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AUSTRALIAN MARINE GEOSCIENCE IN ANTARCTICA

BACKGROUND GEOLOGY, PROGRAM, & MARGIN ACCESSIBILITY

by

H.M.J. Stagg, J.B. Colwell, & R. Whitworth

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DIVISION OF MARINE GEOSCIENCES & PETROLEUM GEOLOGY

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INTRODUCTION

The continental margin of the Australian Antarctic Territory (AAT) extends for almost 5000 km, roughly equivalent to the distance from Brisbane to Perth (via Tasmania) and has a total area within the 200 nautical mile zone of about 1 900 000 km2. Of this area, we have knowledge of only two portions from geophysical surveys (Fig. 1). Prydz Bay has been studied by BMR (Stagg, 1985) and the Japanese (Mizukoshi and others, 1986) in some detail, principally with medium power seismic techniques; the Soviet Antarctic Expedition has also carried out marine geophysical surveying in this area, but no details are available. The eastern sector (130-150 E) has been studied at a reconnaissance level by the French (Wannesson and others, 1985), the Japanese (Tsumuraya and others, 1985), and the USA (Eittreim & Hampton, 1987). At present, we have access to the US data, which is of fairly high quality, but our access to the French data is limited to the scientific press; the Japanese data are of limited value, but available.

Of the remaining margin of the AAT, almost nothing is known, other than from sparse samples from which inferences have been drawn (Domack & Anderson, 1983; Truswell, 1982, 1983). However, an attempt can be made to draw conclusions on such unknown areas by looking at the coastal geology or at the geology of the conjugate (or once adjacent) margins of other continents. though both these approaches are fraught with problems. In the first case, where the coastal geology is reasonably well known, it often bears little resemblance to the structures seen offshore, and being exposed is not likely to be representative. In the second case, the current whereabouts of the conjugate margin is not always known with certainty and the apparent inherent asymmetry of the breakup of old continents to produce conjugate margins (Lister & others, 1986) makes the drawing of inferences difficult.

In summary, the margin of the AAT is almost as poorly known as was the western margin of Australia in the early 1960's. The program which is proposed in this report has three main objectives:

1. To develop an understanding of the geological framework and evolution of the continental margin of the AAT.

2. To understand and model the geological processes responsible for the present physical environment of the continental margin of the AAT; and

3. To further BMR's more general studies of the margins of Australia, including studies of the Australian southern margin which was joined to the AAT margin about 150 Ma ago in the Early Cretaceous.

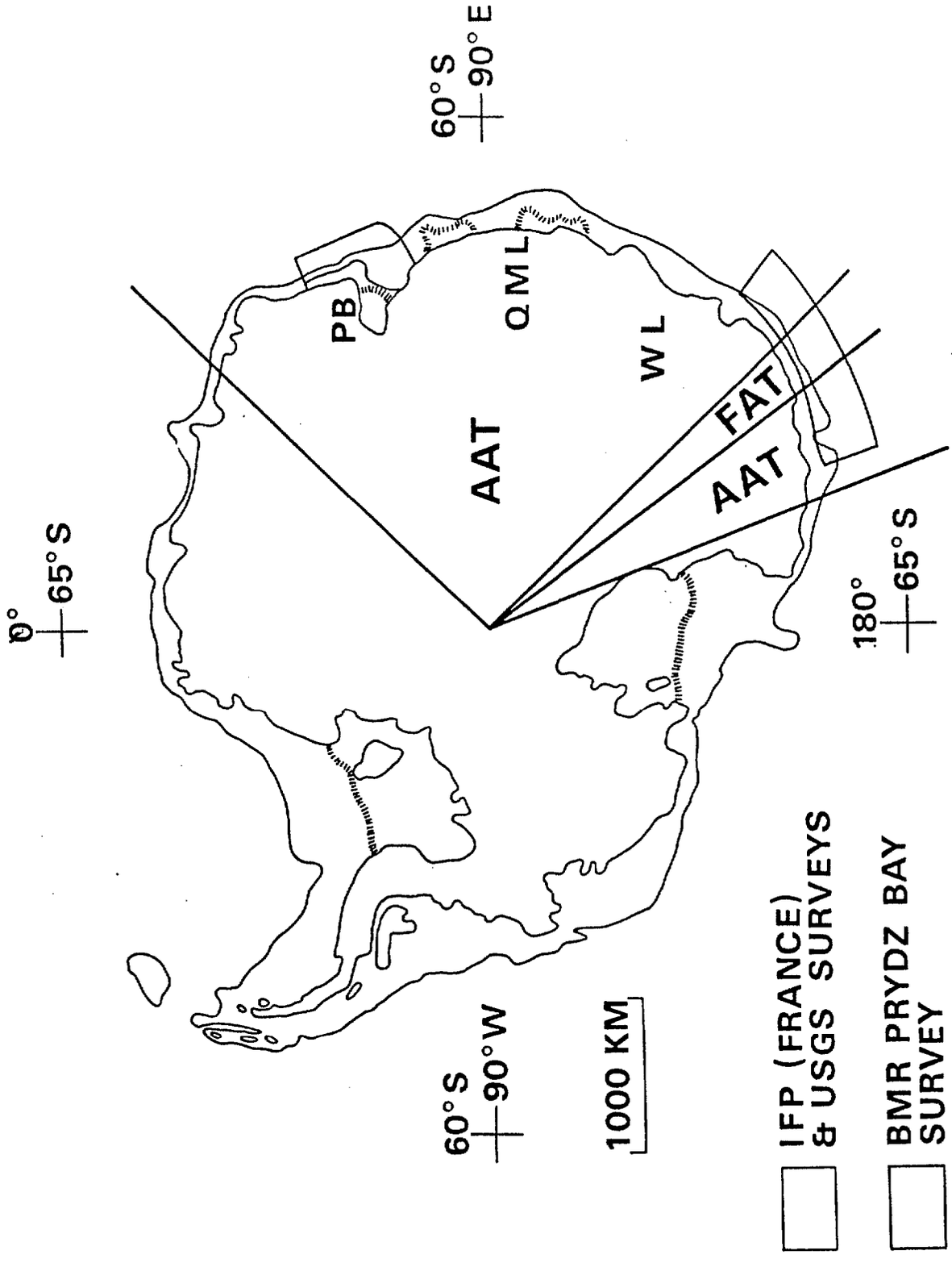
These objectives are appropriate to BMR's role as the Commonwealth agency responsible for geoscientific studies of the AAT. They provide a basis for the assessment of petroleum and mineral potential of the offshore areas and thus support Australia's role under the proposed Antarctic Minerals Regime.

We believe that the most efficient and cost-effective method of achieving these aims is, in the first instance, by a systematic program of regional studies.

This report will address three questions:

1. What can be summarised/surmised of the geology of the margin of the AAT?

Figure 1: Antarctica - showing those areas of the offshore AAT that have been extensively surveyed by geophysical techniques.



2. What is a rational and cost-effective program that will allow us at the end of, say, twelve years to adequately outline the geology and resources potential of the margin of the AAT?

3. What is the accessibility of the AAT margin to research vessels of different ice classifications over a twelve year period?

GEOLOGY OF THE AAT MARGIN

This section details the AAT margin, segment by segment, from west to east, summarising the available information and drawing inferences on the geology, where possible (segment locations in Plate 1).

Area 1: Enderby Land (45E - 70E)

References Relevant to Offshore: Fedorov and others (1982); Kurinin and Grikurov (1982).

Onshore Geology/Geophysics: Kamenev (1982); Sheraton (1982); Wellman and Tingey (1982); Black and James (1983); Ellis (1983); Harley (1983); James and Tingey (1983); Sandiford and Wilson (1983); Sheraton and others (1980); Wellman (1983).

The metamorphic rocks of Enderby Land consist of the ancient Archaean Napier Complex (granulite facies) bound to the south by the Proterozoic Rayner Complex, a lower grade reworking of the Napier Complex. No unmetamorphosed sedimentary rocks have been found from the area.

Conjugate Margin: Assumed to be the east coast of India.

