the presence of *Reticulofenestra umbilica* were recorded from subsample 67/DR 10-2a , dredged during BMR Cruise 67. These assemblages are slightly older that the assemblages recovered from the dredges 48/DR 7-7 and 48/DR 5-1 which were obtained during BMR Cruise 48.

The assemblages of 48/DR 7-7 and 48/DR 5-1 lacked *Reticulofenestra umbilica* but contained the key taxa *Chiasmolitus altus*, *Cyclicargolithus floridanus*, *Reticulofenestra daviesi*, *R. scrippae* and *R. scissura*. The low-latitude *Sphenolithus predistentus* was also encountered in the 48/DR 5-1 assemblage.

Late Oligocene

Assemblages predating the extinction of *Reticulofenestra scissura* and postdating the appearance of *Helicosphaera recta* and *H. obliques* were recovered during BMR Cruises 48 and 67. Those obtained during Cruise 48 include the index species *Chiasmolithus altus*, and correlate with similar assemblages obtained from dredge stations 10, 12, and 14. Assemblages lacking *C. altus* were recovered from core and dredge material obtained during BMR Cruise 67 and not Cruise 48.

An excursion by the low-latitude *Sphenolithus ciperoensis* into southern Australia during the late Oligocene is detected, based on occurrences of the species at three offshore locations (DR14, DR19 and GC54) and in the onshore Gambier Embayment (Shafik, unpublished data). in both offshore and onshore southeastern Australia.

CONCLUSIONS

1. The evidence from dredge stations 2 and 10 suggests progressive shoaling or sea-level fall during the middle Eocene through into the early Oligocene.

2. A temperature decline occurred during the later part of the Eocene and early Oligocene, subsequent to a peak during the middle Eocene DI:**Reticulofenestra scissura*/+*Daktylethra punctulata* (=mid planktic foraminiferal zone P.13).

3. An excursion by the low-latitude *Sphenolithus ciperoensis* into the Otway Basin and western Tasmania occurred during the late Oligocene DI:+*Chiasmolithus altus*/+*Reticulofenestra scissura* is concluded based on evidence from Stations 14, 19 and 54.

4. The widespread occurrence of *Sphenolithus heteromorphus* in the southeastern Australian region, including the offshore Otway Basin, suggests an important event in the Miocene of the region. This event is coeval with a worldwide similar event, and provides a direct correlation with low-latitude nannofossil zonations.

5. During the late Pliocene, surface waters were cold in the Otway Basin as evidenced by the total lack of slim-rayed discoasters and the abundant occurrence of *Coccolithus pelagicus*.

QUATERNARY COCCOLITHS FROM OFFSHORE OTWAY BASIN AND OFF WEST TASMANIA (Samir Shafik)

ABSTRACT

Quaternary coccoliths were extracted from many gravity cores taken along several profiles in the offshore Otway Basin and west of Tasmania during BMR Cruise 67. The absence of the index species *Pseudoemiliania lacunosa* from these cores places them in the late Quaternary. The abundant occurrence of *Coccolithus pelagicus*, the total absence of coeval low-latitude coccoliths such as *Umbellosphaera irregularis* and *Ceratolithus cristatus*, and the low species diversity of the assemblages suggest cold surface waters.

A revision of the biostratigraphic scheme, above the highest occurrence of *Pseudoemiliania lacunosa*, is made based on shipboard examination of the cores.

INTRODUCTION

A major coring programme along several profiles in the offshore Otway Basin and west of Tasmania was carried out during BMR Cruise 67 in order to evaluate hydrocarbon seepage. Coccoliths indicative of Quaternary age were extracted from most of the cores; the writer discussed the calcareous nannofossils of the Tertiary cores in another report. Cores which recovered Tertiary sediments invariably contain Quaternary coccoliths at their tops. Also most of the dredges attempted during the same BMR cruise recovered Quaternary sediments in the pipe dredge.

ASSEMBLAGES

The assemblages extracted from the Quaternary material examined are not dissimilar. Details of examples of these assemblages (in three gravity cores) are given below.

Gravity Core 67/GC 06.

This core was taked at Lat. 39 30.8 S - Long. 139 57.7 E, where the water depth is 4956 metres, and retrieved 265 cm of pelagic oozes, muds and turbidites. These were found to contain Quaternary coccoliths. Several levels were studied but no atttempt was made to biostratigraphically subdivide this core.

The bottom of core (265 cm) is almost barren of calcareous nannofossils, except for a few specimens of *Calcidiscus leptoporus* and *Gephyrocapsa* spp. (which have lost their bridges). While some of these few coccolith specimens could be contaminants, others are a residue left after severe dissolution because of deposition below the CCD: Some calcareous nannofossil taxa are known to persist below the CCD, probably because of protection by an organic film.

The sample from the 190-cm level yielded abundant moderately well preserved Quaternary coccoliths. The assemblage is dominated by small *Gephyrocapsa* spp. but also contains common *Calcidiscus leptoporus*, *Coccolithus pelagicus*, *Gephyrocapsa caribbeanica*, *G. oceanica* and *Helicosphaera carterii*. *Thoracosphaera* sp. is present.

The samples from the turbidites (at the 158- and 44-cm levels) contain similar Quaternary coccoliths, but also a large number of reworked taxa, mostly from early and mid Tertiary sources. The reworked taxa include *Chiasmolithus altus*, *C. eograndis*, *Cyclicargolithus abisectus*, *C. floridanus*, *Discoaster deflandrei*, *D. tani*, *Reticulofenestra hampdenensis*, *R. pseudoumbilica*, *R. scrippsae*, *R. scissura* and *Spenolithus abies*. The Quaternary taxa include both poorly and well preserved elements, and probably have been partly reworked. Ascidian spicules, indicative of shallow-water deposition, are present in the turbidite samples.

A sample from 117 cm yielded a Quaternary assemblage of abundant mainly poorly-preserved taxa, with a very minor reworked component.

The sample from 74 cm contained abundant but mainly poorly-preserved Quaternary taxa, in association with well-preserved Eocene taxa such as *Cyclicargolithus reticulatus*, *Reticulofenestra umbilica*, *Sphenolithus moriformis*, *Transversopontis* spp. and *Zygrhablithus bijugatus bijugatus*, and the later Tertiary *Cyclicargolithus abisectus* and *Sphenolithus abies*. The presence of the holococcolith *Zygrhablithus bijugatus bijugatus* and *Transversopontis* spp. suggests that the reworked Eocene source was deposited under shallow-water conditions, whereas Quaternary taxa were deposited much deeper as attested by their poor state of preservation.

The sample from 54 cm contains poorly-preserved but abundant Quaternary taxa, with very minor older elements. The Quaternary taxa are dominated by *Coccolithus pelagicus*, most of the species of the genus *Gephyrocapsa* are without their central bridges, and *Calcidiscus leptoporus* is represented mainly by single corroded shields.

The two samples from 20 cm and from the top of the core contain moderately well-preserved Quaternary taxa in association with a significant number of early and mid Tertiary species. The Quaternary assemblage from the top of the core includes *Calcidiscus leptoporus*, *Gephyrocapsa oceanica*, *Helicosphaera carterii*, *Pontosphaera plana*, *Rhabdosphaera stylifer* and several small *Gephyrocapsa* species (including *G. aperta* which was found as an intact coccosphere).

Gravity Core 67/GC 07.

This core was taken on the outer ridge of Argonaut well, north of Dredge Station 67/DR 09, at Lat. 39 20.02 S - Long. 139 58.95 E, where water depth is 4120 metres, and recovered 287 cm of oozes, mud and clays.

Coccolith assemblages extracted at several levels are Quaternary in age on account of the presence of *Gephyrocapsa* spp. at some levels, including the bottom of the core at 187 cm (see Table 9). Preservation is generally poor because of partial dissolution, seemingly as a result of deposition near the CCD. Most of the assemblages are dominated by small placoliths, similar in size to the late Pleistocene-Holocene *Emiliania huxleyi*, but often include forms with central bridges referable to the genus *Gephyrocapsa*. Displaced older taxa constitute a very minor component of the assemblages, but their presence is undeniable. These are mainly *Chiasmolithus altus*, *Cyclicargolithus abisectus*, *Discoaster deflandrei* 'group' and *Reticulofenestra scissura*, suggesting mid Tertiary source(s).

Gravity Core 67/GC 11.

This core was taken from south of Argonaut well at Lat. 38 45.00 S - Long. 140 7.70 E where water depth is 3224 metres, and retrieved 308 cm of oozes and mud. It was targeted to sample Eocene sediments at top of seaward dipping fault, but sediments recovered are late Quaternary in age on account of their calcareous nannofossils.

The sample from the corecatcher at 308 cm yielded abundant moderately well-preserved late Quaternary taxa, a few older species, and abundant nannofossil debris. The Quaternary taxa include *Calcidiscus leptoporus*, *Coccolithus pelagicus*, *C. doronicoides*, *Gephyrocapsa caribbeanica*, *G. oceanica*, small *Gephyrocapsa* spp., *Helicosphaera carterii*, *H. colombiana*, and *Rhabdosphaera stylifer*. Older species encountered are *Chiasmolithus altus*, *Cyclicargolithus abisectus* and *Reticulofenestra pseudoumbilica*, which suggest that reworking was from mid and upper Tertiary sources.

Assemblages recovered at 280, 209, 140, and 73 cm and from the top of the core are similar to the assemblage of the corecatcher; abundant nannofossl debris occurs in all samples examined. Forms probably referable to both *Emiliania huxleyi* and *Calcidiscus macintyrei* range up to the top of the core. The ranges of these two taxa elsewhere are mutually exclusive; SEM examination will be carried out to determine (with confidence) the presence of *Emiliania huxleyi*. *Pontosphaera plana* was found at the top of the core. Minor reworking was detected at most levels, and the displaced taxa suggest mid Tertiary source(s).

DISCUSSION AND CONCLUSIONS

The assemblages are interpreted as having lived in cold waters during the late Quaternary:

1. Virtually total lack of the low-latitude taxa such as *Umbellicosphaera irregularis* and *Ceratolithus cristatus* in most of the cores; the very few occurrence of *U. irregularis* noted are notwithstanding.

2. Abundant occurrence of *Coccolithus pelagicus* in most of the cores, suggesting cold surface waters.

3. Generally low species diversity of all assemblages, also suggestive of cold surface waters.

4. Absence of *Pseudoemiliania lacunosa*, suggesting late Quaternary age.

Coccolith events younger than the highest occurrence of *Pseudoemiliania lacusona* are only two in most widely-used zonations, but resolution is great as the extinction of *P. lacunosa* is dated as 0.45 Ma (see Table 10). These events are the lowest occurrence of *Emiliania huxleyi* and the subsequently wordly-wide dominance of the same species. However, *E. huxleyi* is very small and is usually difficult to be recognised in optical microscopy, especially where it is not very abundant. The shipboard study of the Quaternary cores recovered during BMR Cruise 67 has led to a possible refinement of the biostratigraphic scheme above the highest occurrence of *Pseudoemiliania lacunosa* (see Table 11). It made use of an acme of several small *Gephyrocaosa* spp. occurring above the extinction of *P. lacunosa*, and also an acme of the larger *Gephyrocapsa oceanica* above the lowest occurrence of *Emiliania huxleyi*.

Table 9. Quaternary coccolith assemblages of core 67/GC 07.

Level (cm)	Assemblage and remarks
2-3	Small *Gephyrocapsa* spp., *?Emiliania huxleyi*, *Coccolithus pelagicus*, *Calcidiscus leptoporus*, *Helicosphaera carterii* and *Umbilicosphaera sibogae*. Common *Gephyrocapsa oceanica*. Coccolith debris abound. very minor reworking
46-47	Preservation is poor and the assemblages are dominated by *?E. huxleyi*/small *Gephyrocapsa* spp.. Also occurring are *Calcidiscus leptoporus*, *Coccolithus pelagicus*, *Helicosphaera carterii* and *Rhabdosphaera stylifer*. No reworked taxa.
71-72	Preservation is slightly better than above. Assemblages very similar to above. *Gephyrocapsa oceanica* was identified. No reworked taxa.
126-127	Almost barren of coccoliths. Very specimens were noted. Corroded single shields of *Calcidiscus leptoporus* and 'ghosts' of *Coccolithus pelagicus* and *Helicosphaera carterii*.
151-152	Preservation is poor. Assemblages are dominated by *?E. huxleyi*/small *Gephyrocapsa* spp.. Common *Calcidiscus leptoporus*, *Coccolithus pelagicus* and *Helicosphaera carterii*. Very minor reworking.
170	Same as above, but no reworked taxa was detected.
190	Same as at 170
233-234	Small placoliths dominating, but none with a central bridge (*Gephyrocapsa*). Common *Coccolithus pelagicus*, and frequent *Calcidiscus leptoporus* and *Helicosphaera carterii*. Minor rewoking, but displaced taxa are more diversified than in other levels.
235-236	Preservation is poor. Assemblages dominated by *?Emiliania huxleyi*/small *Gephyrocapsa* spp.. *Calcidiscus leptoporus*, *Coccolithus pelagicus*, *Helicosphaera carterii*, *?Pseudoemiliania lacunosa* and *Rhabdosphaera stylifer* are present. Very minor reworking.
287	Similar to above, but with *Calcidiscus macintyrei*. Very minor reworking.

Table 10. Quaternary coccolith biostratigraphy.

Magnetic reversals	Coccolith event and its numerical age
BRUNHES	Acme *Emiliania huxleyi*.........0.07 Ma **Emiliania huxleyi*.............0.27 Ma +*Pseudoemiliania lacunosa*......0.45 Ma
Jaramillo	**Gephyrocapsa oceanica*
MATUYAMA	+*Helicosphaera sellii*
Olduvai	+*Calcidiscus leptoporus* +*Discoaster brouweri*

Normal polarity. *Lowest occurrence.
Reversed polarity. +Highest occurrence.

