# MARINE GEOLOGY OF THE WEDDELL SEA REGION

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February, 1984

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## Physiography

The Weddell Sea shelf, like other parts of the Antarctic continental shelf, is characterized by rugged topography and great depth (average depth 500m). Crary Trough, located in the south-eastern Weddell Sea, is the physiographic dividing line between the narrow (100km) East Antarctic shelf and broad (several hundred kilometers) West Antarctic continental shelf. The West Antarctic shelf extends beneath the Ronne-Filchner Ice Shelf to a deep (up to 1700m) arcuate depression (Thiel Trough); these ice shelves are grounded at approximately 1100m in this depression (Fig. 1). Figure 1 shows that the southern shelf is isolated from the continent on all sides by this depression. The continental shelf in the western Weddell Sea has been virtually unexplored due to severe sea ice cover in this region.

The upper continental slope of the East Antarctic margin is quite steep (7-9$^{o}$) and the lower slope and rise is cut by numerous submarine canyons. In contrast, the West Antarctic margin is characterized by a more gentle upper slope, and submarine canyons are fewer and more widely spaced. The continental rise is much more extensive in the western Weddell Sea than on the eastern margin. The abyssal plain is relatively flat, except in the northernmost Weddell Sea where seamounts, ridges, and linear depressions contribute to the generally irregular topography of the region. See Johnson et al. (1981) for a more detailed description of the bathymetry of the Weddell Sea.

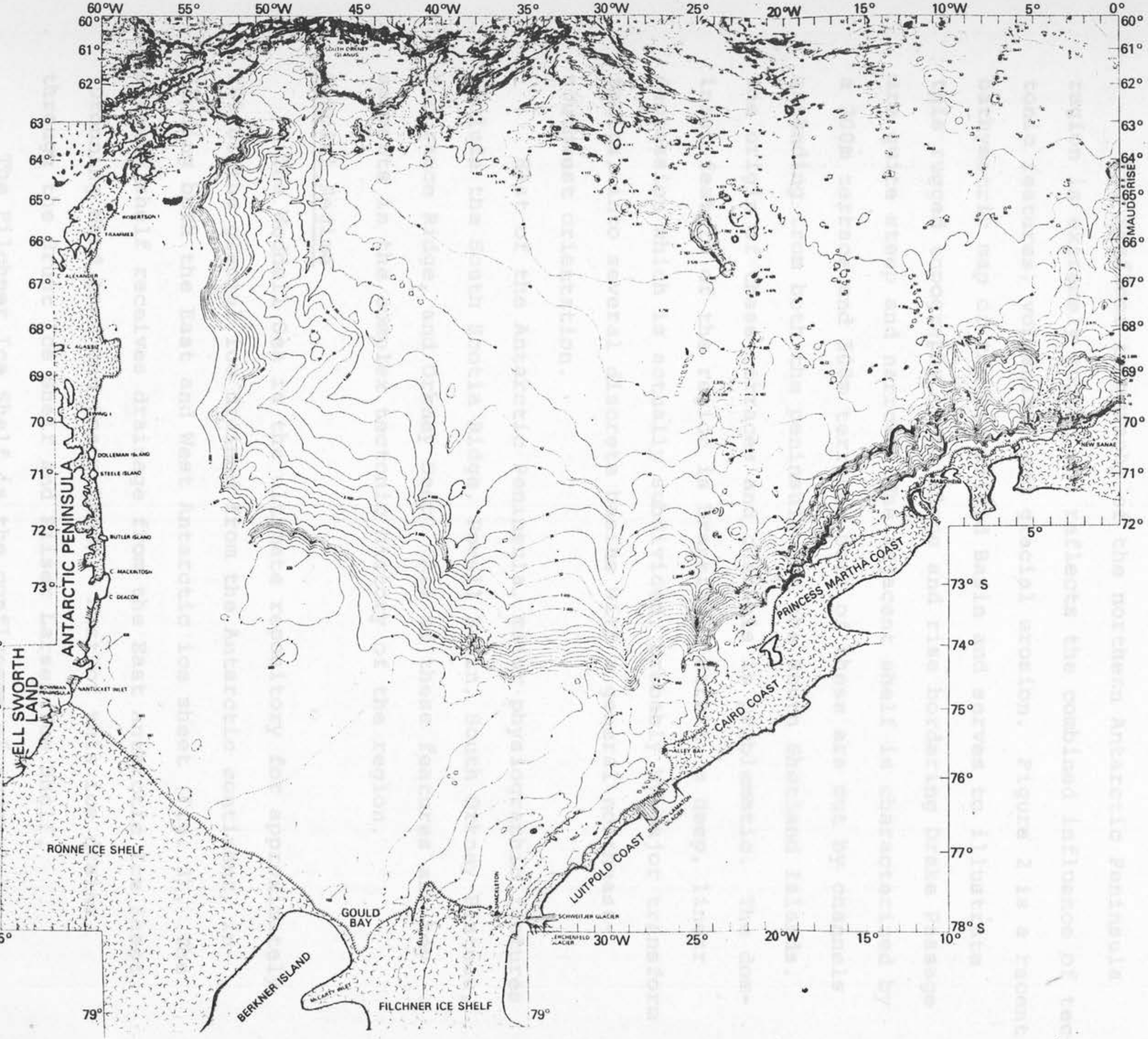


Figure 1. Bathymetry of the Weddell Sea (from Johnson et al. 1981)

The seafloor topography of the northern Antarctic Peninsula region is extremely rugged and reflects the combined influence of tectonic features, volcanism, and glacial erosion. Figure 2 is a recent bathymetric map of the Bransfield Basin and serves to illustrate this rugged topography. The slope and rise bordering Drake Passage are quite steep and narrow. The adjacent shelf is characterized by a 200m terrace and 500m terrace; both of these are cut by channels extending from both the peninsula and the South Shetland Islands. The origin of these terraces and channels is problematic. The dominant feature of the region is Bransfield Strait, a deep, linear depression which is actually subdivided, probably by major transform faults, into several discrete basins with a general northeast-southwest orientation.

East of the Antarctic Peninsula, major physiographic features include the South Scotia Ridge, Powell Basin, South Orkney Plateau, Endurance Ridge, and Orkney Deep. All of these features are key segments in the complex tectonic history of the region.

Glacial Regime

The Weddell Sea is the ultimate repository for approximately 20% of the glacial ice drained from the Antarctic continent, including both the East and West Antarctic ice sheet (Fig. 3). The eastern shelf receives drainage from the East Antarctic Ice Sheet (Dronning Maud Land and Coats Land). Most of this ice drains through the Brunt Ice Shelf and Riiser Larsen Ice Shelf.