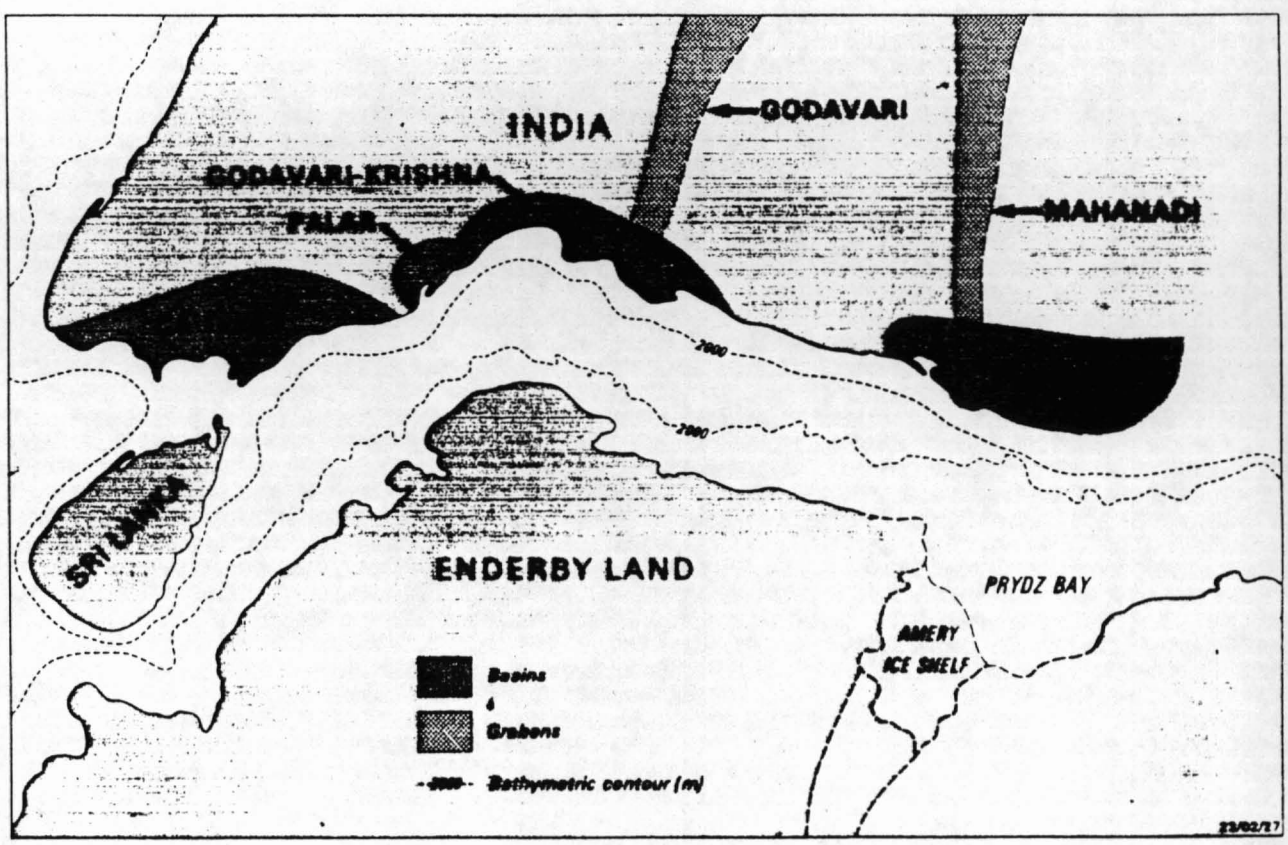
Surveys: 1982 BMR survey in the extreme east.

Offshore Geology: Little can be concluded about the offshore geology of Enderby Land based on direct evidence. Fedorov and others (1982b) follow earlier authors in showing a reconstruction of India against Antarctica (their fig. 7.2; Fig. 2) and attempted to match major structures between the two margins. The principal sedimentary basins of the eastern Indian margin (Sastri & others, 1974, 1981) that would lie opposite Enderby Land are -

Cauvery Basin - occupying the southeast part of Peninsular India, is a block-faulted pericratonic basin comprising horst and graben structures. The maximum sediment thickness is about 5500 m and the sediments range in age from Early Cretaceous to Recent.

Godavari-Krishna Basin/Godavari Graben - a composite basin with comparable areas on land and under the continental shelf, and trending parallel to the coast. The maximum depth to basement is about 4000 m and sediments range in age from Permian to Recent. The underlying Godavari Graben trends at right angles to the coast and contains up to 5000 m of sediments ranging from Early Palaeozoic to Eocene in age. Fedorov and others (1982) have reported that aeromagnetic anomalies over eastern Enderby Land indicate the existence of a sub-longitudinal fault zone with horst and graben-like structures which range from 130-150 km in width and extend for at least 300 km inland between 57 30'E and 60E. They implied that this may be a pre-breakup continuation of the Godavari Graben.

Figure 2: Reconstruction of India against Enderby Land, showing the relationship of the Indian east coast basins to the Antarctic margin (after Stagg, 1985).



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The only marine data available is from the western extremity of the 1982 BMR survey. Only one of the lines extended across the shelf, and it showed that little sediment was present.

Area 2: Prydz Bay (70E - 78E)

References Relevant to Offshore: Fedorov and others (1982a, b); Kurinin and Grikurov (1982); Mizukoshi and others (1986); Stagg and others (1983); Stagg (1985).

Onshore Geology/Geophysics: Mond (1972); Ravich and Fedorov (1982); Tingey (1982); Wellman and Tingey (1976).

Most of the onshore rock exposures occur along the coast and inland in the Prince Charles Mountains chain which extends south of Prydz Bay for at least 600 km. Most exposures consist of Precambrian metamorphics, metasediments, and intrusives. The only known onshore outcrops of Phanerozoic sedimentary rocks are coal-bearing Permian continental strata in the Beaver Lake area, more than 200 km south-southwest of Prydz Bay (Mond, 1972).

The Prince Charles Mountains are exposed along the flanks of and in a regional ice-surface depression caused by ice drainage through the Lambert Glacier. Gravity surveys (Wellman & Tingey, 1976) and deep seismic soundings (Kurinin & Grikurov, 1982; Fedorov & others, 1982b) showed that a major graben structure underlies tha Lambert Glacier and Amery Ice Shelf and extends inland for almost 700 km. Soviet aeromagnetic data offshore suggests that the Lambert Graben continues into Prydz Bay.

Conjugate Margin: East coast of India.

Surveys: BMR (1982) - 5000 km of 6-channel, 3 and 6-fold airgun seismic data; Japan (1985) - 2350 km of 24-channel, 6-fold watergun seismic data (only a small portion in Prydz Bay); Soviet Antarctic Expedition (1986) - details unknown.

Offshore Geology: The principal results of the Prydz Bay study can be summarised as follows (Stagg, 1985) -

1. The Prydz Bay basin occupies an area of at least 40 000 km2 in water depths of 400-900 m and contains at least 5 km of sedimentary rocks.

2. The NE-NNE basin trend suggests that, with the Lambert Graben, the basin forms a failed rift at a triple or four-armed junction.

3. The sedimentary pile in the Prydz Bay basin is little disturbed by folding and faulting other than in the southwest of the bay.

4. Two major groups of seismic sequences can be identified. The lower group possibly consists of Permian to Late Jurassic or Early Cretaceous strata of predominantly continental origin, while the upper group possibly comprises Cretaceous and Cainozoic strata of predominantly shallow marine origin.

5. Three major unconformities can be identified within the Prydz Bay basin. In order of decreasing age, these are interpreted as being due to rift onset (?Triassic-Early Jurassic), margin breakup (?Early Cretaceous), and glacial advances (mid-Miocene-Early Pliocene).

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While Prydz Bay has been studied in considerable areal detail, the seismic technique was relatively low-power, and almost no information is available from below the water bottom multiple on the continental shelf. Some of the interpretation uncertainties will be resolved if the Ocean Drilling Program (ODP) drills stratigraphic holes, as planned, in Prydz Bay in early 1988. However, there is a very strong case for returning to Prydz Bay with a high power seismic system with a long receiver cable to try to detail the deep structure of the Prydz Bay basin.

Area 3: West Ice Shelf (78E - 88E)

References Relevant to Offshore: none known

Onshore Geology/Geophysics: The only known coastal outcrops are of Precambrian granulite facies metamorphic rocks and Cainozoic volcanics.

Conjugate Margin: probably northern India (no longer in existence as a margin; Fig. 3).

Surveys: none.

Offshore Geology: With no useful background information available, it is difficult to draw any conclusions. Dredging by HMS Challenger in the 1870's recovered a variety of rocks that included red sandstone, but no substantial details are available.