Table 11. Proposed late Quaternary coccolith biostratigraphy, offshore Otway Basin, southeastern Australia.

Acme *Emiliania huxleyi*
Acme *Gephyrocapsa oceanica*
**Emiliania huxleyi*
Acme small *Gephyrocapsa* spp.
+*Pseudoemiliania lacunosa*

*Lowest occurrence +Highest occurrence

<u>HEATFLOW</u> (C.S. Lee and C. Penney)

Objectives

The objectives of the heatflow study in the Otway/Tasmania cruise are to examine the present-day heatflow distribution along this complex rifted continental margin, and to apply the results in establishing the maturation geohistory of the various stratigraphic sequences and relating it to the deep crustal structure. Two heatflow transects (BMR 48/43 and SO36/46), one on the offshore Otway margin and one on the west Tasmanian margin were envisaged and carried out.

Thermal Gradient Measurement

Thermal gradient measurements were attempted at 20 stations (Figs. 1 and 2) during the Otway/Tasmania cruise by using the Nichiyu Giken NTS-11 heatflow instrument. This instrument contains an electronic package which can be utilized for up to 15 hours of continuous measurement, eight thermistors which are evenly spaced on a 3-m expendable lance, and a personal computer system for data handing and processing. A more detailed description of the NTS-11 heatflow instrument can be found in the 1985 BMR heatflow cruise report (Choi and Stagg, et al., in press).

During the survey, we have used two different types of thermistor lance. One was the conventional 4-cm diameter lance which was subject to bending at the middle part of the lance and was difficult to straighten back to a re-usable condition. The other, a new design by BMR technical officer Mr Peter Walker, has 3 vanes mounted on the lance to protect the thermistors during deployment and to increase the weight during penetration. The new lance bent less, and because the treatment to correct this bending was much easier than for the conventional lance, the pogo technique for heatflow measurement was tried during this cruise for the first time on a BMR cruise.

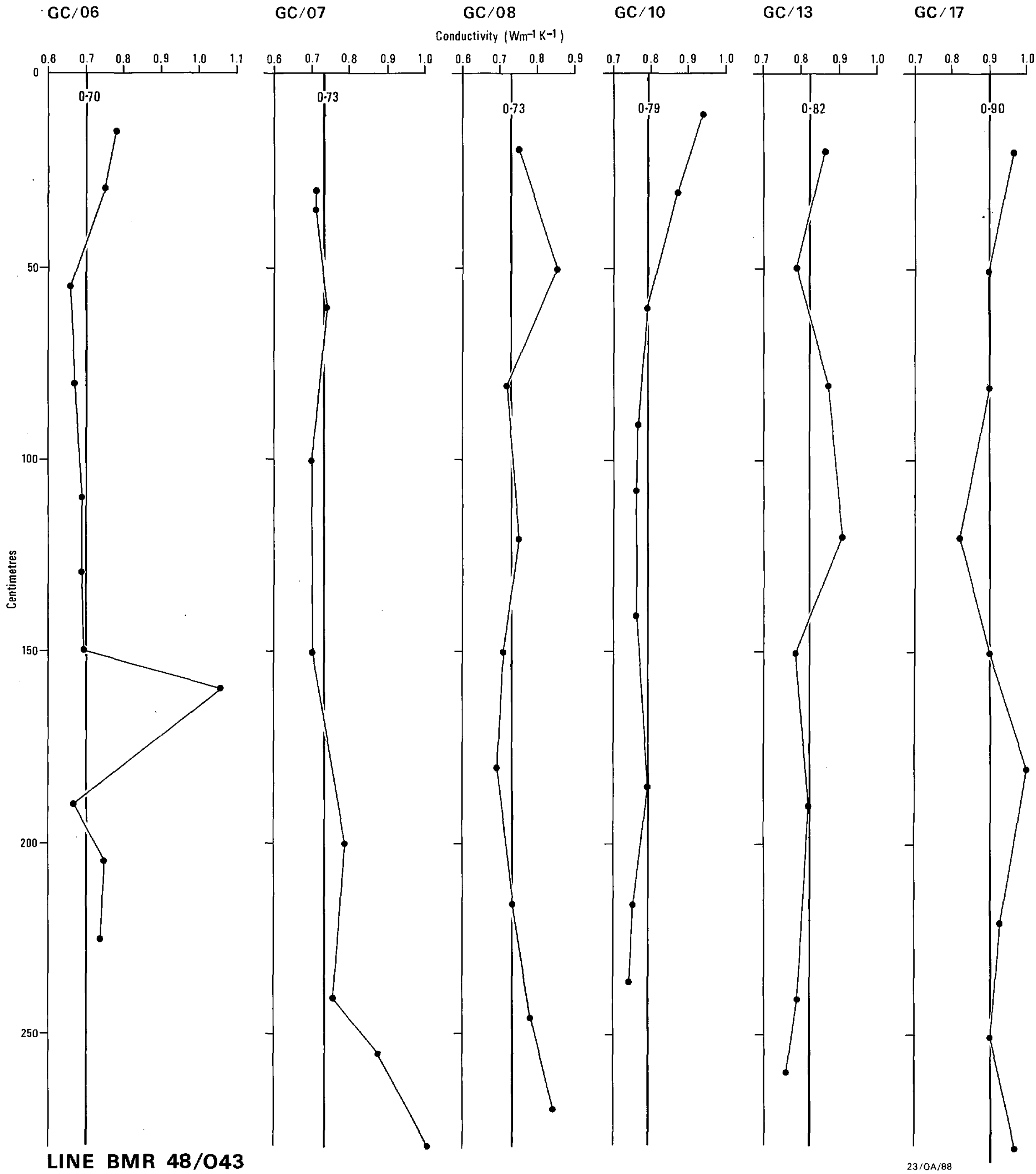
The heatflow probe penetrated at least two to three times at each station (station-pogoing) except at station 2. These multiple penetrations have shown the data to be repeatable and thus have increased the data reliability (Table 12). An attempt of profile-pogoing with the heatflow probe was also made along a 15-km profile with slow ship speed of 2 knots between stations 12-16. This attempt was not successful due to the number of reliable thermistors being reduced eventually to two and tilts being as high as 40 degrees. A careful treatment of this data set is needed to obtain useful information.

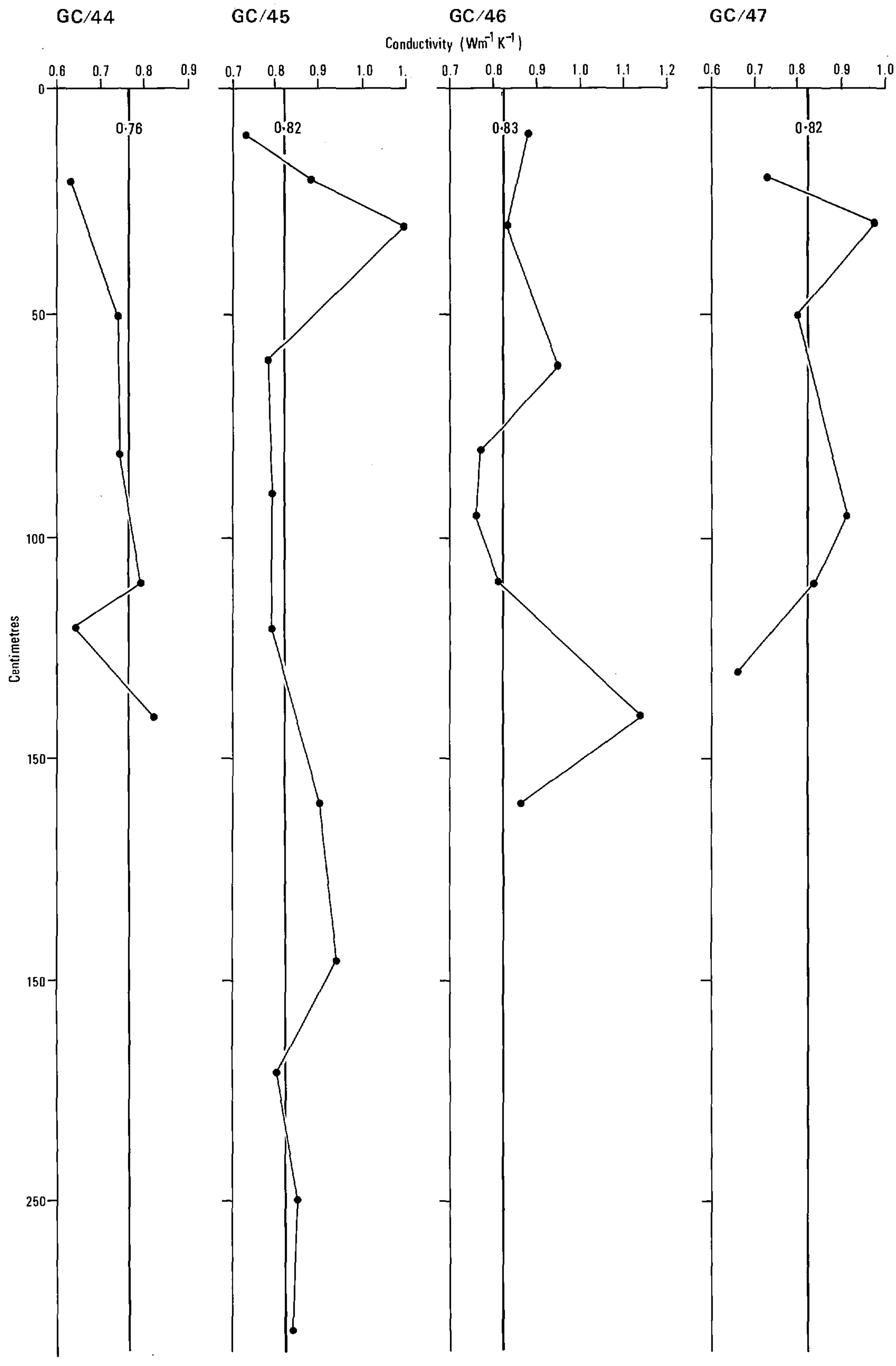
Station 20 was in relatively shallow water (795 m), where the fluctuation of bottom water temperature may cause thermal transients into the sediment. Until we have a substantial shallow water data set over a long period of time, it is difficult to quantify this type of error. Station 1 failed due to a faulty battery unit.

Thermal Conductivity Measurement

The thermal conductivities of sediment was determined by needle probe measurements (von Herzen and Maxwell, 1959) on ten sediment gravity cores ranging from 1.5 to 3 m in length (Figs. 30 and 31). Most of the cores used for conductivity measurement were either on a station where a gravity core was also taken, or on the same tectonic structure within a distince of less than 20 km,

Fig. 30. Conductivity measurements of sediment cores along sc' BMR 48/43.





LINE SO-36-46

Fig. 31. Conductivity measurements of sediment cores along seismic line SO36/46.

TABLE 12: PRELIMINARY HEATFLOW RESULTS OF THE OTWAY/TASMANIA CRUISE

STATION	STATION LAT.	STATION LON.	WATER DEPTH (M)	NO. OF SENSORS PENETRATED	THERMAL GRADIENT (C/KM)	CORE NO.	CONDUCTIVITY (W/M.K)	HEATFLOW (mW/M.M)
ALONG SEISMIC LINE BMR 48/43								
HF/02	39 27.8	139 58.7	4905	7	96.0	GC/06	.73	67.20
HF/03	39 18.3	139 58.9	4090	7	59.0	GC/07	.73	43.07
HF/04	39 12.3	139 59.3	4330	7	56.0	GC/07	.73	40.88
HF/05	39 08.4	140 00.4	4333	7	55.0	GC/08	.73	40.15
HF/06	39 02.2	140 02.6	4010	7	77.5	GC/08	.73	56.58
HF/07	38 51.0	140 06.0	3307	7	83.0	GC/10	.79	65.57
HF/08	38 39.6	140 07.5	2691	7	28.5	GC/13	.82	23.37
				7	37.0	GC/13	.82	30.34
HF/09	38 33.4	140 07.7	2623	7	58.0	GC/13	.82	47.56
HF/10	38 27.7	140 10.2	2463	6	84.5	GC/13	.82	69.29
ALONG SEISMIC LINE SO 36/46								
HF/17	42 14.0	143 32.0	4100	7	54.5	GC/44	.76	41.42
				5	44.0	GC/44	.76	33.44
HF/18	42 14.0	143 53.0	3720	6	38.5	GC/45	.82	31.57
				6	44.5	GC/45	.82	36.49
HF/19	42 12.0	144 25.0	2340	5	25.5	GC/46	.83	21.17

thus ensuring relevant values. A measurement was made at every representative lithology, after cores have been equilibrated at room temperature for at least 24 hours.

The conductivity measurements showed relatively little variation and were in the range of 0.70 - 1.05 W/m.k. Some high values of 1.00 W/m.k and above were obtained from very coarse quartz-rich turbidite sands, and also from apparently much older and compacted sediments, like Paleogene peat. In general, the mean ocnductivity values increase from 0.73 W/m.k in deep water to 0.90 W/m.k in shallow water. The variations are thought to be related to the type, porosity and grain size of the sediment.

Results

The primary shipboard heatflow values were simply calculated from the product of measured thermal gradients and sediment conductivities (Table 12). These values need to be corrected for several environmental factors, like topography, structure, sedimentation rate and the glacial effect on the equilibrium of conductive heat flux (von Herzen et al., 1974). Although we have not applied these corrections to the shipboard measurements, an increase of 10-15% is usually anticipated in the final result (Ben-Avraham and von Herzen, 1987). At this time, the primary heatflow results can be addressed as follows:

1. The average heatflow throughout the continental margin survey area is about 40 mW/sq.m . This is consistent with the age of Late Cretaceous continental breakup between Australia and Antarctica (Falvey and Mutter, 1981; Cande and Mutter, 1982). However, some high values of 70 mW/sq.m, particularly in the mid-slope of the Otway margin are probably related to Tertiary tectonic activity in the region. These values may also be associated with the zone of more dense normal faulting in BMR seismic profile 48/43.