The Filchner Ice Shelf is the confluence of several large East Antarctic ice streams (Ice Streams A, B and C of Drewry, 1983;

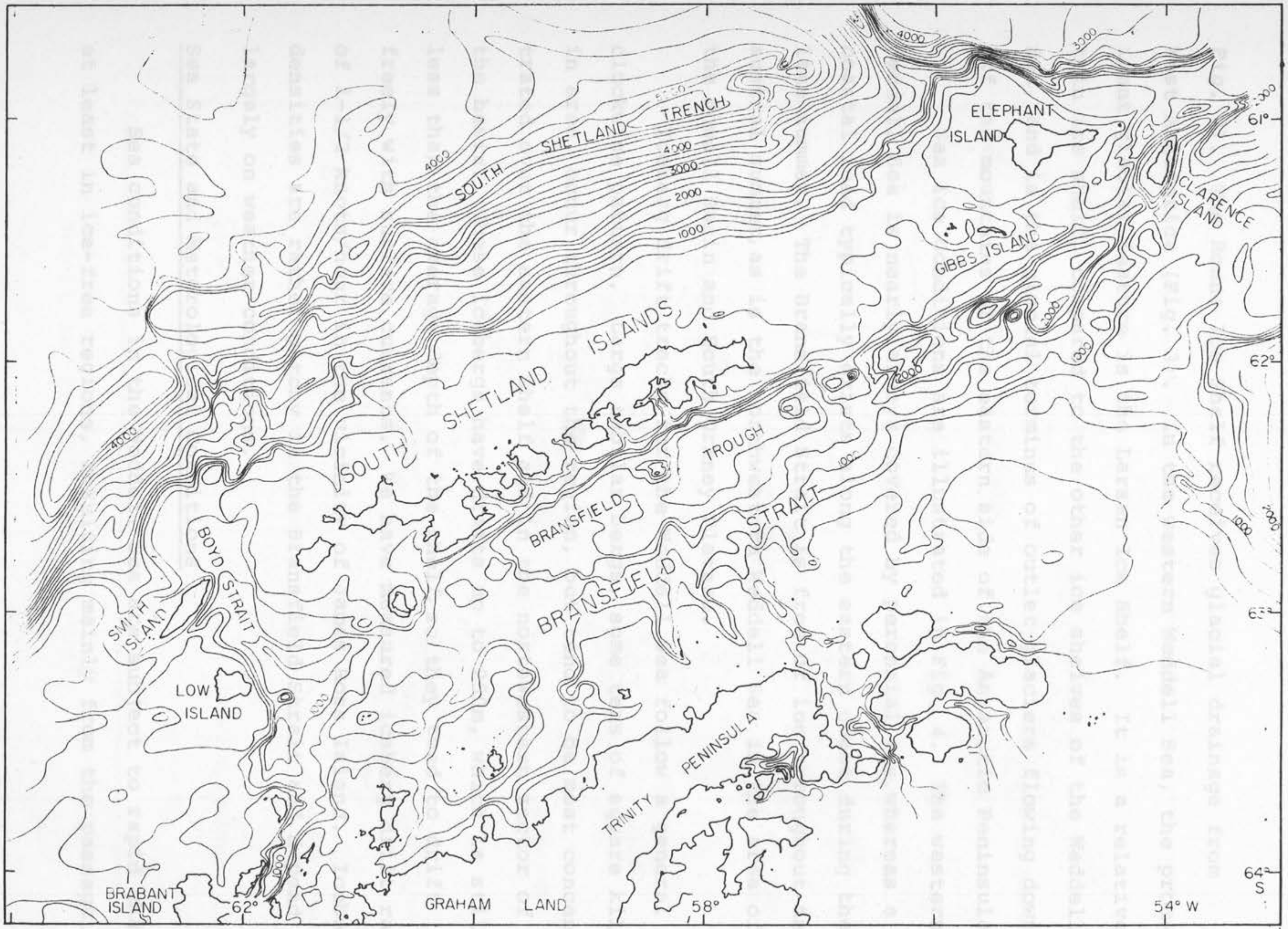


Figure 2. Bathymetry of the Bransfield Strait( from Davey,1972)

Fig. 3). The Ronne Ice Shelf receives glacial drainage from West Antarctica (Fig. 3). In the western Weddell Sea, the prominent glacial feature is the Larsen Ice Shelf. It is a relatively thin ice shelf, compared to the other ice shelves of the Weddell Sea, and is the glacial terminus of outlet glaciers flowing down off the mountains of the eastern side of the Antarctic Peninsula.

Sea ice conditions are illustrated in Fig. 4. The western Weddell Sea is nearly always covered by perennial ice, whereas a coastal lead typically exists along the eastern coast during the late summer. The Bransfield Strait is free of ice throughout the austral summer, as is the northwestern Weddell Sea in the area of the Powell Basin and South Orkney Plateau.

Iceberg drift tracks for the Weddell Sea follow a general clockwise pattern. Large tabular bergs, some tens of square kilometers in area, occur throughout the region, but tend to be most concentrated over the eastern shelf and in the northwestern sector of the basin. These icebergs have drafts up to 250m, which is still less than the average depth of the shelf, so they tend to drift freely with surface currents. We have measured iceberg drift rates of 1-1/2 knots/hour in the vicinity of James Ross Island. Iceberg densities are rather patchy in the Bransfield Strait and depend largely on weather conditions.

Sea State and Meterological Conditions

Sea conditions in the Weddell Sea are subject to rapid change, at least in ice-free regions, resulting mainly from the passage

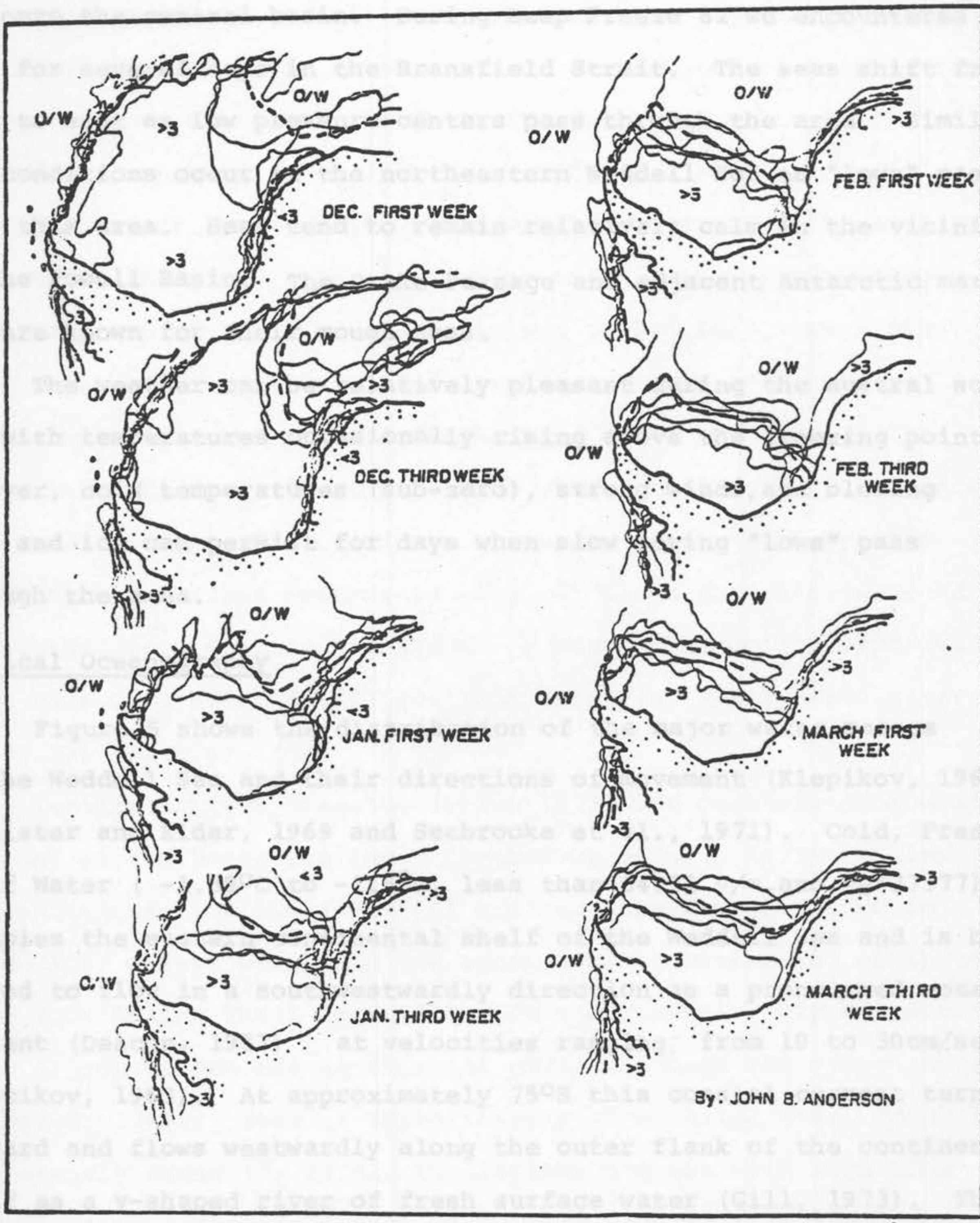


Figure 4. Sea ice conditions for the Weddell Sea (based on average conditions for 1973 through 1978)