Area 4: Mirny-Shackleton Ice Shelf-Casey (88E - 112E)

References Relevant to Offshore: Truswell (1982, 1983); Tsumuraya and others (1985).

Onshore Geology/Geophysics: The coastal outcrops again consist of Precambrian granulite facies and charnockite bodies. The Bunger Hills area, behind the central part of the Shackleton Ice Shelf, has been the target of recent Australian work, but few results have been published so far. No sedimentary rocks have been reported from the coastal strip, but Cambrian sandstones are abundant in moraines and crop out inland.

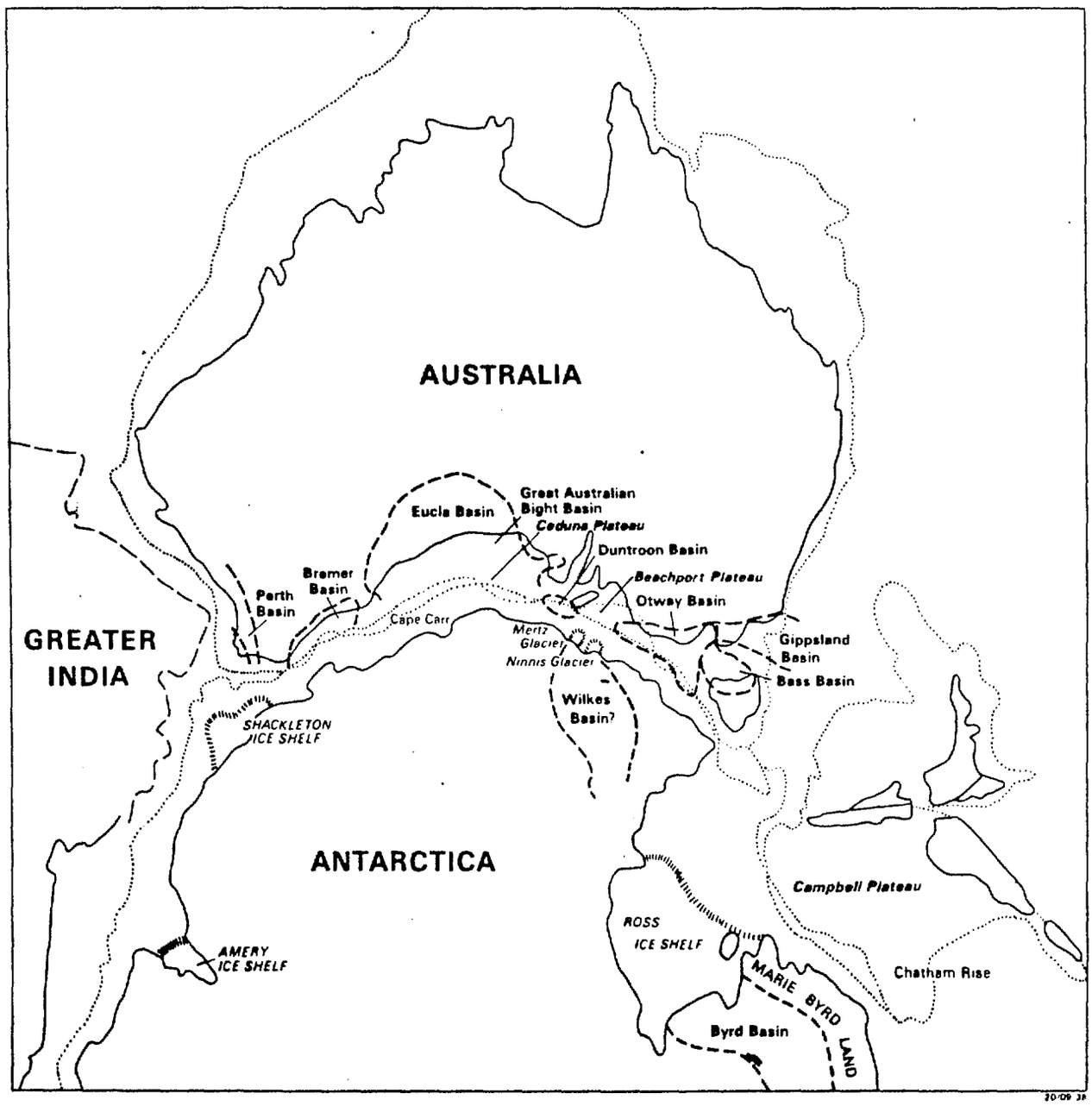
Conjugate Margin: northern India (margin no longer in existence) and southwest Australia (Fig. 3).

Surveys: Japan (1984) - 3 lines (~800 km) of 24-channel, 6-fold airgun seismic data.

Offshore Geology: The three Japanese lines (Tsumuraya & others, 1985) provide little information on the margin. The line drawings presented show the typical Antarctic continentward-dipping shelf, a sharp shelf break, and a steep slope. Little detail is visible beneath the shelf (due to multiples) and the deep-water sequences appear similar to those observed off Prydz Bay.

Truswell (1982, 1983) examined dredge samples collected by Douglas Mawson's 1911-14 Australasian Antarctic Expedition from several areas for traces of recycled palynomorphs in an attempt to predict the presence or otherwise of sedimentary basins, either onshore or beneath the continental shelf. Samples from the western side of the Shackleton Ice Shelf yielded abundant palynomorphs which fell into three age groups - Permian, Late Jurassic to Early Cretaceous, and Late Cretaceous to Early Tertiary. There was little evidence for marine influence in the Late Jurassic-Early Cretaceous element, whereas the Late Cretaceous-Early Tertiary samples appeared to indicate marine source rocks.

Figure 3: Continental reconstruction of Australia, Antarctica, and Greater India (after Truswell, 1983)



Truswell speculated that the Mesozoic and Tertiary palynomorphs may have been derived from sediments being eroded near the shelf edge. In contrast, the Permian samples appear to originate from onshore, possibly from beneath the Denman Rift, which may be a similar feature to the Lambert Graben.

The Perth Basin usually reconstructs against the eastern end of the Shackleton Ice Shelf-Casey area (Fig. 3), and probably forms a triple junction (or perhaps a four-armed junction, if the Vanderford Glacier marks a major rift structure in Antarctica. It is worth pointing out that the only substantial marginal plateau in the offshore AAT (Bruce Rise) lies north of the Shackleton Ice Shelf. Nothing is known of this feature's origins (?continental or oceanic) or how it fits into pre-rift reconstructions. It would not be unreasonable to suggest the presence of sedimentary basins on this part of the Antarctic margin, and we regard the general area as having a high priority for marine geoscience.

Area 5: Sabrine-Banzare-Clarie Coasts (112E - 135E)

References Relevant to Offshore: Truswell (1982, 1983); Tsumuraya and others (1985).

Onshore Geology/Geophysics: ?references. Rare onshore outcrops consist of Precambrian granulite facies and charnockite bodies.

Conjugate Margin: Southern margin of Australia (western half of the Great Australian Bight (GAB) and southwest Australia; Fig. 3).

Surveys: Japan (1984) - ~2300 km of 24-channel, 6-fold airgun seismic data.

Offshore Geology: The Japanese seismic data consist essentially of a long east-west tie line on the slope and rise, and north-south transects at about 120E and 128E. One of the N-S transects (120E) crosses the shelf, and again Tsumuraya and others (1985, fig. 8) show a continentward-dipping shelf, sharp shelf break, and steep slope, with no geological detail visible beneath the shelf, presumably because of multiples. The deep-water sequences appear similar to those off Casey and Prydz Bay.

Truswell (1982, 1983) examined recycled palynomorphs from this area (Cape Carr), reporting the existence of Early to mid-Cretaceous and Late Cretaceous to Early Tertiary components. The only marine influence found was in the late Palaeocene to Eocene assemblages. While sparse sampling made it difficult to pinpoint the source rocks, Truswell speculated that the recycled material may be eroding from strata outcropping at the steep slopes of the shelf break.

The assumed conjugate margin of southwest Australia and the western half of the GAB, does not give much assistance. The Bremer Basin in the west appears to be limited to the continental slope and is poorly known, while the Eyre Sub-basin, although much better known and containing as much as 6 km of sediment (Bein & Taylor, 1981), may be part of a system of grabens on the southern margin of Australia (Willcox & others, in prep) with no obvious counterpart in Antarctica.