2. Comparison of two transects (BMR 48/43 and SO36/46) has shown that the average heatflow in the Otway margin (48.4 mW/sq.m) is generally higher than that in the Tasmanian (32.8 mW/sq.m). The difference may be caused by the different sedimentation rates and tectonic settings of these margins.

3. Assuming the 'oil window' in this region is placed between 80 degrees C and 120 degrees C, the temperature gradient measurements from this study have suggested that mature source rocks would be buried at 2-4 km beneath the seafloor. Future studies include the combined analysis of the actual heatflow measurements, the estimated heatflow values from offshore wells and other relevant geological and geophysical data; these will help us better understand the thermal maturation history of the Otway/Tasmania continental margin.

HYDROCARBON GAS IN SEAFLOOR SEDIMENTS, OFFSHORE OTWAY BASIN AND WEST TASMANIA (D.M. McKirdy, and D.T. Heggie)

INTRODUCTION

Background

Hydrocarbon gases (C1-C4) and volatile hydrocarbons of higher molecular weight (C5-C7) are common in young marine sediments (Claypool and Kvenvolden, 1983; Hunt, 1975b). These naturally occurring hydrocarbons have two possible origins:

1) biogenic, i.e. produced *in situ* by bacterial activity

2) thermogenic, e.e. arising from non-biological processes whereby petroleum is formed when organic-rich sediments, attain burial temperatures of 80-150 degrees C.

In both cases methane is invariably the dominant component. Background concentrations are in the range 0.01-10 micro 1/1.

Thermogenic (petroleum-related) gas can be distinguished from biogenic (microbially-derived) gas on the basis of the relative abundance of its C1-C4 components (e.g. C1/C2+C3, C2/C2:1, C3/C3:1, iC4/n-C4) and the isotopic composition of its methane (δ13C, δD) (Bernard et al., 1976; Reed and Kaplan, 1977; Kvenvolden and Redden, 1980; Kvenvolden *et al.*, 1981; Claypool and Kvenvolden, 1983).

Anomalous concentrations of thermogenic C1-C5 hydrocarbons in the upper 1-3 metres of fine-grained sediment on the continental shelf and slope are direct evidence of submarine seeps. Seeps or vents in turn signify the existence of active source rocks, or discrete petroleum accumulations, at depths up to 5 km below the seafloor. Hydrocarbon seepage is favoured in areas where the continental margin is strongly faulted (Kvenvolden *et al.*, 1981) or intruded by diapirs (Anderson *et al.*, 1983).

Previous Studies of Otway Basin and West Tasmania

In view of its tectonic style, recent earthquake activity and the thickness of its sediment pile, that part of Australia's southern continental margin comprising the offshore Otway basin and western Tasmanian margin was identified by Wilson *et al.* (1974) as an area of moderate potential for submarine oil seepage. This assessment is supported by the weathered bitumen and fresh waxy crude oil which are regularly washed ashore along the coastlines of southeast South Australia and western Victoria (Sprigg and Woolley, 1963; McKirdy and Horvath, 1976; McKirdy *et al.*, 1986).

A large oil slick which polluted beaches along a 70 km stretch of coastline on southern Kangaroo Island in December 1986 can be linked with seismic activity in the western Voluta Trough (McKirdy and Cox, 1987). Twenty four days prior to the stranding of the oil an earthquake (magnitude = 2.2 on Richter scale) with an epicentre located approximately 75 km southwest of Kingston, S.A., was recorded on the SADME seismic array.

A 1600 km seaborne gas sniffer and sidescan sonar survey of EPP-18 identified plumes of thermogenic gas in the water column 16 km due south of Port MacDonnell (Shoreline, 1983). These plumes are notable for their unusually high propane/methane ratios (C3/C1 = 0.03-3, mean = 1).

Likewise, C1-C5 hydrocarbons (up to 1 ppm by weight) were obtained from 27 piston and gravity cores of fine-grained sediment on the continental slope in two areas immediately west of Clam-1 and Cape Sorell-1 off western Tasmania (Hinz *et al.*, 1987). Sediment was degassed using an *in vacuo* acid digestion technique. A thermogenic origin was attributed to these hydrocarbons on the basis of their extremely low Bernard Parameter values (C1/C2+C3 = 1.3-6.7).

Aims of Present Study

The previous studies outlined above make it clear that the offshore Otway Basin and West Tasmanian margin are ideal targets for a regional reconnaissance survey aimed at defining areas of anomalously high thermogenic gas. Accordingly, a major objective of the scientific program of the present cruise was to routinely analyse all gravity cores for C1-C5 hydrocarbons using a headspace gas sampling technique and shipboard gas chromatography.

In the final outcome cores from 43 sites located along 8 different seismic profiles of the continental margin between southeastern South Australia and western Tasmania (Figs. 1 and 2) were successfully analysed. Selected grab and dredge samples also were analysed, but with less than satisfactory results.

ANALYTICAL METHODS

Sampling of Cores

Upon removal from the core barrel the plastic core liner (6.5 cm I.D.) containing up to 3.5 metres of wet sediment was cut into 1 metre lengths and then sectioned longitudinally. Twenty centimetre lengths of half core (usually 2 per core : Tables 13-15) were immediately removed from the anoxic section of the core and placed in metal cans (1.137 litre capacity) each of which had a septum-covered hole in its base. Degassed (i.e. freshly boiled) deionised water was added to the can until a 175 ml headspace remained. The headspace was purged with high purity helium *via* two syringe needles inserted through the septum. The can was then shaken mechanically for 10 minutes to release gases originally dissolved in the pore water into the headspace (Kvenvolden and Redden, 1980). Finally, the can was placed in a water bath at 70degrees C for 30 minutes to desorb any gas still bound to mineral surfaces. Upon cooling to ambient temperature (20degrees C), a 5 ml aliquot of the headspace gas mixture was withdrawn with a syringe and injected into the gas chromatograph.

The principal sediment type analysed was grey calcareous nannofossil ooze of Quaternary age. The grab samples analysed were unconsolidated bryozoal grits and sands. The latter yielded very low concentrations of gas (C1-C4 <1 micro-l/l) and displayed evidence of preferential loss of methane.

Gas Chromatography

The headspace gas was analysed by shipboard gas chromatography using the following instrumental parameters:

Gas chromatograph: Varian Vista 6000 fitted with flame

	ionisation detector
Column:	1.8 m x 3.2 mm I.D. copper column packed with activated alumina (80-100 mesh)
Injector temperature:	50 degrees C
Detector temperature:	25 degrees C
Carrier gas:	He at 35 ml/min
Detector range:	10 to the minus twelve
Column temperature:	50-250 degrees C at 20 degrees C/min
Quantitation:	Peak areas were measured with a Varian Spectra Physics 4270 Integrator and calibrated against a standard mixture of 100 ppm (by vol.) of each of methane, ethane, propane, <u>n</u>-butane, <u>n</u>-pentane and <u>n</u>-hexane in N2.

Concentrations of C1-C4 hydrocarbons, determined initially as ppm (by volume) of headspace, are reported here as micro-l/l of wet sediment (Tables 13-15, Figs. 1 and 2). The lower detection limit of the method is about 0.005 micro-l/l. Regular procedural blanks revealed small background levels of methane (C1), isopentane (<u>i</u>-C5) and normal pentane (<u>n</u>-C5) for which appropriate corrections were made.

INITIAL SHIPBOARD RESULTS

<u>Gravity Core Hydrocarbon Data</u>

Analytical data on 87 core samples are summarised here as follows:

State	Seismic Profile	Core	Table
South Australia	BMR 48/043	9A-19	13
	BMR 48/042	21-23	13
Victoria	BMR 48/007	24-28	14
	BMR 40/022	29-36	14
	BMR 40/023	37-41	14
Tasmania	Sonne 36B-46	44-48	15
	BMR 16/015	49-51	15
	BMR 16/017	52-54	15

<u>Recognition of Thermogenic Hydrocarbons</u>

Several compositional parameters were used to distinguish light hydrocarbons of mainly thermogenic origin from solely biogenic gas:

Table 13: South Australian Gas Data

Seismic profile	Core	Depth in core cm	Water depth m	Total C_1-C_4 ppm v/v	µl/l wet sediment	Wet gas %	$\frac{C_1}{C_2+C_3}$	$\frac{C_2}{C_2:1}$	$\frac{C_3}{C_3:1}$	$\frac{i\text{-}C_4}{n\text{-}C_4}$	$\frac{i\text{-}C_5}{n\text{-}C_5}$
48/043	9A	133-153	3615	3.009	1.595	0.98	115	0.246	1.15	-	0.77
		173-193		3.394	1.799	0.86	151	0.108	0.577	0.67	0.97
	10	286-306	3332	1.025	0.543	3.7	40.6	0.163	0.710	0.50	1.16
		325-345		1.307	0.693	4.5	28.4	0.160	1.02	0.50	0.89
	11	210-230	3214	2.531	1.341	2.6	48.6	0.224	1.12	0.36	0.80
		250-270		2.552	1.353	2.1	66.1	0.206	1.08	0.46	1.03
	12A	210-230	3133	1.052	0.558	4.1	29.9	0.221	1.20	0.39	0.58
		260-280		1.446	0.766	2.8	40.6	0.303	1.10	0.50	0.56
	13	210-230	2525	40.490	21.460	1.2	90.8	4.34	5.55	0.30	0.48
		270-290		65.289	34.603	0.95	109	6.64	3.74	0.50	0.47
	14	270-290	2250	3.662	1.941	4.4	25.0	0.673	3.06	0.35	0.62
		310-330		2.932	1.554	3.4	33.4	0.433	2.07	0.46	0.40
	15	170-190	1964	4.049	2.146	2.8	44.9	0.435	1.62	0.24	0.68
		240-260		5.146	2.727	1.7	70.6	0.404	1.60	0.26	0.81
	16	70- 90	1650	1.618	0.858	5.1	22.3	0.262	1.25	0.36	0.74
		140-160		3.439	1.823	2.5	49.7	0.295	1.46	0.40	0.67
	17	210-230	1490	3.998	2.119	1.9	65.1	0.338	1.62	0.29	0.85
		270-290		4.753	2.519	3.9	30.8	0.500	1.86	0.32	0.61
	18	210-230	1035	188.795	100.061	0.35	380	1.41	7.43	0.55	0.51
		270-290		921.582	488.438	0.26	545	1.07	10.3	0.73	0.66
	19	30- 50	345	2.435	1.291	6.9	16.0	0.848	2.68	0.30	0.49
		70- 90		4.503	2.387	4.3	26.4	0.968	3.32	0.29	0.63
48/042	21	110-135	315	2.632	1.395	4.1	31.3	0.508	2.10	0.54	0.67
		165-190		2.165	1.147	3.6	36.8	0.751	2.69	0.58	0.32
	22	210-230	1003	19.328	10.244	2.3	48.1	0.946	3.70	0.30	0.54
		260-280		40.427	21.426	0.96	116	1.02	3.59	0.29	0.57
	23	170-190	1146	71.091	37.678	1.1	100	0.916	3.16	0.24	0.52
		218-238		81.046	42.954	0.30	357	3.41	4.95	0.35	0.10

Table 14. Victorian Gas Data

Seismic profile	Core	Depth in core cm	Water depth m	Total C1-C4 ppm µl/l wet v/v sediment		Wet gas %	$\frac{C_1}{C_2+C_3}$	$\frac{C_2}{C_{2:1}}$	$\frac{C_3}{C_{3:1}}$	$\frac{i\text{-}C_4}{n\text{-}C_4}$	$\frac{i\text{-}C_5}{n\text{-}C_5}$
48/007	24	110-130	392	2.962	1.570	5.9	18.0	0.635	2.53	0.34	0.35
		151-171		4.772	2.529	4.1	27.6	0.737	3.23	0.36	0.48
	25	114-134	450	5.571	2.953	6.1	18.5	1.12	3.90	0.35	0.72
		154-174		7.296	3.867	2.5	46.0	0.772	3.52	0.36	0.61
	26	157-177	469	5.570	2.952	3.3	34.2	0.668	2.90	0.32	0.71
		197-217		6.708	3.555	4.6	23.9	1.21	3.87	0.35	0.60
	27	159-179	506	4.660	2.470	2.6	44.1	0.641	2.11	0.43	0.81
		197-217		4.982	2.640	2.5	52.6	0.608	2.25	0.35	0.52
	28	159-179	545	5.470	2.899	2.1	54.7	0.753	2.85	0.31	0.41
		219-239		3.521	1.866	3.4	33.3	0.626	2.30	0.35	0.55
40/022	29	0- 20	240	1.325	0.702	4.7	27.2	0.151	0.752	0.32	0.65
		100-120		2.170	1.150	7.5	14.8	0.811	2.14	0.33	0.59
		200-220		1.647	0.873	7.6	15.1	0.510	2.26	0.32	0.86
		332-352		1.218	0.645	16.3	6.08	0.735	2.61	0.35	0.76
	30	65- 85	558	2.025	1.073	9.9	10.1	1.70	3.69	0.24	0.86
		105-125		3.275	1.736	5.6	19.7	1.43	3.81	0.40	0.90
	31	224-244	829	6.280	3.328	3.1	36.1	0.947	4.00	0.31	0.80
		264-284		8.459	4.483	3.1	34.8	1.54	4.43	0.34	0.62
	32	22- 42	1244	1.031	0.546	8.6	12.9	0.227	1.12	0.42	0.70
		62- 82		2.732	1.448	3.4	34.7	0.269	1.41	0.50	0.72
	33	196-216	1433	4.106	2.176	5.1	21.3	0.762	2.70	0.30	0.80
		236-256		4.276	2.266	3.8	28.7	0.809	3.28	0.46	0.85
	34	200-222	1630	17.251	9.143	2.1	51.1	1.51	4.14	0.36	0.51
		241-262		18.175	9.633	1.3	86.4	1.40	3.35	0.32	0.58
	35	69- 89	2280	0.820	0.435	6.2	19.0	0.405	1.13	0.79	-
		109-129		0.874	0.463	6.7	17.3	0.230	0.997	0.62	0.84
	36	150-170	2182	0.255	0.135	14.4	7.7	0.328	0.958	0.42	0.65
		200-220		0.3131	0.166	11.5	10.0	0.303	0.914	0.43	0.28
40/023	37	170-190	3090	1.464	0.776	3.5	34.0	0.206	1.40	0.33	0.77
		220-250		1.616	0.856	4.1	30.2	0.184	1.12	0.39	0.72
	38	120-140	3850	1.276	0.676	12.4	8.47	0.525	1.97	0.30	0.55