of large, low pressure systems from west to east across the peninsula and onto the central basin. During Deep Freeze 82 we encountered 7m seas for several days in the Bransfield Strait. The seas shift from west to east as low pressure centers pass through the area. Similar sea conditions occur in the northeastern Weddell Sea as "lows" pass into this area. Seas tend to remain relatively calm in the vicinity of the Powell Basin. The Drake Passage and adjacent Antarctic margin are known for their rough seas.

The weather can be relatively pleasant during the austral summer with temperatures occasionally rising above the freezing point. However, cold temperatures (sub-zero), strong winds, and blowing snow and ice can persist for days when slow moving "lows" pass through the area.

Physical Oceanography

Figure 5 shows the distribution of the major water masses in the Weddell Sea and their directions of movement (Klepikov, 1960; Hollister and Elder, 1969 and Seabrooke et al., 1971). Cold, Fresh Shelf Water ( -1.89°C to -1.5°C, less than 34.51 °/∞, and $\sigma_T$<27.77) occupies the eastern continental shelf of the Weddell Sea and is believed to flow in a southwestwardly direction as a pronounced coastal current (Deacon, 1937) at velocities ranging from 10 to 30cm/sec (Klepikov, 1963). At approximately 75°S this coastal current turns seaward and flows westwardly along the outer flank of the continental shelf as a v-shaped river of fresh surface water (Gill, 1973). The freshness of this water mass is largely due to seasonal melting of pack ice so that its distribution is, for the most part, restricted to areas where seasonal melting overshadows the effects of freezing. Smaller amounts of fresh water might be contributed by melting ice shelves such as the Brunt Ice Shelf (Thomas and Coslett,1970).

Warm Deep Water ( $-0.36^{O}C$ to $+2.0^{O}C$, 34.45-34.69 $^{O}/_{\infty}$ and $\sigma_{\tau}$ 27.80) enters the Weddell Sea at approximately $15$-$20^{O}E$ and flows south along the slope (Fig. 5) at velocities in excess of 30cm/sec (Klepikov, 1960). This oxygen deficient (4.5-6.4ml/l) Warm Deep Water consists of a mixture of Antarctic Circumpolar Water and smaller quantities of North Atlantic Deep Water (Deacon, 1937), and is believed to be the source from which other Weddell Sea water masses are derived (Gill, 1973). At approximately $74^{O}S$ by $28^{O}W$, Warm Deep Water flows westwardly (Fig. 5) along the outer edge of the southwestern continental slope. A sharp thermocline separates dense Warm Deep Water ($\sigma_{\tau}$<27.80) from overlying Fresh Shelf Water ($\sigma_{\tau}$<27.77) north of $74^{O}S$.

Intense surface freezing (Gill, 1973) and possible sub-basal freezing of the Ronne Ice Shelf (Seabrooke et al., 1971) results in high salinities (34.51-34.84 $^{O}/_{\infty}$) and low temeratures ($-15^{O}C$ to $-2.20^{O}C$) of waters occupying the southwestern continental shelf area.

Most Saline Shelf Water flows in a northwestwardly direction (Fig. 5) out across the continental shelf and onto the slope (Hollister and Elder, 1969). West of approximately $40^{O}W$ Saline Shelf Water is sufficiently dense ($\sigma_{\tau}$<27.81) to displace and mix with Warm Deep Water to form Antarctic Bottom Water ($T=9.44^{O}C$,$S-34.66$ $^{O}/_{\infty}$ ; Sverdrup et al., 1942.)

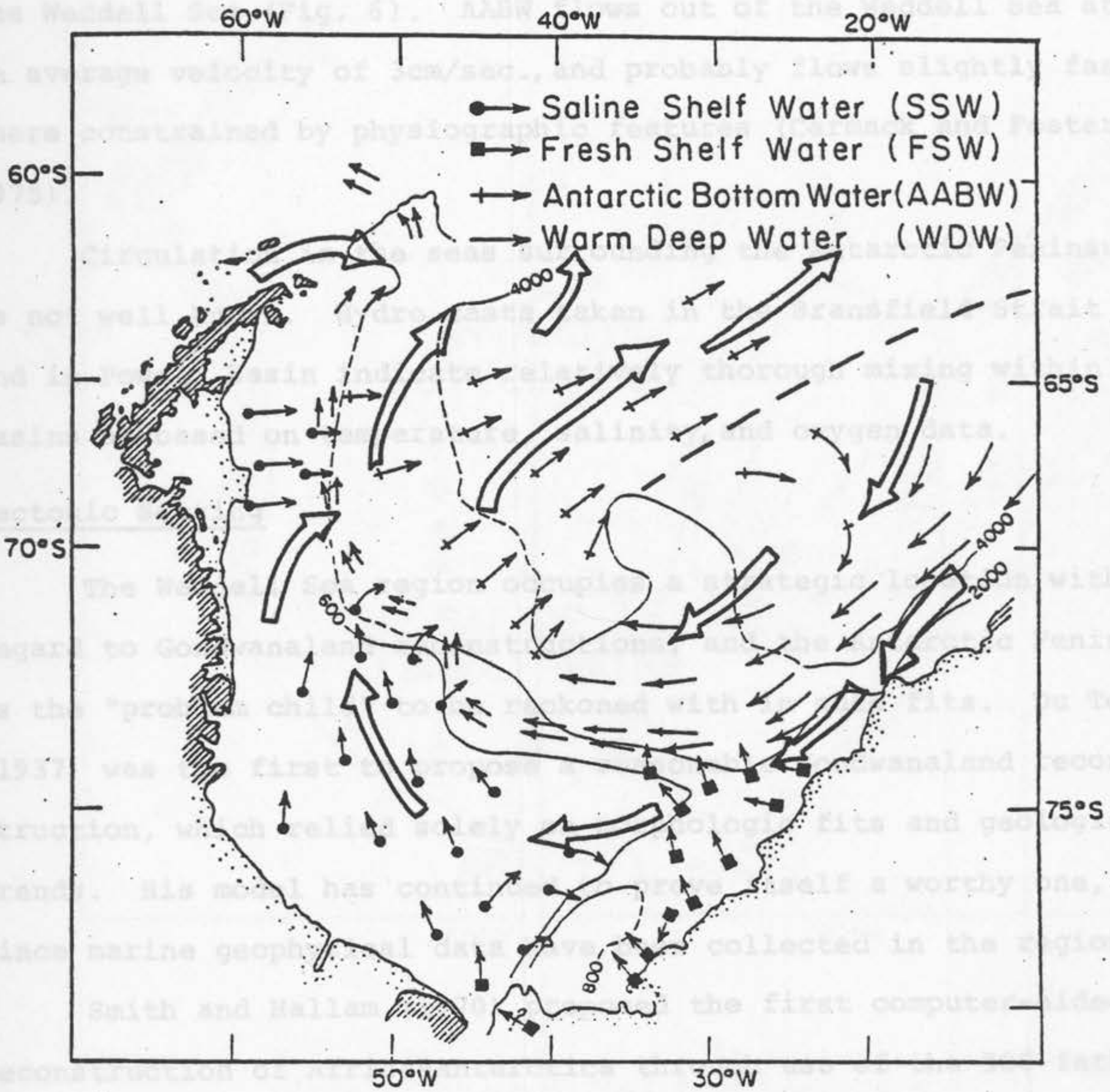


Figure 5. Distribution of major water masses in the Weddell Sea (bottom water circulation from Anderson, 1975, surface circulation from Johnson et al. 1981). Large open arrows show surface circulation. Dashed line shows position of the Antarctic Divergence.