Area 6: Adelie Coast (135E - 147E)

References Relevant to Offshore: Davey (1985); Domack (1982); Domack and Anderson (1983); Domack and others (1980); Eittreim and Hampton (1987); Eittreim and others (1985); Stagg and others (in press); Truswell (1982,

1983); Tsumuraya and others (1985); Vanney and Johnson (1979a, b); Wannesson and others (1985).

Onshore Geology/Geophysics: Mawson (1942); Steed (1980, 1983); Steed and Drewry (1982).

Coastal outcrops here contain more unmetamorphosed sedimentary rocks than are usually found in East Antarctica. In addition to the Precambrian granulite facies and charnockite bodies, common to much of the East Antarctic Shield, Beacon Group sediments (blue and purple shale, sandstone, and argillaceous sandstone; Mawson, 1942) overlain by ?Jurassic dolerite have been found in the cliffs of Horn Bluff (approximately 150E). Davey (1985) suggests that sediments of Beacon age may also be present deep under the margin.

Steed (1980, 1983) and Steed and Drewry (1982) have interpreted a major sub-ice basin, the Wilkes Basin, from radio echo-sounding data. Steed (1983) concluded that the basin is sedimentary in origin and developed by tensional growth and subsidence similar to the development of the North Sea Basin.

Conjugate Margin: southern margin of Australia (?eastern half of the GAB) - Ceduna Terrace (GAB Basin) and Beachport Terrace (Otway Basin; Fig. 3).

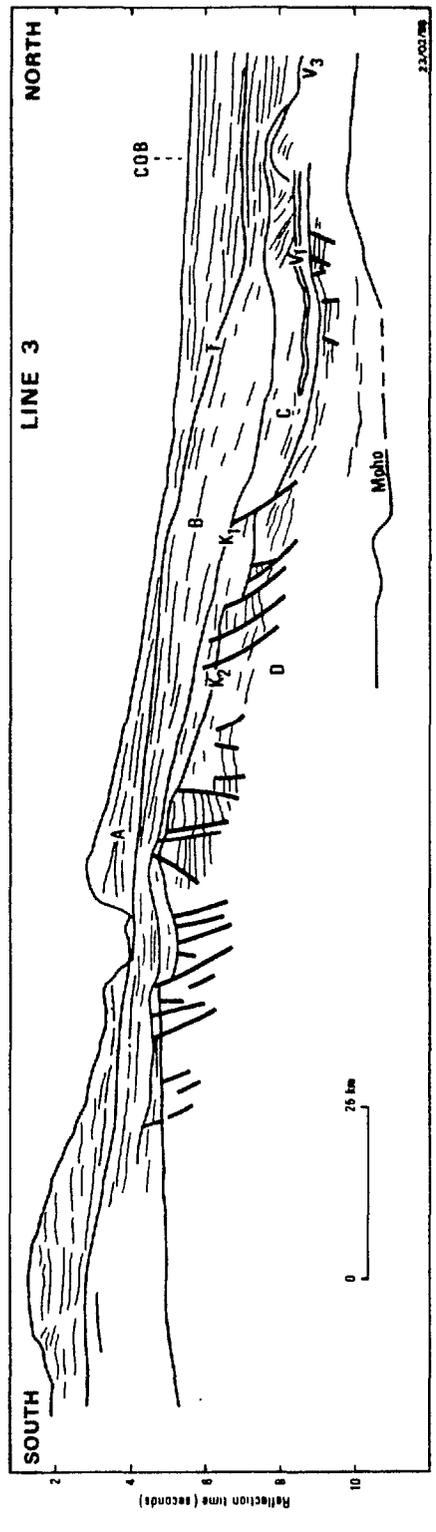
Surveys: France (1982) - ~3000 km of 24-channel 24-fold airgun array seismic data; Japan (1984) - ~600 km (total) of 24-channel 6-fold airgun seismic data; (USA (1984) - 1800 km of 24-channel 24-fold airgun array seismic data.

Offshore Geology: Offshore Wilkes and Adelie Lands now constitute probably the best studied part of the offshore AAT, with French, Japanese, and US multichannel seismic (MCS) programs being completed. It is unfortunate that only a single transect from oceanic crust to inner shelf has been published (Wannesson and others, 1985); the US study was principally restricted to the continental slope and rise by adverse ice conditions. The single French line defines three major seismic sequences overlying acoustic basement beneath the shelf and slope. The ages of the intra-sequence unconformities were considered to be Upper Eocene (42 Ma) and late Oligocene (25 Ma). The total thickness of sediments under the continental shelf and above acoustic basement exceeds 4s two-way time (twt).

The only available geological sample that gives an indication of the age of the older part of the section is a non-marine Aptian core obtained from the flank of the George V (morphologic) Basin between the Ninnis and Mertz Glaciers (Domack and others, 1980; Domack, 1982; Domack and Anderson, 1983). Truswell (1982, 1983) also examined palynomorphs from the Mawson dredge collection in this area and found Early Cretaceous spores and pollen that resembled an assemblage recovered from the Georg V Basin core, and less common Late Cretaceous to Early Tertiary taxa.

As previously noted, the US MCS data, whilst of high quality and displaying Moho reflections in a number of places, were restricted to the slope and rise (Eittreim & Hampton, 1987). Four major sedimentary sequences were identified (Fig. 4) and interpreted as being terrestrial or early synrift basin, synrift basin, continental shelf, and continental slope and rise sequences. The total sedimentary thickness is again at least 4s twt.

Figure 4: Line drawing of reflection seismic profile recorded by US Geological Survey approximately along longitude 131 E (after Stagg & others, in press).



In summary, a considerable thickness of sediment appears to be present beneath the shelf and the slope/rise. While we have access to the US MCS data, we are unlikely to see any more of the French data than has already been published in the scientific press. Although this area is an attractive area for further exploration, we suggest that the poorer-known parts of the AAT margin warrant first priority.

Area 7: George V - Oates Coasts (147E - 160E)

References Relevant to Offshore: none known.

Onshore Geology/Geophysics: McLeod and Gregory (1967); Ravich and others (1968). Beacon Group (Permian - Jurassic) sediments are found in the west (Horn Bluff); Upper Precambrian metasediments and older Precambrian medium to high grade metasediments and metavolcanics are found in the east. The Horn Bluff dolerites are an important potential geological tie to Australia.

Conjugate Margin: southeast Australia (?Otway Basin; basins of the Tasmanian west coast; Fig. 3).

Surveys: none.

Offshore Geology: Nothing is known directly. Given the presence on the conjugate margin of complex rift/wrench basins, we speculate that there is good potential for the development of similar basins on the Antarctic margin.

MARGIN PROGRAM

There are two methods of conducting an AAT margin geoscientific program - by aircraft and by ship.

Aeromagnetic Studies

In past years, proposals have been submitted for a follow-up to the highly successful Project Investigator-I aeromagnetic survey of the Australian-Antarctic Discordance (Vogt & others, 1983). Such a project would involve flying a systematic coverage of the margin of the AAT with RAAF aircraft operating from bases in southern Australia. In addition to the extremely useful information which would be gained on depth to magnetic basement (and hence sediment thickness), aeromagnetic surveying is unaffected by the presence of ice. However, while such a program would be highly desirable, particularly on the continental shelf, the costs are likely to be comparable to those for a summer program of marine geoscience. For this reason, it is debatable whether such an aeromagnetic program can be justified, particularly if it is to be at the expense of a summer marine program.

Marine Studies

Two issues will be addressed here - firstly, what shipboard geoscientific program is required to achieve the aims set out in the introduction to this report, and secondly, what is the order of priority for areas to be studied.

Shipboard Scientific Effort

Geoscience studies of the margin of the AAT can be divided into three morphologic areas (Plate 1; areas are approximate).

1. Continental shelf

   Total area - 700 000 km2
   Area covered by ice shelves - 66 000 km2
   Area theoretically accessible - 634 000 km2

2. Continental slope (Including marginal plateaux) - water depths from shelf break to ~3000 m; average width 75 km.

   Total area - 365 000 km2

3. Continental rise (as far as COB) - average width 170 km.

   Total area - 820 000 km2

Obviously, from a potential resources viewpoint, the order of priority for studying the above areas is - continental shelf, slope, and rise.