Table 13 (continued)

Table 14 (continued)

Seismic profile	Core	Depth in core cm	Water depth m	Total C1-C4 ppm v/v	μl/l wet sediment	Wet gas %	$\frac{C}{C_2+C_3}$	$\frac{C}{C_{2:1}}$	$\frac{C}{C_{3:1}}$	$\frac{i\text{-}C}{n\text{-}C_4}$	$\frac{i\text{-}C}{n\text{-}C_5}$
		150-170		0.456	0.242	3.3	38.6	-	0.578	-	0.98
	39	82-102	4300	0.280	0.148	7.2	15.9	1.17	0.587	-	0.63
	40	32- 52	4370	0.159	0.843	12.3	10.0	0.454	1.56	0.75	1.00
	41	108-128	4645	1.853	0.982	1.1	157	0.165	0.546	0.50	0.59
		148-168		1.664	0.882	1.2	108	0.100	0.683	-	0.71

Table 15. West Tasmanian Gas Data

Seismic profile	Core	Depth in core cm	Water depth m	Total C_1-C_4 ppm µl/l wet v/v sediment		Wet gas %	$\frac{C_1}{C_2+C_3}$	$\frac{C_2}{C_{2:1}}$	$\frac{C_3}{C_{3:1}}$	$\frac{i-C_4}{n-C_4}$	$\frac{i-C_5}{n-C_5}$
Sonne 46	44	70- 90	4103	0.481	0.255	10.3	11.2	0.200	1.31	0.44	-
		120-140		0.750	0.387	14.7	7.12	0.360	1.59	0.40	0.68
	45	230-250	3715	3.215	1.704	1.2	176	0.060	1.89	0.70	0.40
		310-330		5.434	2.880	0.67	195	0.166	1.07	0.50	0.3
	46	70- 90	2360	2.037	1.080	4.0	29.1	0.684	1.99	0.38	0.41
		143-168		2.623	1.390	2.5	46.9	0.699	2.60	0.46	1.27
	47	70- 90	765	2.868	1.520	4.6	24.2	1.07	2.46	0.31	0.63
		110-130		4.019	2.130	4.4	24.8	1.50	3.14	0.26	0.59
	48	113-133	377	0.285	0.151	26.9	3.14	1.08	2.75	0.28	1.03
		160-180		0.650	0.344	12.7	8.32	0.924	2.51	0.24	1.12
16/015	49	174-194	838	5.810	3.079	1.5	75.0	1.72	3.91	0.36	0.44
		224-244		0.997	0.528	6.5	19.7	0.373	1.01	0.55	0.90
		264-284		1.668	0.884	4.6	24.8	1.59	1.46	0.62	0.86
	50A	76- 96	1081	2.094	1.110	3.4	33.6	0.632	2.39	0.44	0.61
		116-136		1.242	0.658	10.3	10.2	1.52	3.81	0.36	0.49
	51	37- 57	1557	1.182	0.626	3.6	36.3	0.262	1.21	0.57	0.75
		77- 97		3.820	2.025	2.6	46.6	0.733	2.93	0.50	0.68
16/017	52	70- 90	1145	0.740	0.392	16.2	6.33	0.732	2.21	0.40	1.03
		130-150		1.413	0.749	10.9	9.80	0.844	2.60	0.35	0.76
	53	70- 90	1367	1.321	0.700	3.9	49.6	0.395	1.42	0.37	0.44
		123-143		1.623	0.860	8.8	11.9	1.25	3.72	0.42	0.70
	54	20- 40	1634	0.161	0.085	26.9	3.30	0.284	0.956	0.38	0.65
		60- 80		0.285	0.151	21.9	4.72	0.366	1.40	0.36	0.56

1)	C1/C2+C3	< 500	(Bernard *et al.*, 1976)
2)	C2/C2:1	> 1	(Kvenvolden *et al.*, 1981)
3)	C3/C3:1	> 3	(this study)
4)	*i*-C4/*n*-C4	< 1	(Monnier *et al.*, 1983; Alexander *et al.*, 1983).
5)	*i*-C5/*n*-C5	< 4	(Hunt, 1984)

Parameters (1)-(3) are based on the fact that contemporary bacterial activity in marine sediments produced mainly methane, resulting in very high C1/C2+C3 ratios (>1000), and minor but significant amounts of ethene (C2:1) and propene (C3:1) which are not components of thermogenic gas.

Parameters (4) and (5) are maturity indicators. The values specified correspond to the principal phase of thermogenic hydrocarbon generation (vitrinite reflectance, VR = 0.6-1.35%).

Hydrocarbon Anomalies

Application of the aforementioned criteria to the hydrocarbon data in Tables 13-15 led to the recognition of anomalous concentrations of thermogenic gas at a minimum of eleven localities (Tables 16-18, Figs. 1 and 2).

Throughout the study area hydrocarbon gas concentrations were generally in the range 0.1-2.5 micro-l C1-C4/l of wet sediment. Background concentrations were highest on the upper slope along BMR seismic line 48/007, south southeast of Discovery Bay-1 on the northern flank of the Voluta Trough (Tables 14 and 17). The lowest background C1-C4 values were recorded in the eastern Otway basin along BMR seismic lines 40/022 and 023 southwest of Prawn-1 on the Mussel Platform, and along BMR 16/015 and 017 which traverse the upper slope south of Clam-1 at the northern end of the West Tasmanian margin (Tables 14, 17 and 18).

Major thermogenic anomalies were identified at four sea-bottom localities off South Australia (Table 16), five off Victoria (Table 17) and two off Tasmania (Table 18) (see also Figs. 1 and 2). These sites in water depths of 450-2500 metres appear to be active submarine gas seeps. Most of the seeps lie above major faults. The contrast between anomaly and background is greatest in the western Voluta Trough where C1-C4 concentrations up to 488 micro-l/l were recorded (Table 16) and faulting offsets the seafloor.

The faults associated with major anomalies are fracture zones which appear to be acting as conduits for petroleum-related gas migrating upwards from deeply buried Cretaceous source rocks. The gas comprising these anomalies is very dry and probably of late catagenic origin. The wetness of the gas seeps (C2-C4 as a percentage of C1-C4) varies across the study area as follows:

western Voluta Trough	0.3-2.3%	(mean = 0.93%)
north flank of Voluta Trough	2.5-6.1%	(mean = 4.4%)
eastern Voluta Trough	1.3-9.9%	(mean = 4.2%)

TABLE 16: HYDROCARBON ANOMALIES, OFFSHORE SOUTH AUSTRALIA

Seismic Profile	Gravity Core	Water Depth m	Depth in Core cm	C_1-C_4 Alkanes μl/l	Anomaly/Background*
BMR 48/043	13	2525	210-230	21.5	14.0
			270-290	34.6	22.6
	18	1035	210-230	100	65.4
			270-290	488	319
BMR 48/042	22	1003	210-230	10.2	6.67
			260-280	21.4	14.0
	23	1146	170-190	37.7	24.6
			218-328	43.0	28.1

*Mean background (μl C_1-C_4/l wet sediment) = 1.53 (n = 20)

TABLE 17: HYDROCARBON ANOMALIES, OFFSHORE VICTORIA

Seismic Profile	Gravity Core	Water Depth m	Depth in Core cm	C_1-C_4 Alkanes μl/l	Anomaly/Background*
BMR 48/007	25	450	114-134	2.95	1.22
			154-174	3.87	1.60
	26	469	197-217	3.56	1.47
BMR 40/022	30	558	65- 85	1.07	1.31
			105-125	1.74	2.12
	31	829	224-244	3.33	4.06
			264-284	4.48	5.47
	34	1630	200-222	9.14	11.2
			242-262	9.63	11.7

*Mean background (μl C_1-C_4/l wet sediment) =

2.42 (BMR 48/007, n = 7)
0.82 (BMR 40/022 & 023, n = 20)

TABLE 18 : HYDROCARBON ANOMALIES, OFFSHORE TASMANIA

Seismic Profile	Gravity Core	Water Depth m	Depth in Core cm	C_1-C_4 Alkanes μl/l	Anomaly/Background*
Sonne 36B-46	47	765	110-130	2.13	1.97
BMR 16/015	49	838	174-194	3.08	4.22

*Mean background (μl C_1-C_4/l wet sediment) =

1.08 (Sonne 368-46, n = 9)
0.73 (BMR 16/015 & 017, n = 12)

West Tasmanian margin 1.5-4.4% (mean = 3.0%)

The absence of gas anomalies at other core sites located above faults attests to the fact that not all faults necessarily facilitate hydrocarbon escape to the seafloor.

Two hydrocarbon anomalies in the eastern Otway Basin (viz. core sites 25 and 34 : Table 17) are not directly related to faulting but lie above large horst blocks which display seismic evidence of possible anticlinal closures at the top Sherbrook Group level. Such anomalies may indicate hydrocarbon accumulations at depth in Cretaceous reservoir sands and therefore are of particular significance for petroleum exploration.

SEDIMENT AND POREWATER GEOCHEMISTRIES (D. Heggie)

INTRODUCTION

The objectives of the sediment and pore water geochemistry program included the following:-

1. To document the 'redox' nature of continental margin sediments to contribute to an understanding of the sediment hydrocarbon gas data. (see McKirdy and Heggie, this volume).

2. To examine the processes that control organic carbon preservation in continental margin sediments particularly within the oxygen minimum zone.

3. To test if (and how) organic carbon preservation in margin sediments controls the manganese (and other trace metal) sediment inventories This work examines trace metal contents and distributions as potential palaeoceanographic tracers.

4. To determine how early diagenesis exerts a control on the chemical composition of the sediments.

5. To determine the relative importances of terrigenous inputs, in-situ production of organic carbon and regional oceanography as controls on surface sediment distributions and compositions.

Methods

To achieve these objectives eleven gravity cores were processed aboard the ship to separate sediment pore fluids from the sediment matrix. The cores processed are summarised in Table 19 & shown in Figs. 32 & 33. The protocol for handling sediment cores is shown in Fig. 34.

1. The core was split in the geology lab and one half, after description, archived.

2. The remaining half section was inspected and usually 10-16 samples, in 3 cm slices, were taken from the top 2 m of the core and loaded into centrifuge tubes.

3. Selected samples (1 cm) were taken in 10cc syringes for 35-S isotope studies of sulphate reduction rates and stored at in-situ temperatures of 30 degrees C for subsequent analyses at BMR.

4. Sediment samples were centrifuged at 14,000 rpm for 5 mins, at 3 degrees C, in a gimbal-mounted Sonvall RC-5 superspeed refrigerated centrifuge.

5. Pore waters were syphoned from the sediments and aliquotted to sample vials.

6. All pore waters were analysed aboard ship for ammonia and manganese.

7. Remaining pore waters were stored refrigerated for subsequent analyses.

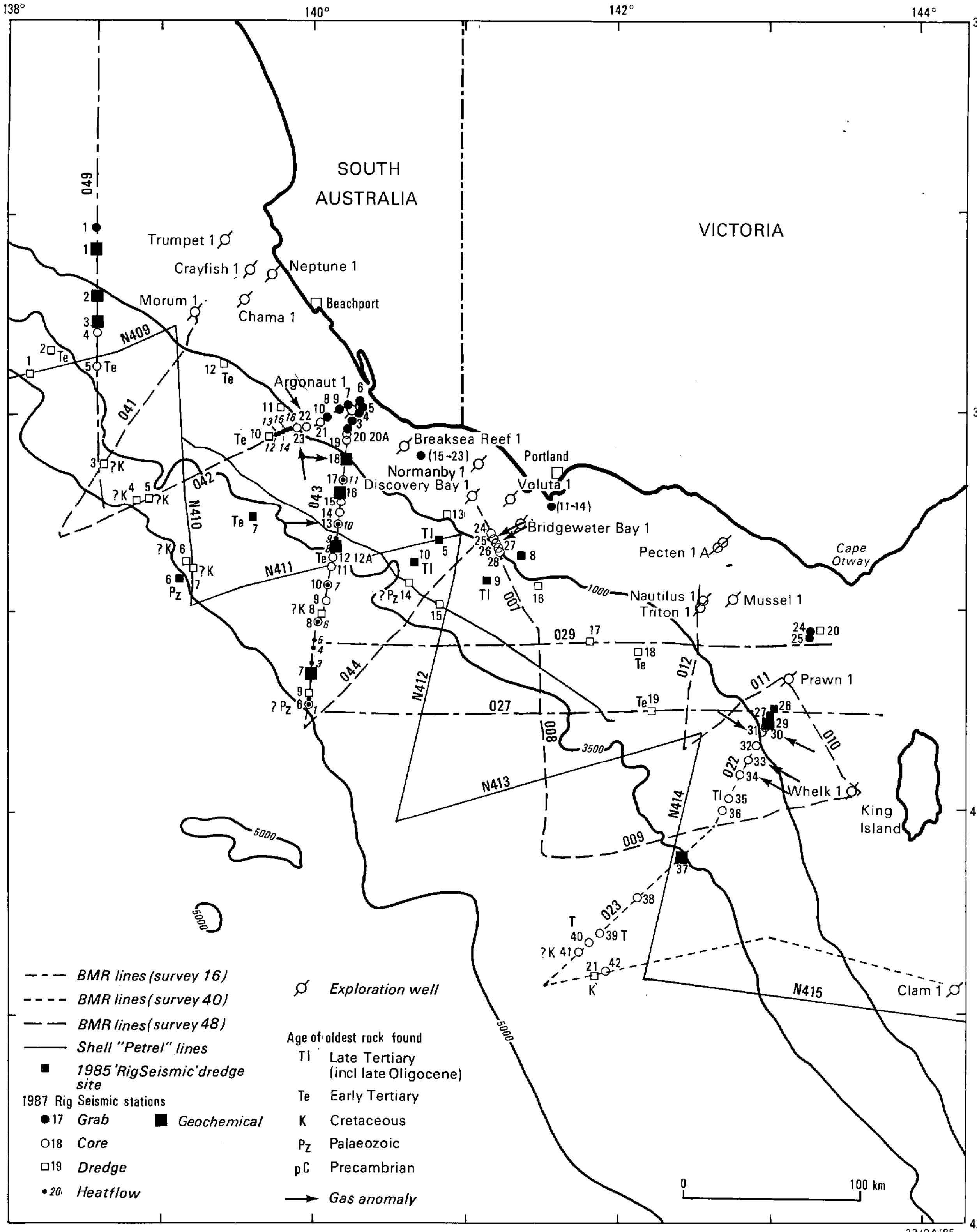


Fig. 32. Map showing location of stations off Victoria and South Australia where sediment and porewater geochemistry was studied.