Newly formed AABW flows down the continental rise in a northeastward direction across the abyssal floor. This deep water circulation model is best illustrated using a near bottom temperature map for the Weddell Sea (Fig. 6). AABW flows out of the Weddell Sea at an average velocity of 3cm/sec., and probably flows slightly faster where constrained by physiographic features (Carmack and Foster, 1975).

Circulation in the seas surrounding the Antarctic Peninsula is not well known. Hydro casts taken in the Bransfield Strait and in Powell Basin indicate relatively thorough mixing within these basins as based on temperature, salinity, and oxygen data.

<u>Tectonic Setting</u>

The Weddell Sea region occupies a strategic location with regard to Gondwanaland reconstructions, and the Antarctic Peninsula is the "problem child" to be reckoned with in such fits. Du Toit (1937) was the first to propose a reasonable Gondwanaland reconstruction, which relied solely on morphologic fits and geological trends. His model has continued to prove itself a worthy one, even since marine geophysical data have been collected in the region.

Smith and Hallam (1970) proposed the first computer-aided reconstruction of Africa-Antarctica through use of the 500 fathom ( 1km) isobath (Fig. 7). Dietz and Sproll (1970) used the 1000 fathom (2km) isobath in their reconstruction (Fig. 8). Their study yielded generally similar results to Smith and Hallam's model. Differences between the two models occur mainly in the area of the

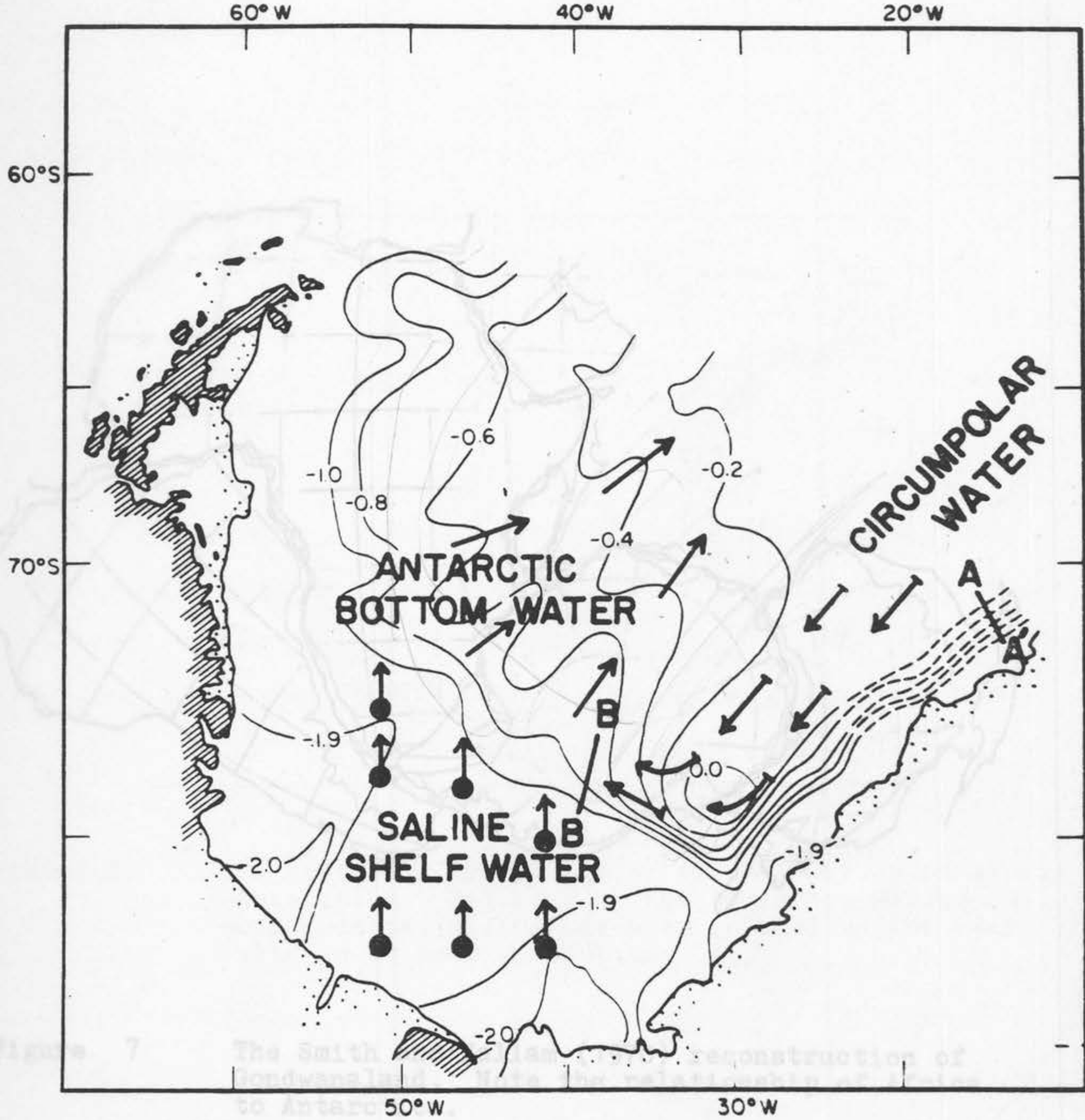


Figure 6. Near-bottom temperature distribution and deep water circulation (modified from Anderson, 1972)