The prime geoscientific tool to be applied on the Antarctic margin is multichannel reflection seismic (MCS). However, given the dearth of geological information, geological sampling, heatflow, geochemical sampling, and side-scan sonar will also be very important. If it is assumed that seismic data are shot at a line spacing of about 35 km on the shelf and slope and at 100 km on the continental rise, and that all the shelf was accessible, then a total of about 36 500 km of seismic data is required (18000 + 10300 + 8200 km); to this should be added a further 4800 km in tie lines, giving a total of 41300 km. Of this, a total of about 5500 km has already been shot by BMR (albeit at a lower capability than we would like).

Priorities

In the previous section, it was stated that the continental shelf was the highest priority area for marine geoscience. Obviously, for efficient deployment of the ship, the adjacent slope and rise would be studied at the same time as any segment of the shelf. Based on the summary of the known/predicted offshore geology outlined in this report, we believe that the following shelf areas should be studied in the order of priority:

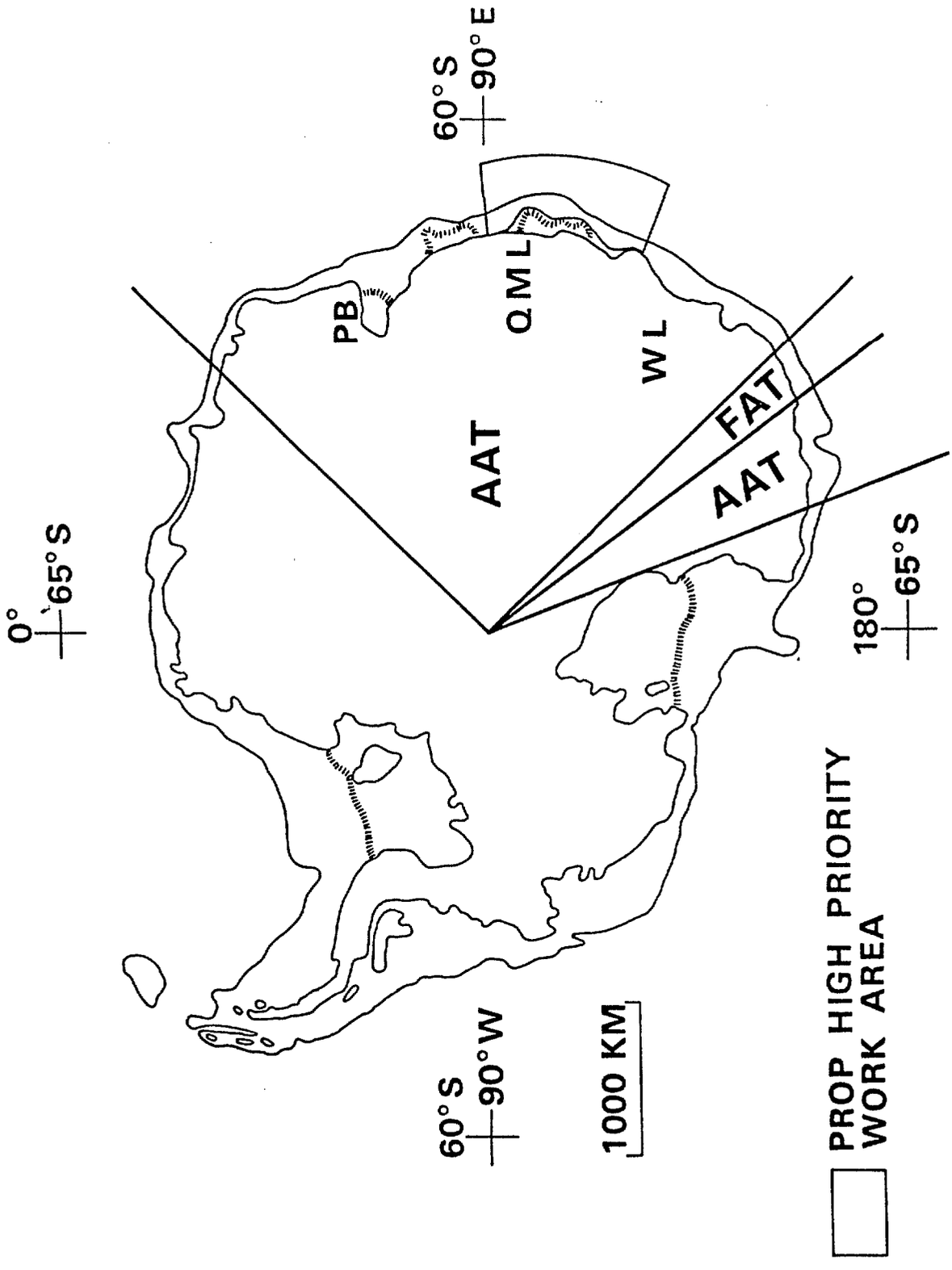
1. Mirny-Shackleton-Casey ('Offshore Queen Mary Land') - 6900 km seismic

2. Sabrina-Banzare-Clarie Coasts - 6400 km seismic

3. Adelie-George V-Oates Coasts - 10000 km seismic.
   In the next section (Margin Accessibility) it will be seen that much of the George V and Oates Coast shelves are probably inaccessible to geoscience; this will probably reduce the total seismic distance to less than 7500 km. It is further assumed that the 1800 km of MCS data acquired by the US Geological Survey in 1984 is used as part of the study.

4. Prydz Bay-West Ice Shelf - 6100 km.
   Although we already have seismic coverage in Prydz Bay, there is a need to extend this to the east and into deep water and to supplement the existing data with high-multiplicity airgun array data to elucidate the deep structure.

Figure 5: Antarctica - showing the highest priority area of the offshore AAT for marine geoscience.



5. Enderby Land - 7400 km.
   This area is considered to be of lowest priority because it is the most distant part of the AAT from Australia and we consider it is probably less likely to contain sedimentary basins than other parts of the margin.

Each of these areas would take up an entire Antarctic summer (prime access) season of 2 months from mid January to mid March to survey. Naturally, if any area was inaccessible because of ice, the vessel would re-deploy to adjacent areas or to the southern Kerguelen Plateau, if feasible. If it is assumed further that one season is a total write-off because of inclement ice conditions, and that one program is mounted every two years, then a time scale of twelve years for the 'first-look' program appears reasonable.

An approximate breakdown of each summer's program is as follows:

Transit to and from Antarctica	-	18 days
Multichannel seismic (Including down-time)	-	40 days
Geological sampling/heatflow	-	12 days
Bad weather standby in Antarctic waters	-	10 days
TOTAL	-	80 days

MARGIN ACCESSIBILITY

It must be emphasised most strongly that any estimates of ice extent and accessibility to the margin of the AAT during the summer are only estimates and no more. Furthermore, there is little chance of predicting in any given summer whether ice conditions will be good or bad. Two separate cases illustrate this point very well.

1. Ice limit maps compiled from 1973-82 suggest that substantial parts of the continental shelf in the vicinity of the Shackleton Ice Shelf may be accessible for geophysical work during the summer. However, in the 1986/87 season a major iceberg (34x60 km as measured by Advanced Very High Resolution Radiometer, or AVHRR) grounded on the shelf and caused a major buildup of pack ice that would normally have cleared during the summer. This ice buildup was entirely unpredicted and caused the cancelation of the second season of the Bunger Hills operations. Glaciologists at Antarctic Division say that, on the basis of past experience, the iceberg could take up to 15 years to melt and break up; however, it is not certain that it will cause an excessive buildup of pack ice every summer.

2. When BMR conducted its geophysical survey of Prydz Bay in early 1982, ice was so sparse that most lines were run to within sight of the coast. The following summer, Prydz Bay was heavily choked with ice, and very little work would have been possible.

Accessibility

Five maps are attached. Plate 1 shows a crude division of the margin of the AAT (except for the segments from 45-60E and 153-160E) into the morphological units listed above; the continental shelf is further divided into logical 'compartments'. Plates 2, 3, and 4 show the ice limits at every 10 degrees of longitude for the months of January,

February, and March. ('Ice limit' is defined here as the limit of 15% ice density.) The lines shown are the minimum, mean, and maximum ice limits based on data from 1973-82, compiled by Antarctic Division. The map for February, the most ice-free month, also includes two lines, each one standard deviation each side of the mean ice limit.