Fig. 33. Map showing location of stations off Tasmania where sediment and porewater geochemistry was studied.

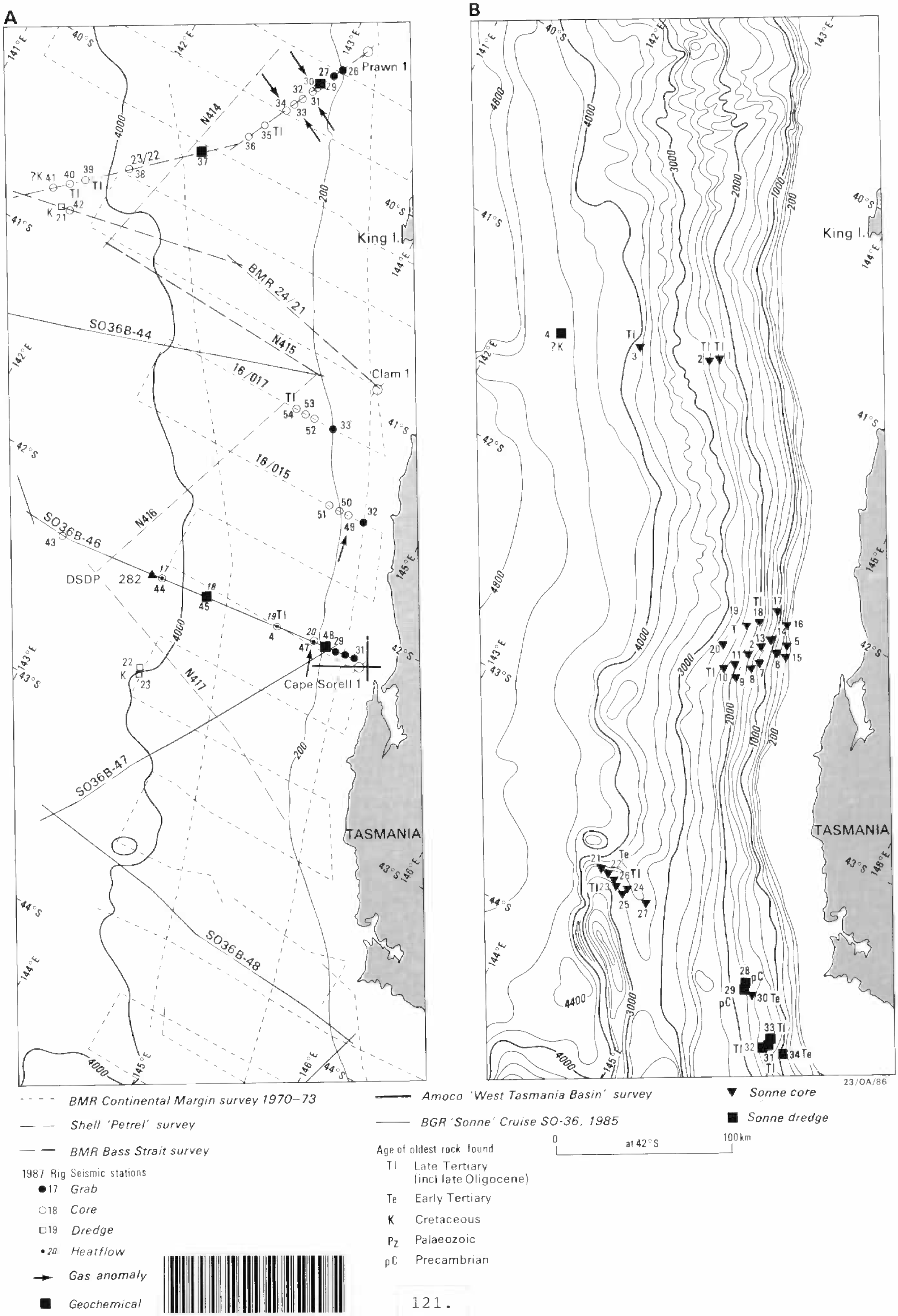
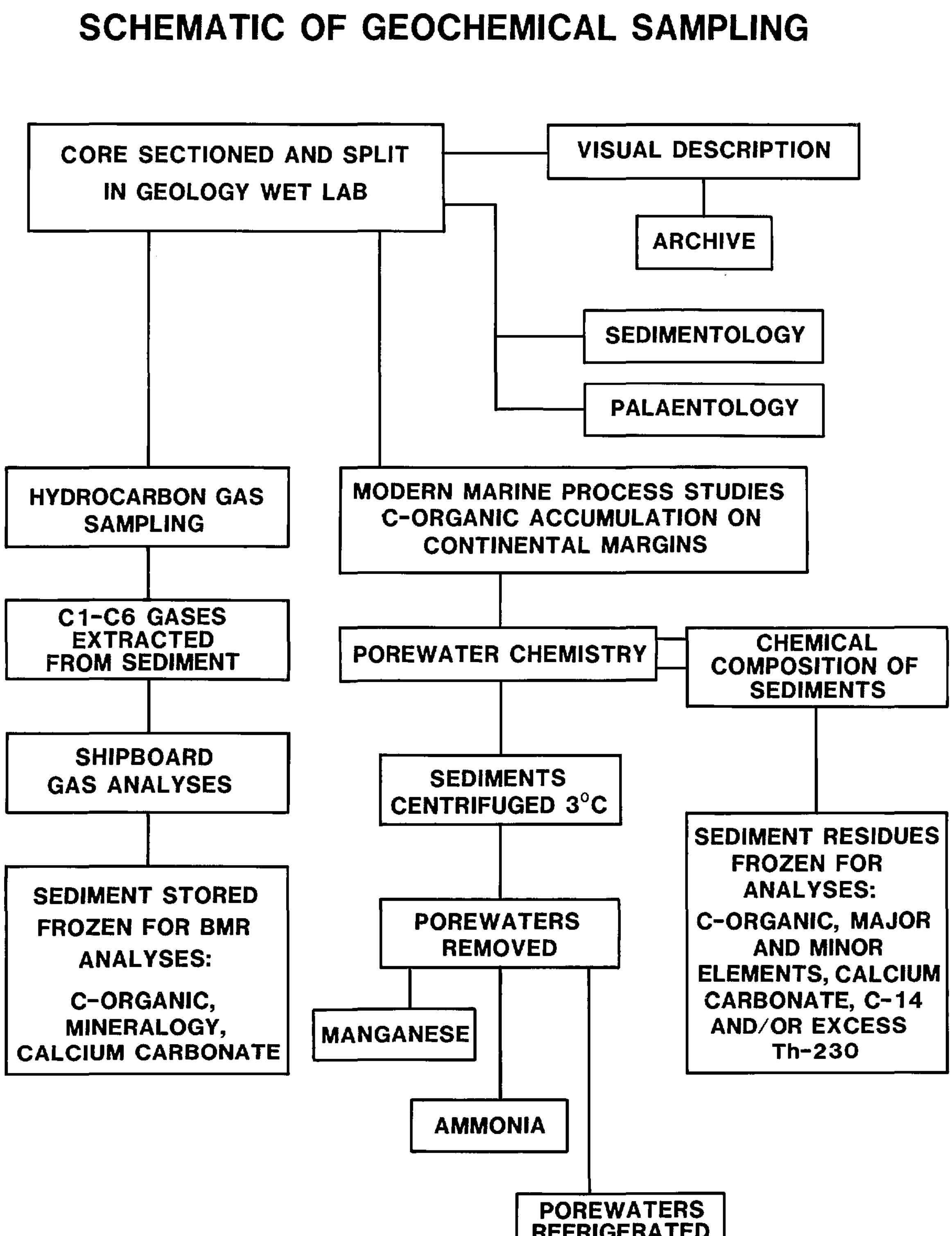


Fig. 34. Schematic of geochemical sampling.



8. All centrifuge sediment plugs were stored frozen for subsequent determinations of major and trace elements, organic carbon contents and sedimentation rate determinations via 14-C or 230Th methods.

Table 19
Cores Processed for Pore Water Geochemistry

Station	Lat.	Long.	Water depth (m)	Seismic Line	Recovery (cm)
GC01	37 10.2'	138 35.8'	425	16/049	220
GC02	37 23.9'	138 34.2'	1270	16/049	54
GC03	37 33.0'	138 35.0'	1476	16/049	310
GC07	39 20.1'	139 59.2'	4120	48/043	287
GC12A	38 42.6'	140 07.1'	3133	48/043	306
GC16	38 20.0'	140 10.9'	1650	48/043	196
GC18	38 11.6'	140 11.5'	1035	48/043	233
GC29	39 34.0'	142 59.0'	240	40/22	364
GC37	40 14.1'	142 25.2	3090	40/23	275
GC45	42 13.6'	142 52.5'	3715	Sonne 46	360
GC48	42 10.8'	144 44.3'	377	Sonne 46	190

Results and Discussion

The manganese and ammonia data collected from the eleven cores are summarised in Tables 20-30, and Figs. 35-38.

1. Organic carbon preservaton in continental margin sediments.

Manganese and ammonia measured at sea are used as indicators of different organic carbon oxidation processes in marine sediments. Manganese in oxic sediments resides primarily as MnIV in oxyhydroxide phases. Pore water Mn concentrations in oxic sediments are indistinguishable from overlying bottom water concentrations and are undetectable when measured colorimetrically and are <0.1 micromol/l. When Mn-oxides dissolve, reduced Mn II is released to pore waters. The depth at which pore water Mn concentrations begin to rise rapidly above bottom water concentrations is used as one indicator of the approximate depth of oxygen penetration into the sediments which is used to define the 'oxic' sediment zone.

Ammonia is produced during anaerobic oxidation of organic matter during sulfate reduction. The depth at which pore water ammonia begins to rise rapidly indicates the onset of sulfate reduction and the upper depth horizon of 'anoxic' sediments.

All data from the four transects show consistent trends in the depth distributions of manganese and ammonia across the continental margin. Data from cores collected in water depths near 4000 m indicate that the top few (<20) centimetres of the sediments are 'oxic' (GC07, GC45). As water depth decreases, the depth at which ammonia begins to rise rapidly in pore water is closer to the sediment/seawater interface. Ammonia concentrations increase with increasing depth, indicating extensive sulphate reduction at shallow depths in the sediments. The highest ammonia concentrations were found in GC18 indicating 'anoxic' conditions at the sediment/seawater interface. These data, while indicating 'anoxic' sediments at shallow depths, also indicate that porewater

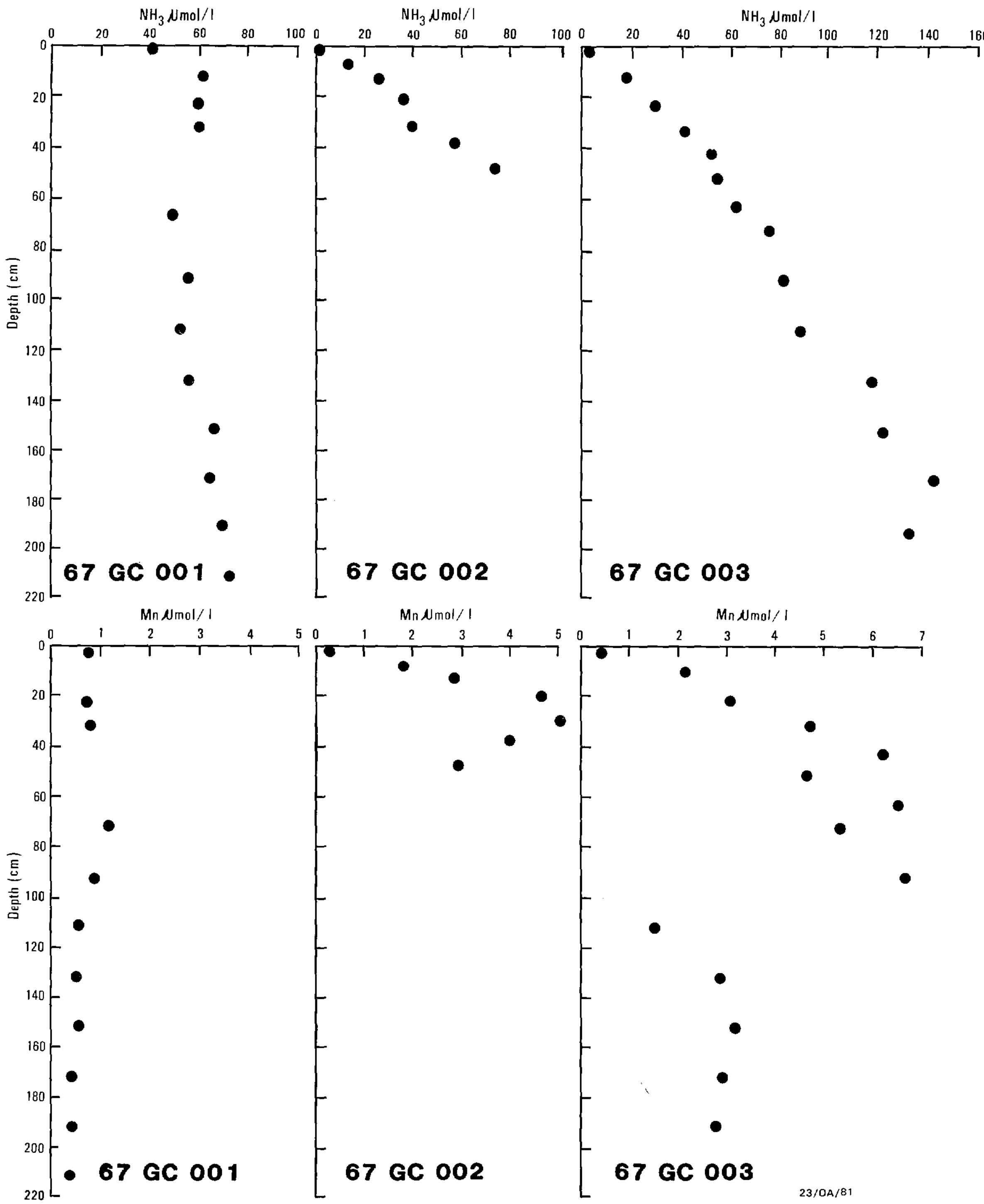


Fig. 35. Porewater ammonia and manganese data from cores off South Australia on seismic line 16/049.