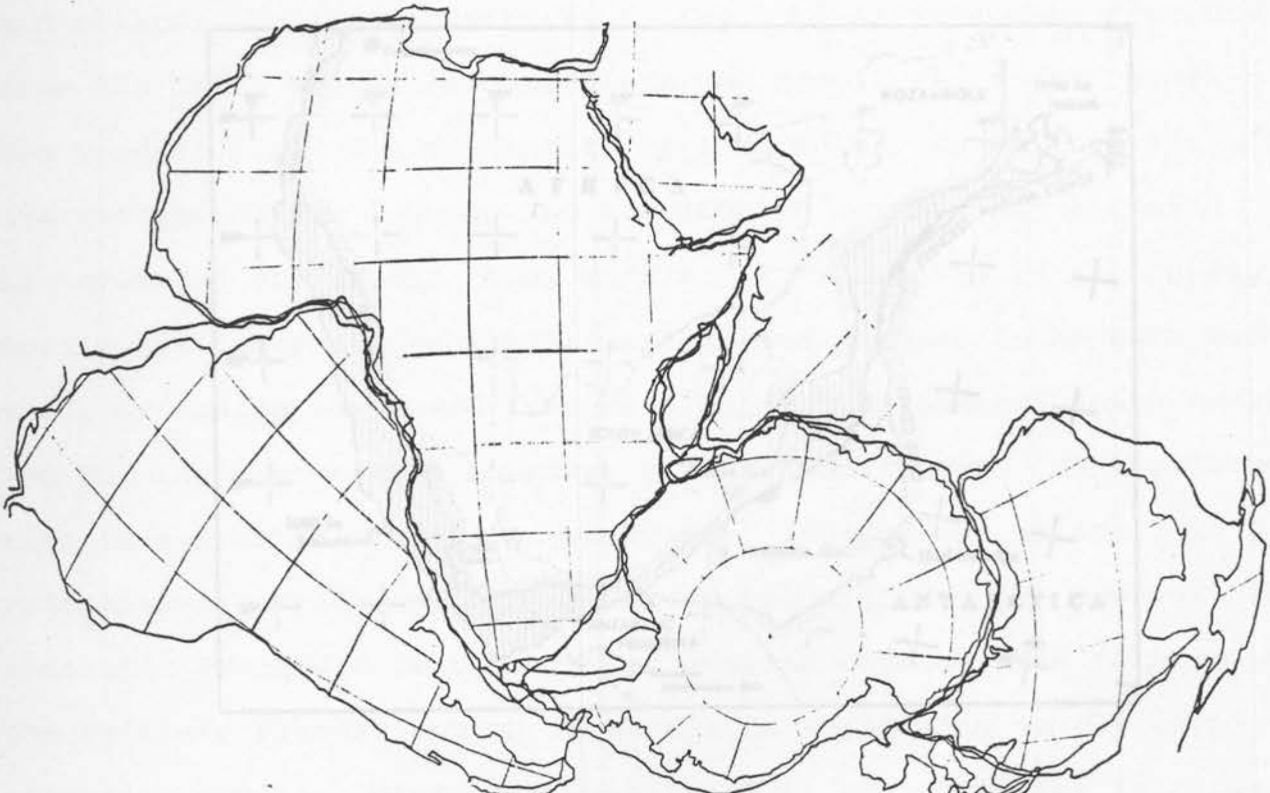

Figure 7 The Smith and Hallam (1970) reconstruction of Gondwanaland. Note the relationship of Africa to Antarctica.

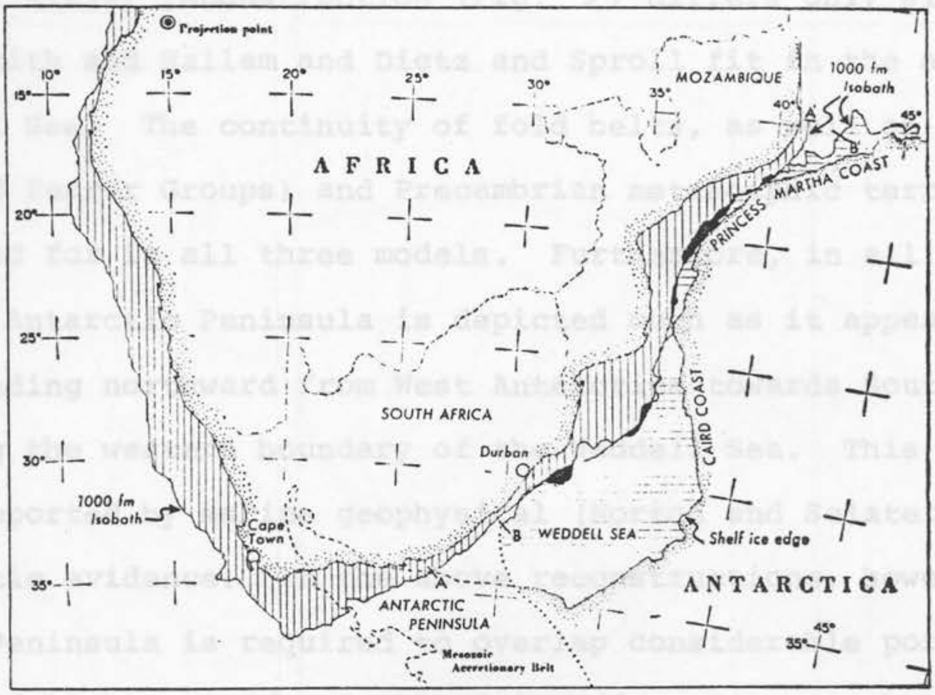


Figure 8 The Dietz and Sproll (1970) reconstruction of Africa -Antarctica. Relative to the Smith and Hallam reconstruction, Africa has been rotated to the west relative to East Antarctica.

Weddell Sea; the Smith and Hallam model does not completely close the Weddell Sea, while the Dietz and Sproll model does. The Norton and Sclater (1979) reconstruction (Fig. 9) differs only slightly from the Smith and Hallam and Dietz and Sproll fit in the area of the Weddell Sea. The continuity of fold belts, as well as volcanic (Karroo and Ferrar Groups) and Precambrian metamorphic terrains is accounted for in all three models. Furthermore, in all three models the Antarctic Peninsula is depicted much as it appears today, i.e., extending northward from West Antarctica towards South America and forming the western boundary of the Weddell Sea. This paleoposition is supported by marine geophysical (Norton and Sclater, 1979) and paleomagnetic evidence. In the above reconstructions, however, the Antarctic Peninsula is required to overlap considerable portions of the Falkland Plateau and/or South Africa (depending on the reconstructive model). Dietz and Sproll (1970) accounted for this overlap by dismissing the Antarctic Peninsula as a "Mesozoic accretionary belt", while Smith and Hallam attributed the observable overlap to continental distortion resulting from the breakup of Gondwanaland. More recent work in this region has shown that the solution to the Antarctic Peninsula problem is not as simple as that proposed by Dietz and Sproll or Smith and Hallam.

It has been well established that Precambrian basement underlies much of southern Africa (Haughton, 1969). In addition, migmatitic gneiss of upper Precambrian or lower Paleozoic age was recovered from Site 330 of leg 36 of the Deep Sea Drilling Project on the eastern Falkland Plateau, which supports the continental nature of this submerged crustal block (Barker et al., 1976). Further supporting

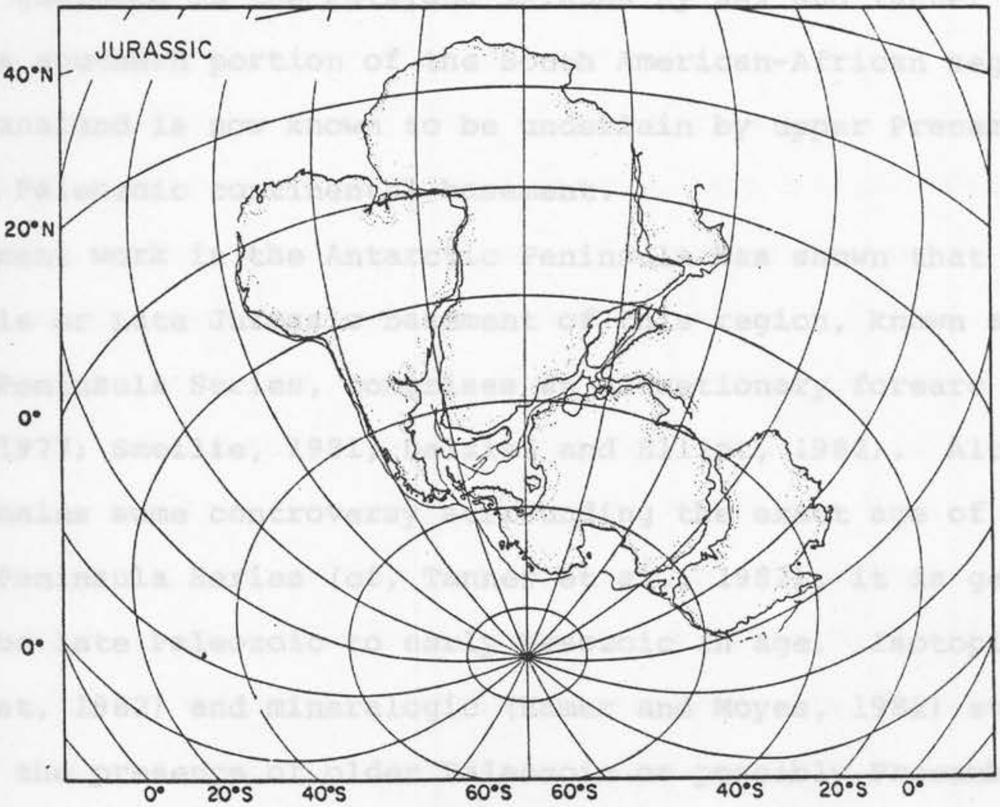


Figure 9 The Norton and Sclater (1979) reconstruction of Gondwanaland. This model differs slightly from the Smith and Hallam reconstruction and is preferred by this report.