We also have access to the Sea Ice Climatic Atlas for the Antarctic, produced by the US Naval Oceanography Command. While the Atlas generally agrees with the Antarctic Division data, it also provides several other sets of maps, of which two are particularly useful -

1. Mean concentration of ice when ice is present - these maps show that when ice is present, it is almost always present in high concentrations - typically 50-80%. It is reasonable to assume that when ice is present, no systematic geophysical work can be done.

2. Probability of any ice being present (Plate 5) - if it is assumed that the presence of sea ice precludes marine geophysical surveys, then this map gives a percentage probability that such operations can be conducted in a given area.

Antarctic Division have advised that the resolution of the satellite imagery is about 30 km; consequently, the maps in the Atlas, at a scale of 1:25m are rather coarse. Although digital data are available from the US, Antarctic Division say that the digital information will probably not be any more enlightening than the Atlas maps. However, it is possible that higher resolution imagery may be available in almost real time in the next few years either on board ship or at Casey ANARE station.

From the maps, we believe the following conclusions may be drawn. In these conclusions, Ship A will refer to an equivalent of the *Rig Seismic* (DNV Ice Class C, with single-skinned hull), Ship B refers to an upgraded Ice Class C vessel with improved ice protection as outlined in Appendix A, and Ship C refers to a ship with Ice Class A strengthening.

1. All of the continental rise would be accessible to ship A.

2. Over several seasons, the entire continental slope would be accessible to ship A, with minimal risk of entrapment. Ship B would further reduce what would be a small risk.

3. The continental shelf can be divided into three areas as follows -

   (a) Areas where there is a relatively high probability (>60%) of the continental shelf being clear of ice as far south as the coast (*eg* Prydz Bay and the sector from 135-150E).
   (b) Areas where the probability of ice being found increases steadily as one approaches the coast - ie the probability contours are sub-parallel to the coast (eg 100-130E).
   (c) Areas where there is low ice probability close to the coast, but a higher probability farther offshore (eg 91-95E).

We believe that either Ship A or Ship B would be suitable in shelf area (b). Ship B would have an improved margin of safety in case of heavy ice and would obviously be preferred from the point of view of ice protection and risk of total loss. In area (b), no attempt would normally be made to steam south of the ice edge with a seismic streamer deployed - ie the chance of being beset should be small. As there is some danger in area (a) of being cut off from the open sea by ice drifting off the pack in adjacent areas, Ship B is the preferred option here. We do not believe that area (c) should be tackled with less ice

capability than Ship C, as this area is the highest risk area for entrapment. An assessment of vessel operations and safety is given in Appendix B.

Summary

In summary, we believe that the difference in the areas of the continental shelf that could theoretically be explored in the long term by Ships A or B is not large (without regard to risk factor). The advantage of Ship B is primarily the significantly reduced risk of entrapment or damage, and potential loss (which all on board would appreciate). Ship C would provide a further reduced risk factor, but would only allow marginally more access to the shelf.

The areas of continental shelf (excluding all ice shelves) that could be studied by the different vessels over a 12 year period are assessed as follows (see also Plate 6) -

		Long. Limits	Shelf Area (km2)	%
Ship A or B	As far as coast	135 - 145	164 000	10
	Majority of shelf	45 - 70E	110 000	17 (max)
		78 - 88E	48 000	8 (max)
		105 - 135E	131 000	21 (max)
Ship B	As far as coast	70 - 78E	100 000	16
Ship C	Majority of shelf	88 - 105E	69 000	11 (max)
		145 - 150E	20 000	3 (max)
Probably totally inaccessible		150 - 160E	92 000	15

In practice, although 56% of the shelf is assessed as being accessible during the 12-year period to either Ship A or Ship B, caution on the part of the Master and the Chief Scientist on board would probably reduce the amount of the shelf that would be studied using Ship A.

ACKNOWLEDGEMENTS

We would like to express our appreciation to Dr T.H. Jacka and his fellow glaciologists at Antarctic Division, Department of Science, for providing invaluable assisstance in the area of margin accessibility, and to Mr R.J. Tingey of BMR for critically reading this report.

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APPENDIX A: PROPOSED MODIFICATIONS TO *RIG SEISMIC* to provide a safety factor when operating off Antarctica.

(After M.J. Doherty & Co. Pty. Ltd)

The following alterations describe additional watertight subdivision to provide some degree of protection to the dangers of operating off the ice. One compartment subdivision cannot be achieved because of the size of the engine room, but the alterations will provide a reasonable level of protection against flooding. There is no increase to the Ice Classification by DNV.

(Note: numbers in brackets in the following text refer to the numbers on the lower part of Figure 6.)

The compartment between frame 87 (1) and frame 40 (2) shall be divided into three watertight compartments by the addition of two watertight steel bulkheads, one on frame 70 (3) across the full width of the vessel (thereby separating the instrument room and the workshop area), and one on frame 50 (4) at the starboard side between the instrument room and the office. Each of these steel bulkheads shall be fitted with a hinged W/T steel door.

The shell plating shall be increased in thickness by the addition of 8mm doubler plates plug welded to the outside of the existing shell between frames 78 and 14 (5), and extending from the tank top to the shelter deck approximately, thereby covering the instrument room and the engine room.

All steel used in the modifications shall be approved to DNV standard.

All electrical and pipework services passing through the main deck shall be made watertight with glands and/or packing, as shall the services passing through bulkheads 50, 54, 70, and 75.

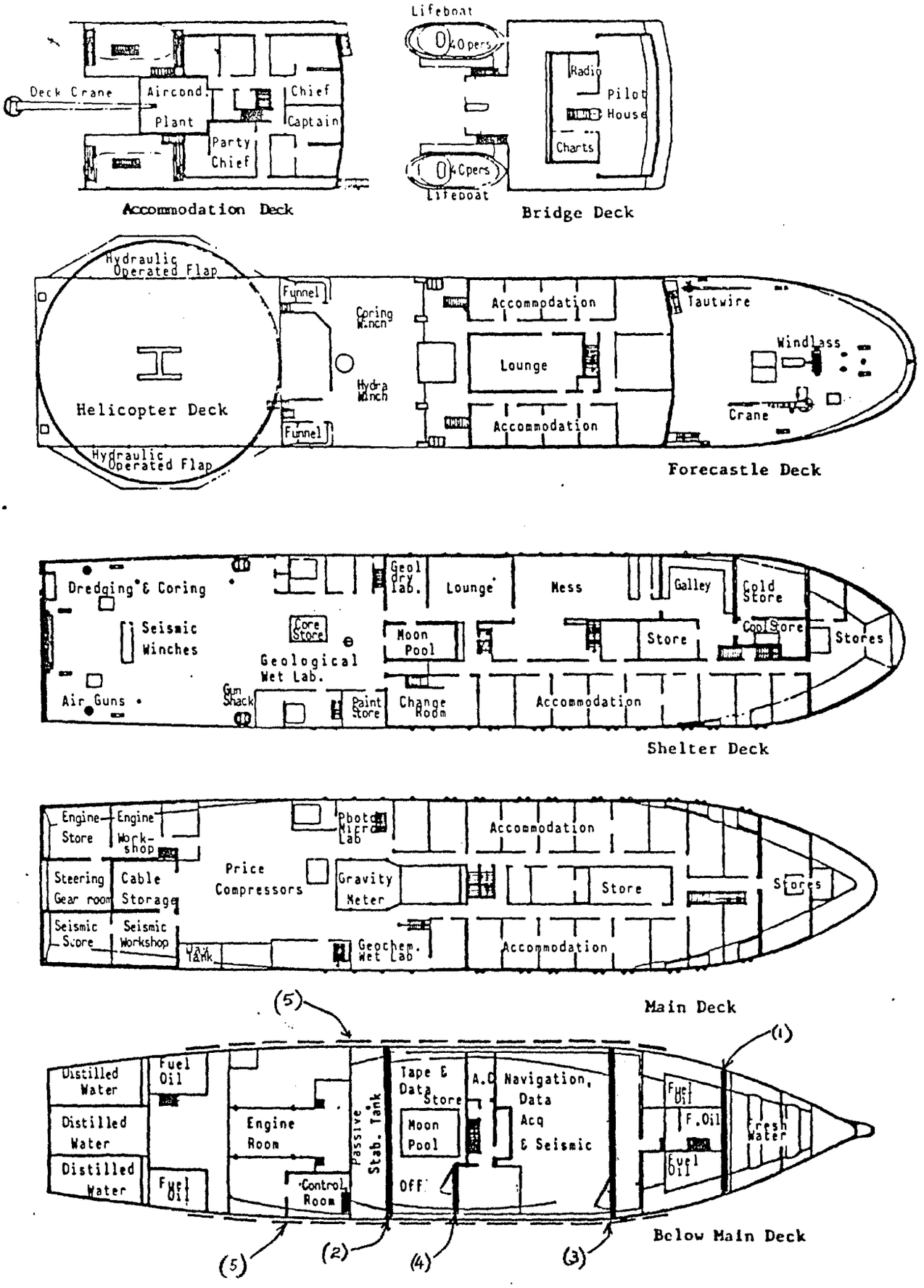
The sonar trunk at frame 54 approximately shall be made watertight up to the shelterdeck level by the addition of bulkheads and watertight doors above the main deck.