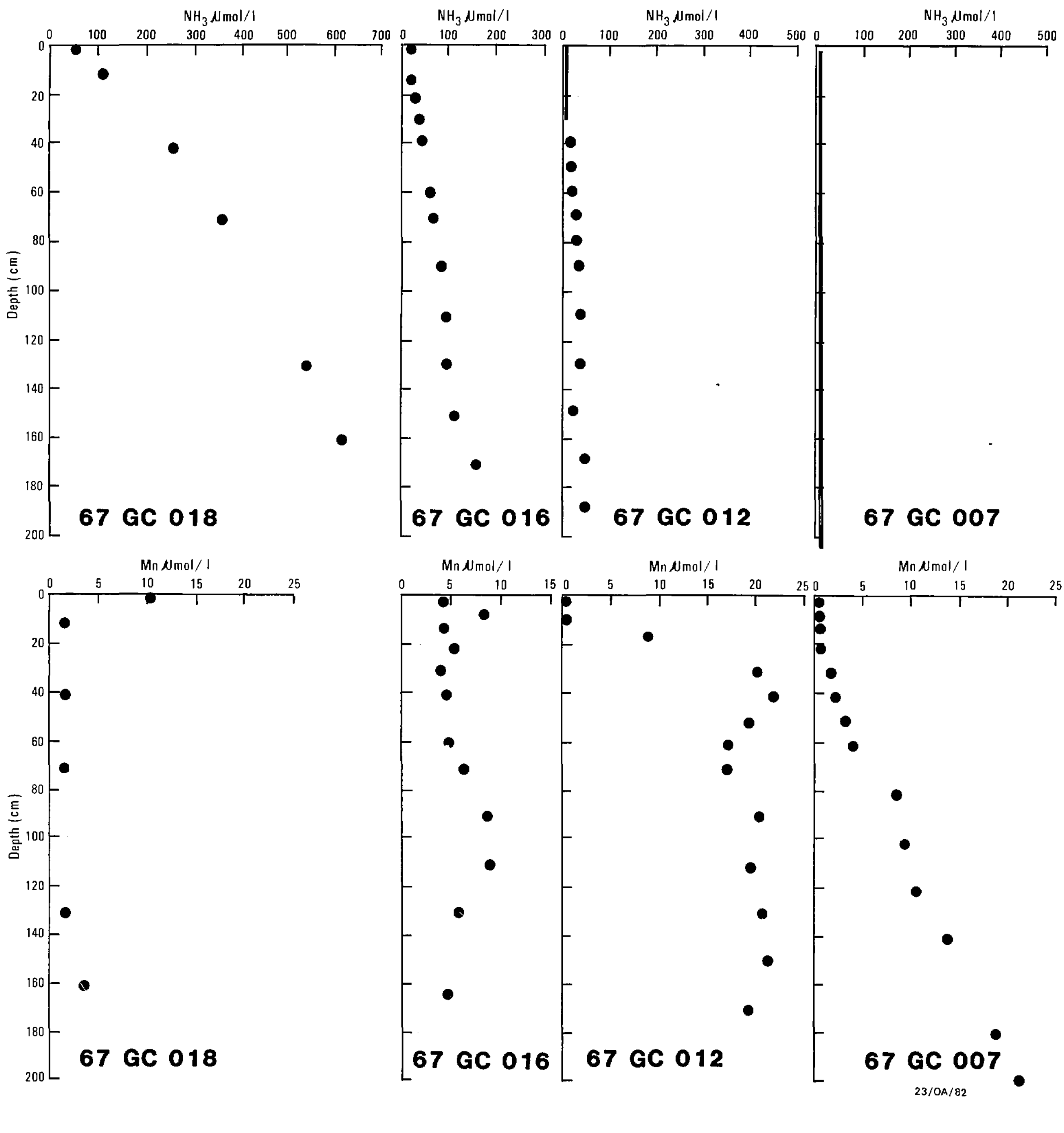


Fig. 36. Porewater ammonia and manganese data from cores off South Australia on seismic line 48/043.

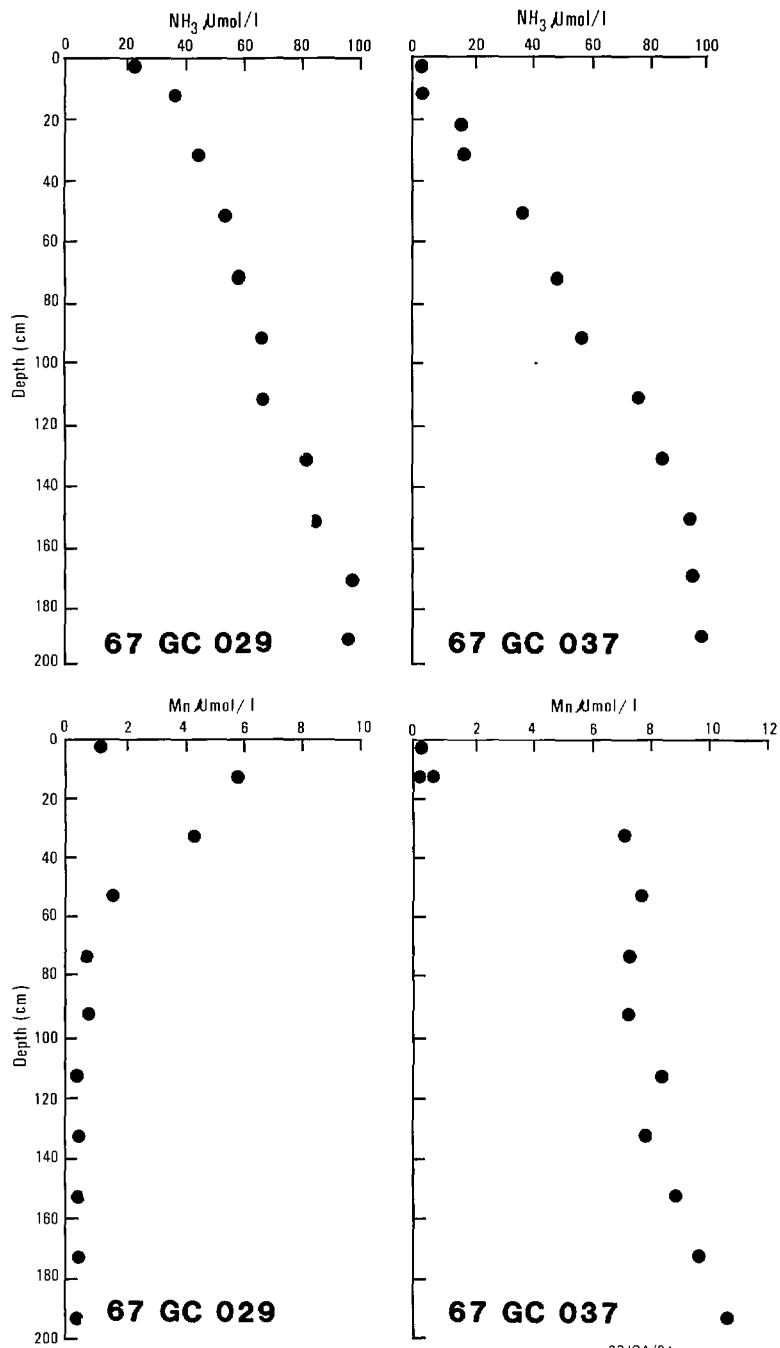


Fig. 37. Porewater ammonia and manganese data from cores off King Island on seismic lines 40/22-23.

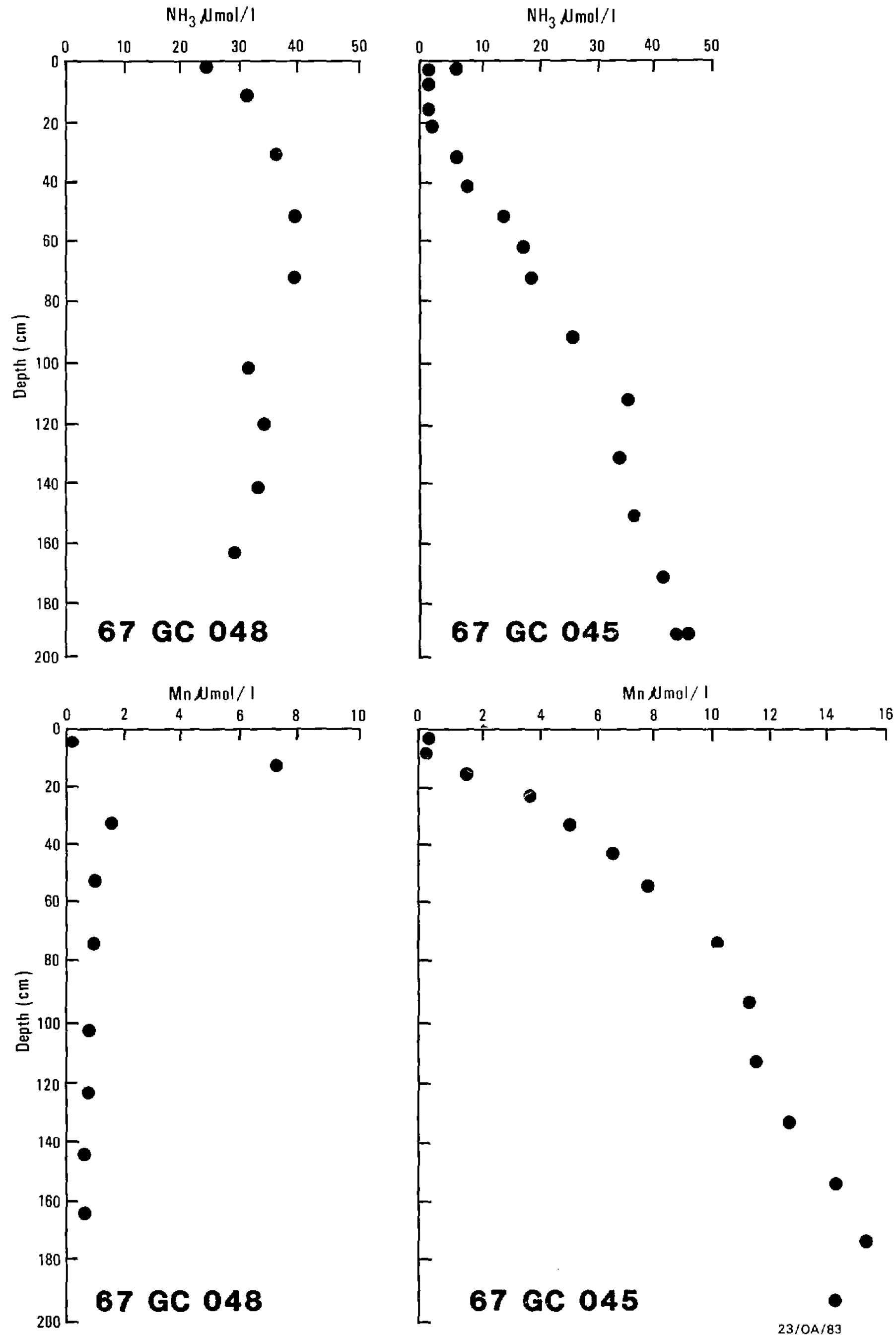


Fig. 38. Porewater ammonia and manganese data from cores of west Tasmania on "Sonne" seismic line SO36/46.

sulphate is not significantly depleted from sediments and biogenic methane production is unlikely in the top 2 m of recent sediment.

To examine organic carbon accumulation processes on Australian margins, different methods are being assessed to determine the rates of biogeochemical oxidation and preservation processes. The down core distributions of ammonia provide estimates of sulphate reduction rates from models of ammonia production and transport in recent sediments. Independant rates of sulfate reduction will be determined from S-35 isotope spike experiments. These data will be compared to organic carbon accumulation rates in the sediments which will provide one assessment of the efficiency of organic carbon preservation under anoxic conditions.