evidence for the continental nature of the Falkland Plateau comes from the upper Precambrian radiometric ages reported for the Cape Merideth gneisses in the Falkland Islands by Rex and Tanner (1982). Thus, the southern portion of the South American-African segments of Gondwanaland is now known to be underlain by upper Precambrian to lower Paleozoic continental basement.

Recent work in the Antarctic Peninsula has shown that the pre-Middle or Late Jurassic basement of this region, known as the Trinity Peninsula Series, comprises an accretionary forearc terrain (DeWit, 1977; Smellie, 1981; Dalziel and Elliot, 1982). Although there remains some controversy surrounding the exact age of the Trinity Peninsula Series (cf, Tanner et al., 1982), it is generally felt to be late Paleozoic to early Mesozoic in age. Isotopic (Pankhurst, 1982) and mineralogic (Hamer and Moyes, 1982) evidence suggests the presence of older Paleozoic or possibly Precambrian basement beneath at least part of the Antarctic Peninsula.

Because the exposed basement rocks of the Antarctic Peninsula (i.e., the Trinity Peninsula Series) predate the breakup of Gondwanaland, it follows that the Antarctic Peninsula must have existed in some form prior to the breakup of the supercontinent. Overlap of the Antarctic Peninsula with the Falkland Plateau and/or South Africa is questionable not only because of the tectonic problems associated with overlapping continental (or quasicontinental, as may be the case of the Antarctic Peninsula) segments floored by Precambrian basement, but also because of the differences in the geologic development of these regions. Because of the obvious problems associated with Antarctic Peninsula overlap, numerous alternative models have been proposed in attempts to account for the Antarctic Peninsula in a Gondwanaland context.

Heirtzler (1971; see Fig. 10) and Dalziel (1982a) suggested that the Antarctic Peninsula, due to its similarity in shape to the East Antarctic Coast and Caird Coast of the eastern Weddell Sea, once rested against East Antarctica. Subsequent counterclockwise rotation of the peninsula due to spreading along a failed rift, presently underlying the Weddell Sea, was invoked in Heirtzler's model. Such a reconstruction is consistent with the currently accepted counterclockwise rotation of the Ellsworth Mountains (Dalziel, 1982a), yet suffers from some serious problems. One major problem is that this model requires a tremendous offset of the east-dipping subduction complex associated with the arc terrains of the Andes and Antarctic Peninsula. Another problem is that if the Antarctic Peninsula had rested against East Antarctica, it would have extended into Mozambique if the Dietz and Sproll (1970) or Smith and Hallam (1970) reconstructions are correct, and would have overlapped the continental shelf of Africa if the Norton and Sclater (1979) model is correct. There is little evidence to support a rift origin for the Weddell Sea, while marine magnetic anomalies in the northern Weddell Sea argue against this reconstruction (LaBrecque and Barker, 1981).

Another alternative reconstruction was suggested by Tarling (1972) in which the eastern margin of the Antarctic Peninsula was juxtaposed along the western margin of South America. Although

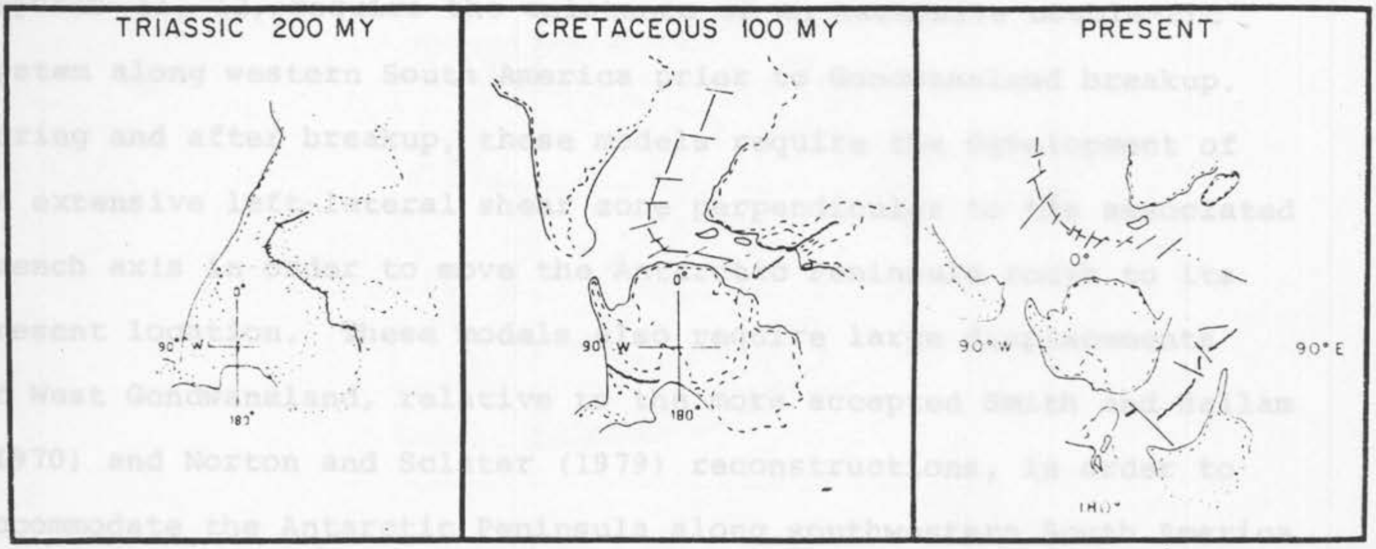


Figure 10 The Heirtzler (1971) reconstruction. More recent data on sea floor spreading patterns discredit this model. Note the position of the Antarctic Peninsula relative to East Antarctica.

this model has been recently advocated by Harrison et al. (1979, 1980), Powell et al. (1980), and Miller (1981, 1982, 1983), it has drawn crtiicism from Dalziel (1980) and Godoy and Podozio (1980). The Tarling and Harrison et al. models, as shown in Figures 11, 12, require the existence of an extensive double-arc system along western South America prior to Gondwanaland breakup. During and after breakup, these models require the development of an extensive left-lateral shear zone perpendicular to the associated trench axis in order to move the Antarctic Peninsula south to its present location. These models also require large displacements of West Gondwanaland, relative to the more accepted Smith and Hallam (1970) and Norton and Sclater (1979) reconstructions, in order to accommodate the Antarctic Peninsula along southwestern South America.