All access doors down through the main deck shall be fitted with W/T doors, and steel bulkheads around as necessary (frame 82, 51, 30P, 30S, 10).

The ship side insulation shall be removed as necessary to allow welding of the side shell doubler plate, and replaced on completion.

Ventilation trunking, watertight as required, shall be provided to the workshop and office as necessary.

Figure 6: *Rig Seismic* general arrangement, showing modifications proposed by M.J. Doherty & Co Pty Ltd.



APPENDIX B: COMMENTS ON VESSEL OPERATION & SAFETY

The following comments on vessel operations and safety were made by Captain Henry Foreman of the Commonwealth Department of Transport after examination of the "Margin Accessibility" section of this report, the US Naval Sea Ice Climatic Atlas, and the ANARE Research Notes on sea ice extent (Jacka, 1983).

"From these papers and my experience of the Kerguelen Plateau and *Icebird* to Casey and back, I would suggest:-

1. If it is proposed to limit the cruise to within sight of the ice edge, or more likely, off lying ice bergs, *Rig Seismic* would be suitable as she is.

2. If it is proposed to close the ice edge or enter Prydz Bay, then I would request the watertight integrity of the Instrument Room be improved as suggested by N.A. Armstrong of Dohertys.

3. In the event of (2) I would request a Third Mate and a Third Engineer and equipment capable of receiving ice pictures from NOAA."

PLATE1

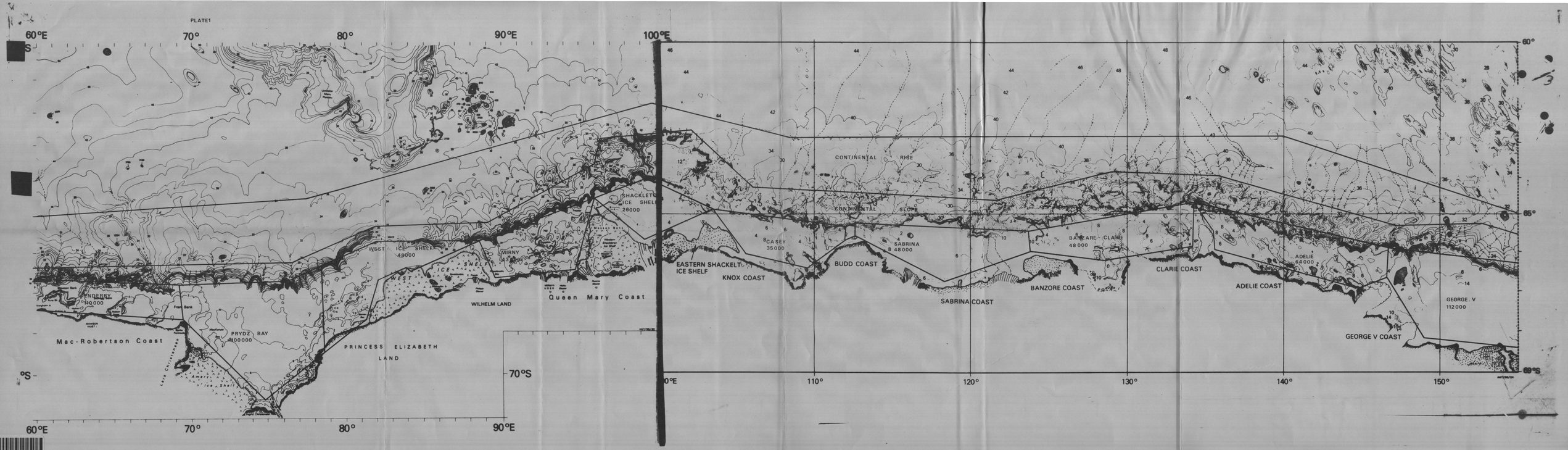


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PLATE 2

R870+108

PLATE 3

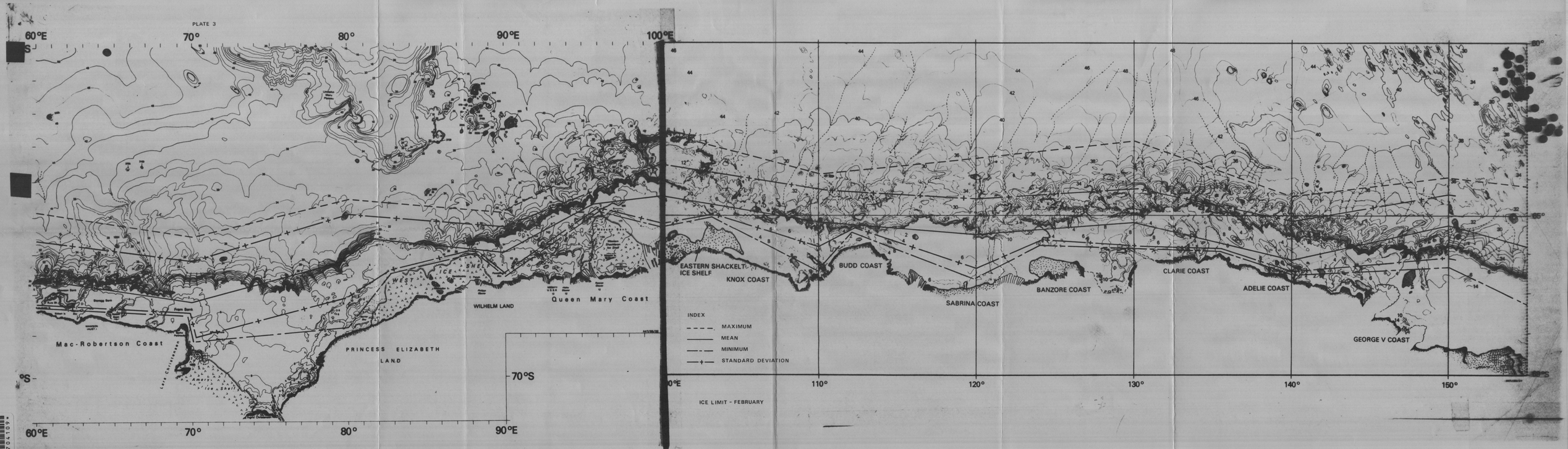

60°E
70°
80°
90°E
100°E
110°
120°
130°
140°
150°
60°S
70°S
Mac-Robertson Coast
PRINCESS ELIZABETH LAND
WILHELM LAND
Queen Mary Coast
EASTERN SHACKELTON ICE SHELF
KNOX COAST
BUDD COAST
SABRINA COAST
BANZORE COAST
CLARIE COAST
ADELIE COAST
GEORGE V COAST
INDEX
MAXIMUM
MEAN
MINIMUM
STANDARD DEVIATION
ICE LIMIT - FEBRUARY