2. Organic carbon and Sedimentary Manganese

Manganese in sediments may serve as a useful palaeoceanographic indicator because it exhibits different behaviour in oxic and anoxic sediments. Manganese in 'oxic' sediments is locked in the solid phase, but under 'sub-oxic' reducing conditions, the solid phase Mn-oxyhydroxide dissolve releasing Mn II to pore water which migrates toward the sediment/seawater interface. When pore water Mn encounters oxygen leaking down through surface sediments it is oxidised and removed again to the solid phase. This recycling of Mn in surface sediments results in a surface sediment layer enriched in manganese.

Deepwater locations GC07 and GC45 indicate Mn oxide dissolution in the top 20-30 cm of sediments, with concentrations approaching 20 micromol/l at 2 m depth in the sediments. With decreasing water depth, the depth of the Mn reduction zone rises in the sediments and surface sediment pore water Mn concentrations are greater than bottom water concentrations indicating a flux of Mn from reduced margin sediments. The aymptotic pore water Mn values at depth systematically decrease with decreasing water depth, being <5 micromol/l in upper slope sediments. These data suggest that the sedimentary Mn inventory is depleted as Mn is lost from anoxic sediments. Additional data on the solid phase Mn concentrations and distributions will provide a quantitative evaluation of the Mn recycling processes.

<u>Summary</u>

Eleven gravity cores from four transects across the continental margins of South Australia, Victoria and West Tasmania were processed for sediment and pore water geochemistries. A preliminary assessment of the shipboard data indicates the following.

1. Anoxic conditions were encountered in near surface sediments in water depths less than 3000 m. Upper slope sediments were anoxic at the sediment/seawater interface. Ammonia data indicate that sulphate reduction is widespread, but sulphate is probably not entirely depleted in the upper 2 m of sediment. This suggests that biogenic methane production is probably not occurring within the top 2 m of sediment.

2. The anoxic sediments of the upper slope, and the rapid rates of organic carbon accumulation therein, may result in a depletion of the sediment Mn inventory as reduced dissolved Mn is lost from the sediments within the oxygen minimum zone. These results have application to the development of Mn (and other metals recycled with Mn) as a potential palaeoceanographic indicator.

This effort will continue with further assessments of the marine Mn mass balance.

Tables 20-30

Manganese and Ammonia Pore Water Data (all concentrations in micromole/ bitu pore water, depth in centimetres)

Table 20. 67 GC 001

Depth	NH-3	Mn
BW	<1	0.1
0-3	40.3	0.7
10-13	61.0	-
20-23	58.6	0.7
30-33	59.6	0.8
70-73	48.7	1.1
90-93	55.3	0.8
110-113	51.9	0.5
130-133	55.1	0.5
150-153	65.6	0.5
170-173	63.5	0.4
190-193	69.8	0.4
210-213	70.4	0.3

Table 21. 67 GC 002

Depth	NH-3	Mn
0-3	2.6	0.3
6-9	11.5	1.8
12-15	25.8	2.7
18-21	35.6	4.6
28-31	39.6	5.0
34-37	58.5	3.8
46-49	72.7	2.9

Table 22. 67 GC 003

Depth	NH-3	Mn
0-3	2.0	0.4
9-12	16.2	2.2
20-23	29.7	3.0
30-33	41.6	4.7
40-43	51.9	6.2
50-53	54.7	4.5
60-63	61.5	6.5
70-73	77.2	5.3
90-93	82.3	6.7
110-113	87.7	1.5
130-133	119.4	2.9
150-153	122.4	3.2
170-173	142.8	2.7
190-193	132.6	2.7

Table 23. 67 GC 002

Depth	NH-3	Mn
0-3	2.5	0.1
6-9	2.0	0.3
12-15	2.2	0.3
20-23	2.3	0.5
30-33	3.2	1.7
40-43	2.6	1.9
50-53	1.8	3.0
60-63	2.6	3.9
80-83	3.8	8.8
100-103	5.5	9.1
120-123	6.5	10.5
140-143	8.6	13.6
160-163	8.6	
180-183	9.2	18.2
200-203	10.3	22.1

Table 24. 67 GC012 A

Depth	NH-3	Mn
0-3	3.1	0.2
7-11	1.5	<0.1
15-19	3.7	8.6
30-33	9.7	20.7
40-43	13.4	22.2
50-53	16.6	19.9
60-63	19.7	17.6
70-73	23.5	17.3
80-83	26.4	
90-93	27.4	70.6
110-113	30.4	19.1
130-133	30.4	21.2
150-153	18.4	21.6
170-173	44.5	19.9

Table 25. 67 GC016

Depth	NH-3	Mn
0-3	8.0	4.4
6-9	19.5	8.5
12-15	20.9	4.3
20-23	29.0	5.4
30-33	36.9	3.5
40-43	46.6	4.9
60-63	58.1	5.0
70-73	68.6	6.6
90-93	80.6	8.7
110-113	98.4	8.6

130-133	98.9	5.1
150-153	107.6	-
166-169	157.0	4.8

Table 26. 67 GC018

Depth	NH-3	Mn
0-3	62.4	10.7
10-13	101.2	1.3
40-43	257.6	1.3
70-73	350.8	2.0
130-133	538.8	1.9
160-163	605.6	3.0

Table 27. 67 GC029

Depth	NH-3	Mn
0-3	22.7	1.1
10-13	37.1	5.8
31.33	44.1	4.2
50.53	53.1	1.4
70-73	58.0	0.6
90-93	65.9	0.7
110-113	65.6	0.4
130-133	80.6	0.3
150-153	82.4	0.4
170-173	97.3	0.3
190-193	94.0	0.3

Table 28. 67 GC037

Depth	NH-3	Mn
0-3	2.2	0.1
10-13	2.9	0.2
30-33	16.4	7.2
50-53	36.7	7.7
70-73	48.4	7.3
90-93	56.9	7.4
110-113	76.1	8.4
130-133	84.1	7.9
150-153	92.5	8.9
170-173	93.0	9.5
190-193	97.5	10.8

Table 29. 67 GC045

Depth	NH-3	Mn
0-3	0.8	0.2
6-9	1.4	0.3
14-17	<0.5	1.9
20-23	1.5	3.9
30-33	6.2	5.1
40-43	7.9	6.6
50-53	14.4	7.6
60-63	17.5	7.9
70-73	18.0	10.0
90-93	26.4	11.3
110-113	35.2	11.5
130-133	33.2	12.7
150-153	35.9	14.3
170-173	42.6	15.3

Table 30. 67 GC048

Depth	NH-3	Mn
0-3	18.8	0.3
10-13	25.2	7.3
30-33	30.3	1.5
50-53	33.6	1.0
70-73	33.5	0.9
100-103	25.0	0.8
120-123	29.6	0.7
140-143	27.2	0.6
160-163	23.6	0.6

SYSTEMS PERFORMANCE (Craig Penney)

NON-SEISMIC SYSTEM (DAS)

The usually reliable Non-Seismic Acquisition System (DAS) has had a high number of unexpected system harware and software failures. On several occasions they have been serious enough to require the system to be restarted. Some of the problems occurred when a plot of target positioning was being done in the winch control room.

With the large number of geological samples collected this cruise, site identification has proven to be a major problem. The current DAS system numbers the sites sequentially and disregards whether the site was a dredge, gravity core, grab sample, heat flow etc.. This has made the retieval of a specific type of data from the Data Base difficult without a series of cross-reference tables. There is no reason why the DAS system could not keep a better system of filing data internally and produce a data base of its own output.

Navigation

Global Positioning System (GPS)

A MAGNAVOX T-SET which can give absolute position to within 20 metres r.m.s. was used as the preferential positioning system during the cruise. The GPS is still an experimental system and the full satellite array has yet to be installed. Delays with installation of the array have meant that many of the current satellites have exceeded their expected life-times. This has been highlighted this cruise by the erratic performance of satellite 11 of the GPS system. The eight hours of coverage expected at these latitudes has been reduced because of this satellite's failure.

Apart from this problem, the overall performance of the T-Set has been excellent. This in itself has presented a problem in that complacency and a sense of dependence on the T-Set positioning have evolved for which the system's results have shown is unwarranted.

Dead Reckoning system (DR)

Two independent DR systems incorporating gyro-compass, dual axis log and TRANSIT satellite receiver, provide basic dead reckoning positions at all times.

The Primary dead reckoning system consists of Arma-Brown gyro-compass, Magnavox MX610D sonar-doppler, and Magnavox MX1107RS Satnav receiver, and provides the best available positioning of this type on-board ship. The secondary system consists of a Robertson gyro, Raytheon DSN450 sonar-doppler, and Magnavox-1142 Satnav receiver.

Both systems have problems in rough weather or when heading into the sea, due to air entrapment under the hull. A small paddle wheel log has proved invaluable during rough weather. This is because it can be extended beyond the turbulent layer beneath the ship.

The primary system worked very well during transits, but positioning did tend to deteriorate when on station for periods of up to eight hours. Some thought should be given to an automatic output of suspected drift so that this value can be better taken into account in determining position when remaining on station.

The secondary system has proven to be most unsatisfactory and has been considered to be non-operational for most of the cruise. The Raytheon DSN450 has constantly lost track even in very calm sea-states, and has consequentially consistently corrupted the DR position from that system. There also appear to be data transmission problems from the sonar-doppler to the Magnavox 1142.

Bathymetry

Both 3.5 KHz and 12 KHz echo sounders operated well during the cruise, except when in rough sea-states. Even in rough sea-states, when on site the signal was regained and quite good results obtained.

The EPC recorders have proven to be very unreliable, with all available machines needing to be repaired at some time during the cruise. Serious thought should be given to their replacement, because of the man-power and inventory of spares required to keep them going for a month.

Gravity

The Bodenseewerke KSS-31 marine gravity meter performed well and data were collected during the entire cruise. Gravity ties were done in Adelaide and Sydney and a new regional marine gravity station established at Portland in Victoria.

Some problems occurred with the analogue record of gravity, but a digital record was maintained during these periods.

Magnetics

Good single channel magnetic data were obtained from a GEOMETRICS magnetometer at various times during the cruise.

Data base and processing

During the cruise initial processing and verification plots were done for all the DAS data collected. All printed data have been catalogued and are ready for use by participants.

SEISMIC SYSTEM

The Seismic System was used as a site survey tool in several areas were more information was required before dredging began. As the cruise progressed it was felt that there was less need for a site survey to be done.

Intially a GSI airgun with a 40 cubic inch chamber was used as the energy source, but it was found that there was in-sufficent energy for satisfactory penetration in depths over 2000 metres. A single BOLT airgun with a 100 cubic inch chamber was then used and gave adequate results for the site surveys.

A short section of high-resolution cable with 4 channels and 25 metre spacing, configured with stretch sections front and rear, plus a rope and bouy was used as the hydrophone streamer.

During one of the site surveys, a portion of a rear stretch section and the tail rope and buoy, were lost. As this was behind the active sections its loss was not realised until the streamer was retrieved.

CONCLUSIONS

The 1987 "Rig Seismic" sampling cruise over the Otway Basin and west Tasmanian margin succeeded in its overall aim of providing valuable new geological, geochemical and heatflow data to better define the geological framework and petroleum potential of the region. The cruise time from Adelaide to Sydney was 29 days, but one day was lost through a port call to Portland to repair a damaged core cradle, and half a day through a port call to King Island for a medical emergency. Equipment generally worked very well with the exception of the large vibrocorer which is too cumbersome to deploy from "Rig Seismic". Altogether 130 stations were occupied - 23 dredge, 54 core, 33 grab and 20 heatflow - in water depths of 50 to 5000 m (Figs. 1 and 2; Tables 3-6).

Dredge and corer recovered pre-Quaternary rocks and sediments at 22 stations: Palaeozoic volcanics and metasediments in the central Otway Basin, Otway Group sandstones off Tasmania, Cretaceous mudstones in much of the Otway Basin, Early Tertiary siltstones and peat in the Otway Basin, and Late Tertiary carbonates in both Otway and Tasmanian regions. These results, in conjunction with earlier ones, show that continental basement and Early and Late Cretaceous detrital sedimentary rocks crop out on the lowermost continental slope in water 4000-5000 m deep. The mid-slope is characterized by Early Tertiary detrital sediments, and the upper slope by Late Tertiary carbonates. All samples were taken along seismic profiles, and can be added to data from outcrop and shelf wells to help refine knowledge of the regional geology. Table 31 summarises the character and age of samples recovered in 1985 by "Sonne", and in 1985 and 1987 by "Rig Seismic".

On the present cruise Quaternary sediments were obtained in most cores and grab samples, again along seismic profiles. Grab sampling has established the nature of the outer shelf sands, largely bryozoal, which provide turbidites to the Quaternary sediments on the continental slope, otherwise pelagic and hemipelagic in nature. All these samples will help to establish, for the first time, a detailed model of sedimentation on the southern margin, which can be extended back well into the Tertiary.

Temperature gradient measurements at 20 stations, made by a heatflow probe penetrating the top 3 metres of sediment, in conjunction with thermal conductivity measurements on sediment cores, have enabled heatflow calculations to be made. These measurements on BMR seismic line 48/043 south of Argonaut No. 1 well, and "Sonne" seismic line SO36-46 west of Cape Sorell No. 1 well, vary from 25 to 70mW/m , values consistent with the accepted breakup history of the margin, and suggest that the zone of thermal maturation of hydrocarbons generally lies at depths of 2-4 km.

Most lithotypes found beneath the shelf are present on the continental margin. The depths at which sediments originally deposited near sea level were dredged and cored on this cruise are : Early Cretaceous sandstone at 4000-4300 m, Cretaceous mudstone at 3900-4500 m, and Eocene siltstone and peat at 1800-4000 m. This compares with depths in shelf wells of Early Cretaceous 500-3200 m, Late Cretaceous 350-4500 m, and Eocene 300-1700 m. Maximum depths are hence comparable in the Cretaceous, where there is thick overburden on the shelf, but Eocene sediments lie much deeper on the slope than anywhere on the shelf. Additional subsidence in the Eocene on the outer margin averages 1500-2000 m.