Other reconstructions of the paleoposition of the Antarctic Peninsula have been proposed by Elliot (1972), Suarez (1976), and Barker and Griffiths (1972, 1977). These reconstructions are based on a linear to sublinear (or cuspate) relationship of the Antarctic Peninsula to the tip of South America in order to provide continuity of the arc terrains of these regions. They require modification by later events in the Scotia Arc Region in order to attain the present configuration of the Antarctic Peninsula relative to the southern Andes.

Barker et al. (1976), DeWit (1977), and Dalziel (1982b) have suggested a fourth alternative reconstruction of the Antarctic Peninsula. Their models suggest that prior to breakup of Gondwanaland the Antarctic Peninsula was rotated approximately 90$^{o}$ counterclockwise from its present position and was connected at

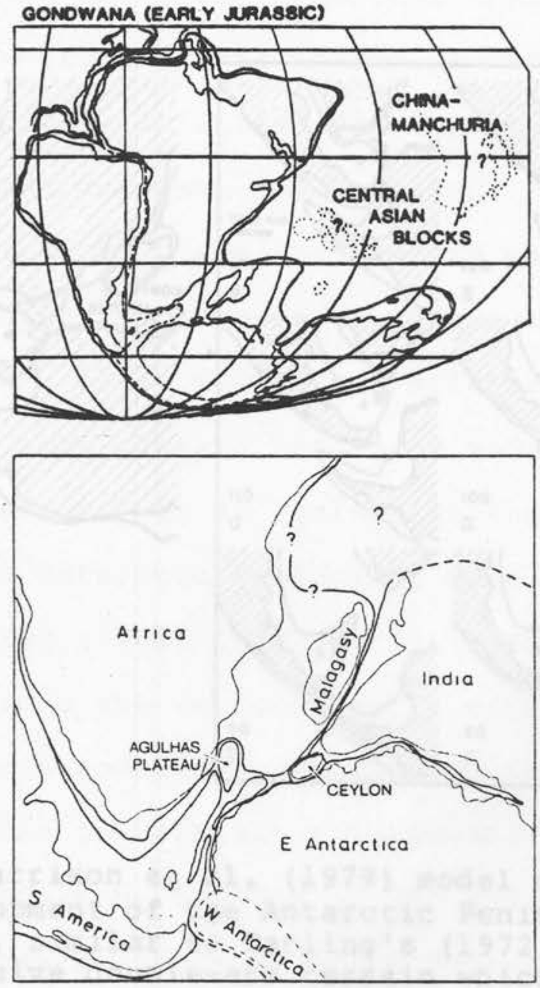


Figure 11. Tarling's (1980 ) Gondwanaland reconstruction

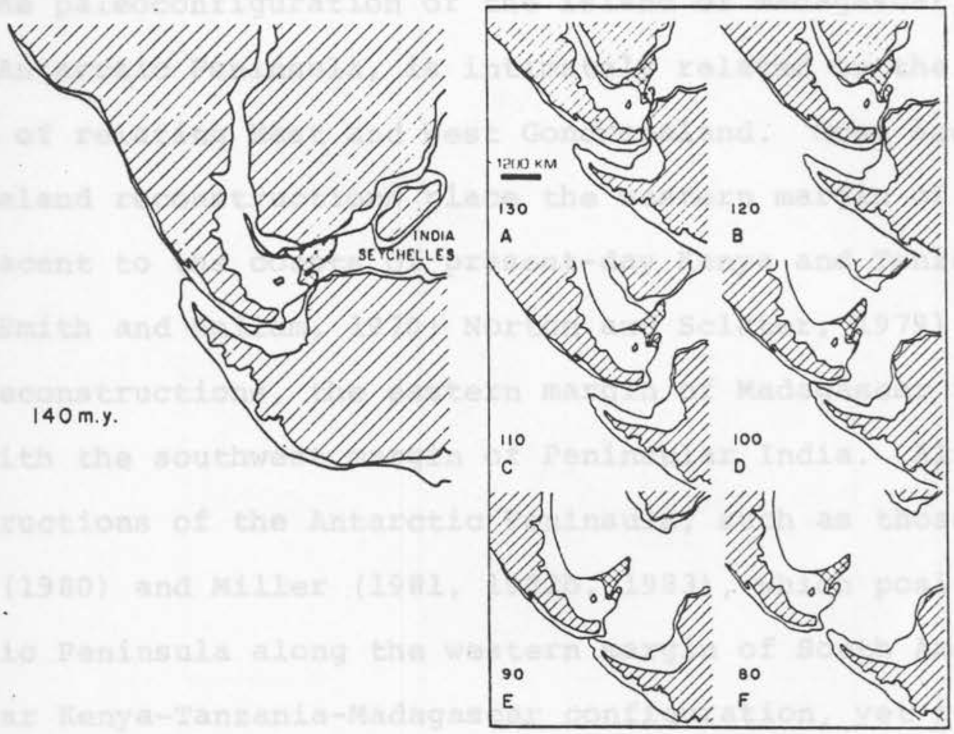


Figure 12 The Harrison et al. (1979) model of the paleo-development of the Antarctic Peninsula. This model, similar to Tarling's (1972), requires an extensive double-arc terrain which is later disrupted by large-scale left-lateral faulting.

its tip to the southern Andes. Dalziel's (1982b) version of this model is shown in Fig. 13. This reconstruction is appealing as it accounts for known age progressions in forearc terrains of this region and allows for continuity of the subduction related arc terrains of the southern Andes and Antarctic Peninsula.

The paleoconfiguration of the island of Madagascar, like that of the Antarctic Peninsula, is intimately related to the larger problem of relating East and West Gondwanaland. Most accepted Gondwanaland reconstructions place the western margin of Madagascar adjacent to the coasts of present-day Kenya and Tanzania (e.g., Smith and Hallam, 1970; Norton and Sclater, 1979). In these reconstructions, the eastern margin of Madagascar is juxtaposed with the southwest margin of Peninsular India. Alternative reconstructions of the Antarctic Peninsula, such as those of Powell et al. (1980) and Miller (1981, 1982b, 1983), which position the Antarctic Peninsula along the western margin of South America, allow a similar Kenya-Tanzania-Madagascar configuration, yet require a southward shift of India to maintain a reasonable geometry. Similar Antarctic Peninsula models by Tarling (1972) and Harrison et al. (1979) require a southward displacement of Magagascar to a position adjacent to the South Africa-Mozambique margin in order to maintain a southwestern India-Madagascar relationship (see Figs. 11, 12). Although there is no consensus on the past configuration of the Antarctic Peninsula, there is evidence from paleomagnetic data (Embleton and McElhinney, 1975, 1982; McElhinney and Embleton, 1976; McElhinney et al., 1976) and from marine magnetic anomalies (Norton and Sclater, 1979) which supports the more accepted Kenya-Tanzania-Madagascar relationship.


Figure 13. Dalziel's (1983) model of the paleoconfiguration of the Antarctic Peninsula with respect to South America.

In a recent paper, Tarling (1981) proposed a novel reconstruction of Gondwanaland based on an alternative position of Madagascar. By dismissing the above cited marine magnetic and paleomagnetic data for Madagascar, Tarling proposed that the island had maintained its present configuration relative to Africa, even when it was part of Gondwanaland. His model, shown in Fig. 14, requires a 2500-3000 km northeastward displacement of West Gondwanaland relative to Antarctica-India-Australia in order to maintain a proper Madagascar-India relationship. The large displacement results in the juxtaposition of the Falkland Plateau and the East Antarctic Princess Martha Coast. In this configuration, a continuous arc terrain between the Antarctic Peninsula and the Southern Andes, similar in geometry to the present Aleutian-Kamchatka Peninsula Arc, could be reconstructed by rotating the Antarctic Peninsula into the Weddell Sea (cf. Heirtzler, 1971; Dalziel, 1982a). Although the Tarling model provides an alternative to the more accepted Gondwanaland reconstructions, it may not be consistent with present paleomagnetic and marine geophysical data; it remains to be seen as to whether it will pass these tests.