PLATE 4

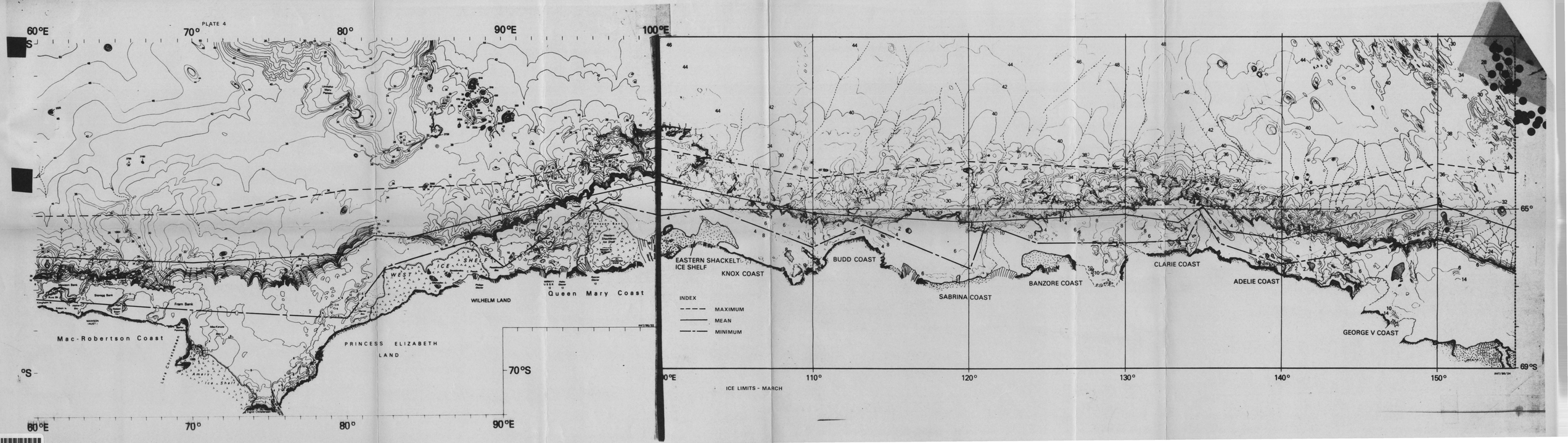
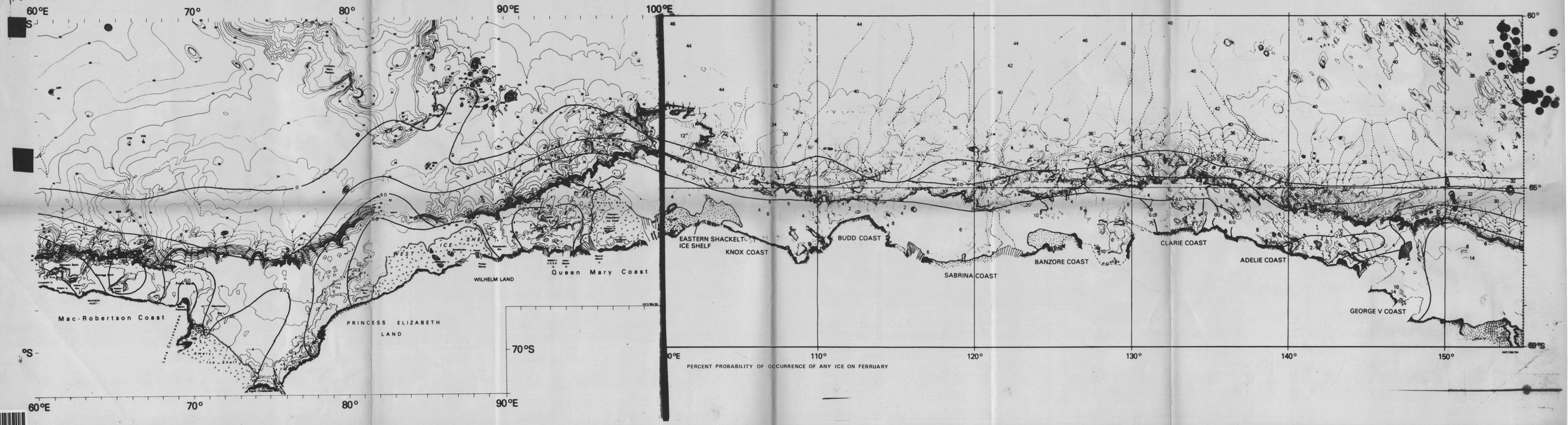

60°E
70°
80°
90°E
100°E
110°
120°
130°
140°
150°
65°
69°S
70°S
°S
Mac-Robertson Coast
PRINCESS ELIZABETH LAND
WEST ICE SHELF
WILHELM LAND
Queen Mary Coast
EASTERN SHACKELTON ICE SHELF
KNOX COAST
BUDD COAST
SABRINA COAST
BANZORE COAST
CLARIE COAST
ADELIE COAST
GEORGE V COAST
INDEX
MAXIMUM
MEAN
MINIMUM
ICE LIMITS - MARCH

PLATE 5



PERCENT PROBABILITY OF OCCURRENCE OF ANY ICE ON FEBRUARY

R8704106

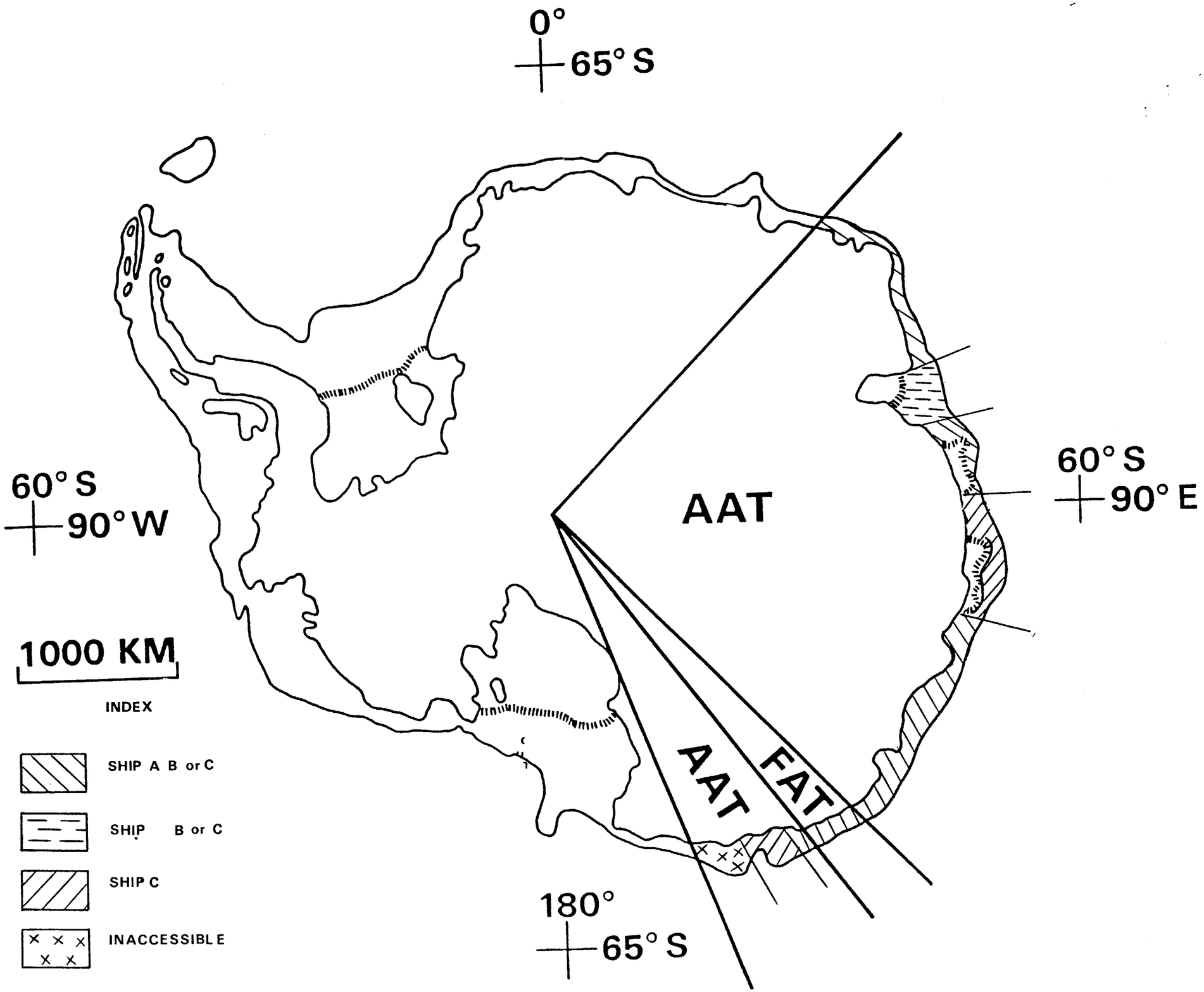

0°
65° S
60° S
90° W
60° S
90° E
AAT
AAT
FAT
180°
65° S
1000 KM
INDEX
SHIP A B or C
SHIP B or C
SHIP C
INACCESSIBLE

PLATE 6