A major analytical technique applied on board was headspace gas analysis of selected intervals from virtually all the cores and many of the grab samples. This work showed that thermogenic hydrocarbons were widespread, with background readings of 1-2 ppm. Particularly anomalous readings, with up to 400 times background, came from twelve cores : 4 western Otway, 6 eastern Otway, two western Tasmania. In general, the highest readings were associated with faults extending to, or nearly to, the surface, in areas where Tertiary cover was not thick. It appears that mature hydrocarbon source rocks are present almost everywhere on the upper continental slope.

A full interpretation of the new data, and its integration with the pre-existing seismic data, will enable a more reliable outline of the margin's stratigraphy, structure and geological history to be established, and will aid in regional assessment of petroleum potential. It has already shown that continental basement is present to the edge of the abyssal plain, that the rifts in which Otway Group sandstones were deposited extended well down the western margin of Tasmania, and that most subsidence on the margin occurred after the Eocene.

TABLE 31 : CHARACTER AND AGE OF SAMPLES : "SONNE" & "RIG SEISMIC" CRUISES

Sequence	Stations	Depth Range
Pleistocene to Recent shelf sands	Many 1987 grabs	27 - 294 m
Pleistocene to Recent ooze and turbidites	27 "Sonne" and 53 "Rig Seismic" cores	240 - 4830 m
L. Oligocene - Pliocene marl, limestone, and chalk	S1,2,3,19,23,26,31, 32,33; 1985/5,9,10; GC 35,39,40,46,54; DR10,12,14,18,19	1150 - 4370 m
Eocene - E. Oligocene calcareous siltstone and limestone	S29,32,34; 1985/7; GC5; DR2,10,12,18	650 - 4100 m
Eocene peaty sand and peat	S22,30; GC 12	1757 - 3710 m
Cretaceous sandstone and mudstone	S4; DR2,3,4,5,6,7, 21,22; GC 42	3900 - 4700 m
Basement metamorphics and volcanics	S28,29; 1985/6	1800 - 3750 m

NB : S = 1985 "Sonne" station; 1985 = 1985 "Rig Seismic" dredge; GC = 1987 "Rig Seismic" core; DR = 1987 "Rig Seismic" dredge

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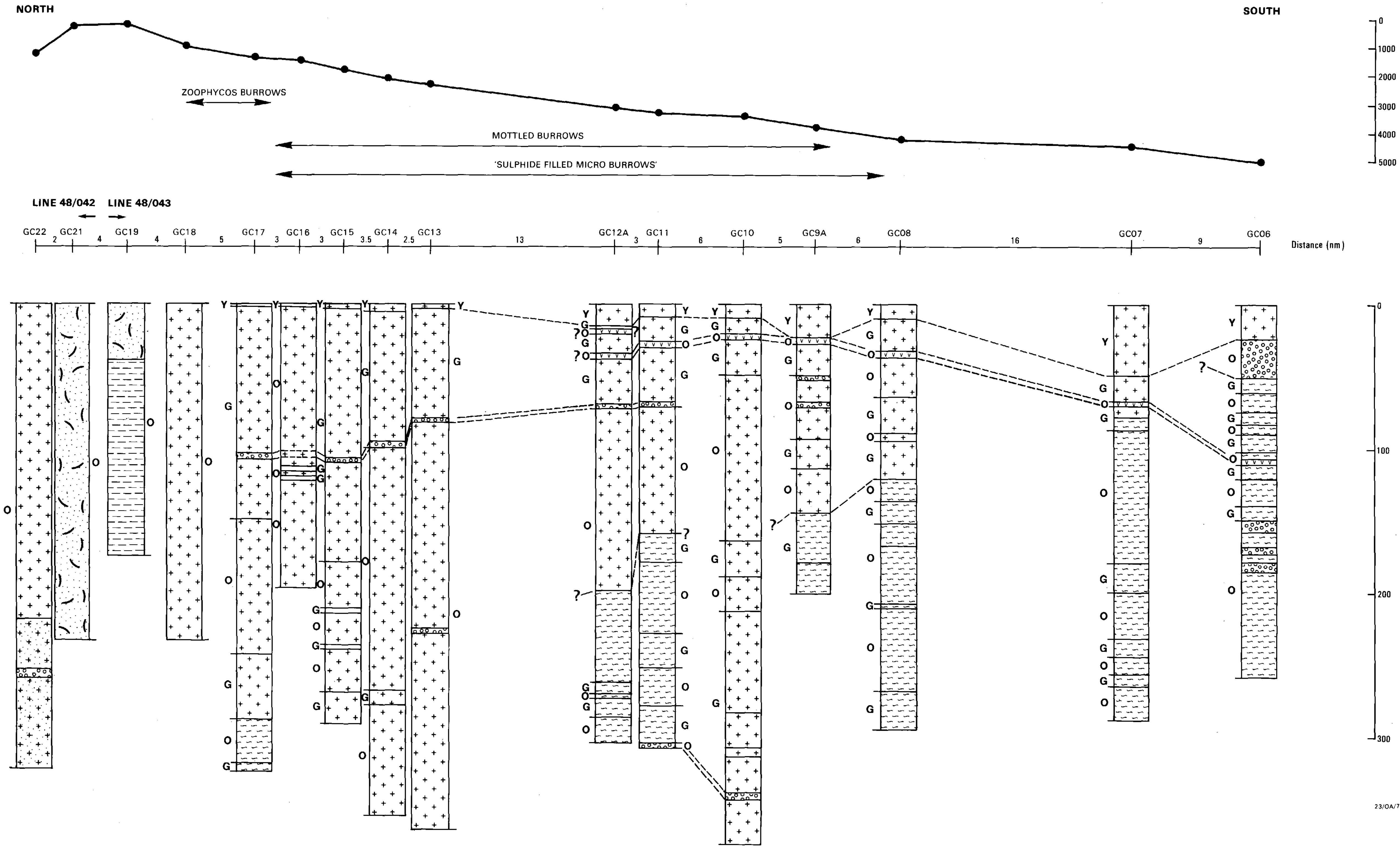

Fig. 21. Cores GC06-19 on BMR seismic lines 48/042 and 48/043, from shelf to abyssal plain south of Beachport.

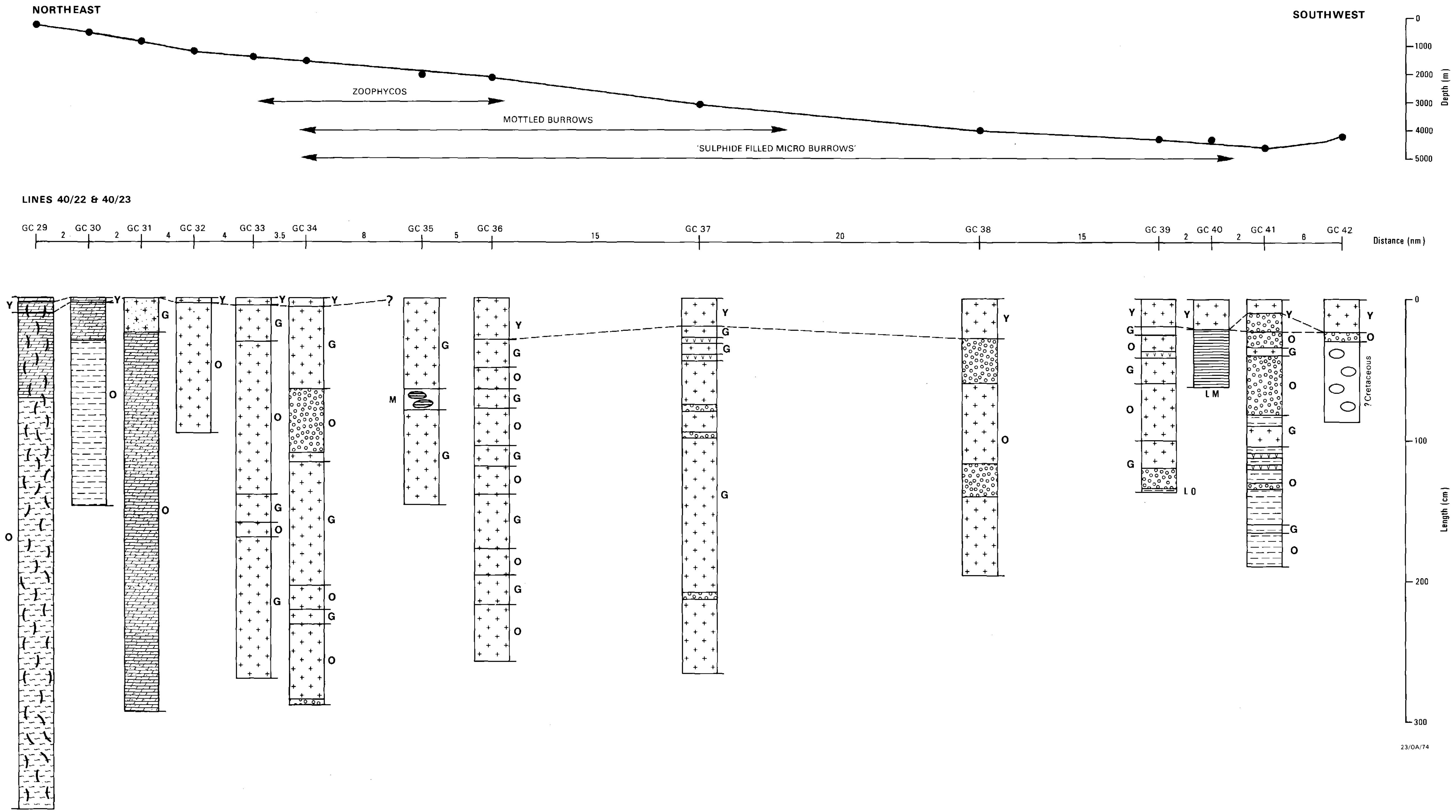

Fig. 24. Cores GC29-42 on BMR seismic lines 40/22 and 40/23, from shelf to continental rise off King Island.

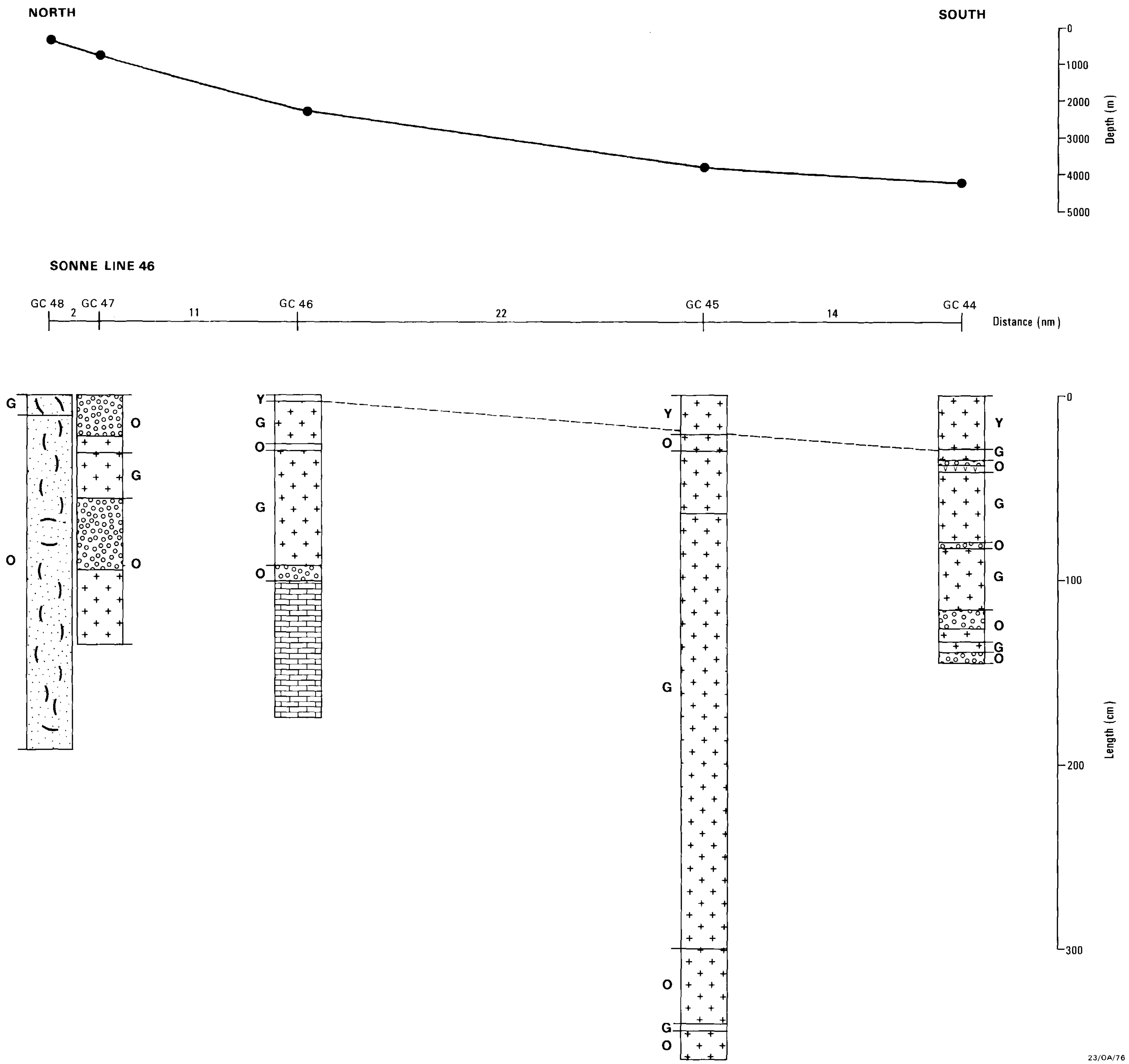

Fig. 26. Cores GC44-48 on "Sonne" seismic line 36-46 west of Cape Sorell, from shelf to continental rise.