Timing of Major Plate Tectonic Events

The initial breakup of Gondwanaland is believed to have occurred since Mid to Late Jurassic time (Simpson et al., 1979; Bergh, 1977 and Rabinowitz et al., 1983), with the development of the Weddell Basin occurring mainly during pre-Late Jurassic to Cretaceous time (LaBrecque and Barker, 1981; LaBrecque and Keller,

1982) and the Scotia Sea was probably not present prior to mid-Oligocene time (Barker and Dalziel, 1983). The South Orkney Plateau, Powell Basin and Bransfield Strait are all considered to be relatively young features, indeed the Bransfield Basin may be as young as 2 m.y. old (Weaver et al., 1982; Dalziel, 1983).

The Continental Margin

Marine geophysical surveys on the Weddell Sea continental margin have been confined to the eastern half of the basin because of severe sea ice conditions in the western Weddell Sea. In 1962 Behrendt published an important paper describing the subglacial topography of the Filchner Ice Shelf region as based on gravity measurements obtained from the ice. The earliest marine seismic surveys were conducted during the austral summer of 1977 by scientists from the Norwegian Polar Institute (NPI) (Orheim, 1977; Fossum et al. 1982; Haugland, 1982) and during Islas Orcadas Cruise 1277 (Gordon and LaBrecque, 1977). To date, only preliminary findings of the Norwegian multichannel survey have been published (Haugland, 1982).

Aeromagnetic and seismic surveys of the Weddell Sea were carried out during the Soviet Antarctic Expeditions of 1975-82 (Grikurov, 1980; Kamenev and Ivanov, 1983). During the 1978 austral summer the German Federal Institute of Geosciences and Natural Resources (BGR) conducted a multichannel seismic reflection and sonobuoy refraction survey of the continental margin of the northeastern Weddell Sea (Hinz and Krause, 1982 and Hinz, 1983). Also in 1978, single channel seismic reflection and sonobuoy data were acquired in the same area during Islas Orcadas Cruise 1578 (LaBrecque, et al., 1978), and in 1981 the Japanese Technology Research Center (TRC) obtained multichannel seismic reflection profiles of the lower continental margin off Queen Maud Land (Okuda et al., 1983). Most recently, during the austral summer of 1982/83, the German research vessel Polarstern was used to acquire marine geophysical data (magnetics and MCS survey) in the Bransfield Strait and the Antarctic Peninsula region.

The multichannel seismic reflection records collected on the lower continental margin of Queen Maud Land by Hinz and Krause (1982) show a relatively undeformed sequence of low velocity (<3 km/s) sediments resting unconformably on a deformed sequence of higher velocity (4-6 km/s) deposits (Fig. 15). The older sequence is characterized by seaward dipping reflectors and has been named the "Explora Wedge" by Hinz and Krause (1982). They infer that this sequence is comprised of Late Jurassic volcanic and volcaniclastic sedimentary rocks deposited during the early rifting stage of basin development. The Explora Wedge is truncated by an unconformity (the "Weddell Sea Continental Margin Unconformity") of possible Late Jurassic age (Hinz and Krause, 1982). The overlying sequence consists of four units (WS-1 through WS-3B, Fig. 15), each separated by unconformities (Hinz and Krause, 1982).

The continental margin of the eastern Weddell Sea includes at least two sedimentary basins, the Brunt Basin and the Weddell Basin. The Brunt Basin is situated between approximately 73°S and 75°S and contains between 1.5 and 2.5 km of sedimentary deposits

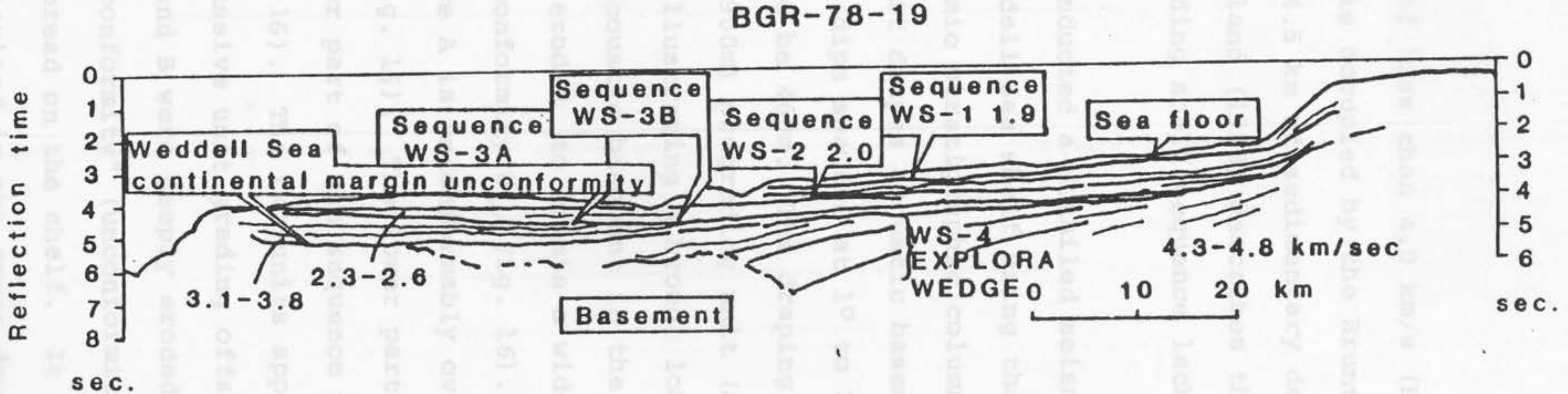


Figure 15. Interpreted Seismic reflection profile across the Queen Maud Land continental slope (from Hinz and Krause, 1982)

with seismic velocities of less than 4.0 km/s (Haugland, 1982). The center of the basin is occupied by the Brunt Megatrough, which may contain as much as 14.5 km of sedimentary deposits (Kamenev and Ivanov, 1983). Haugland (1982) describes the strata in this area as a typical prograding shelf sequence lacking significant tectonic features.

Roqueplo (1982) conducted a detailed seismic stratigraphic study of the eastern Weddell Sea shelf using the 1977 Norwegian (NPI) records. Her seismic stratigraphic column is shown in Fig. 16. The lowermost seismic unit drapes acoustic basement (draping unit), is finely laminated, and dips seaward at $1^{\circ}$ to $2^{\circ}$. Its maximum thickness is estimated to be 460m. The draping unit is overlain by a relatively thick (~900m) prograding unit (sequence A) with $2^{\circ}$ to $3^{\circ}$ seaward dips and illustrating a broad, lobate pattern. This unit rests directly on acoustic basement in the vicinity of Crary Trough. Sequence A was eroded to create a widespread, relatively planar unconformity (unconformity $U_1$, Fig. 16). In the Brunt Megatrough area, Sequence A is unconformably overlain by an onlap sequence (Sequence B, Fig. 16). The lower part of Sequence B is laminated while the upper part of the sequence has very few internal reflectors (Fig. 16). The two units appear to be facies equivalents, with the massive unit grading offshore into laminated deposits. Sequences A and B were deeply eroded to create the "Weddell Sea Glacial Unconformity" (unconformity $U_2$, Roqueplo, 1982; Fig. 16) which is widespread on the shelf. It was this glacial erosional event which resulted in the great depth and irregular

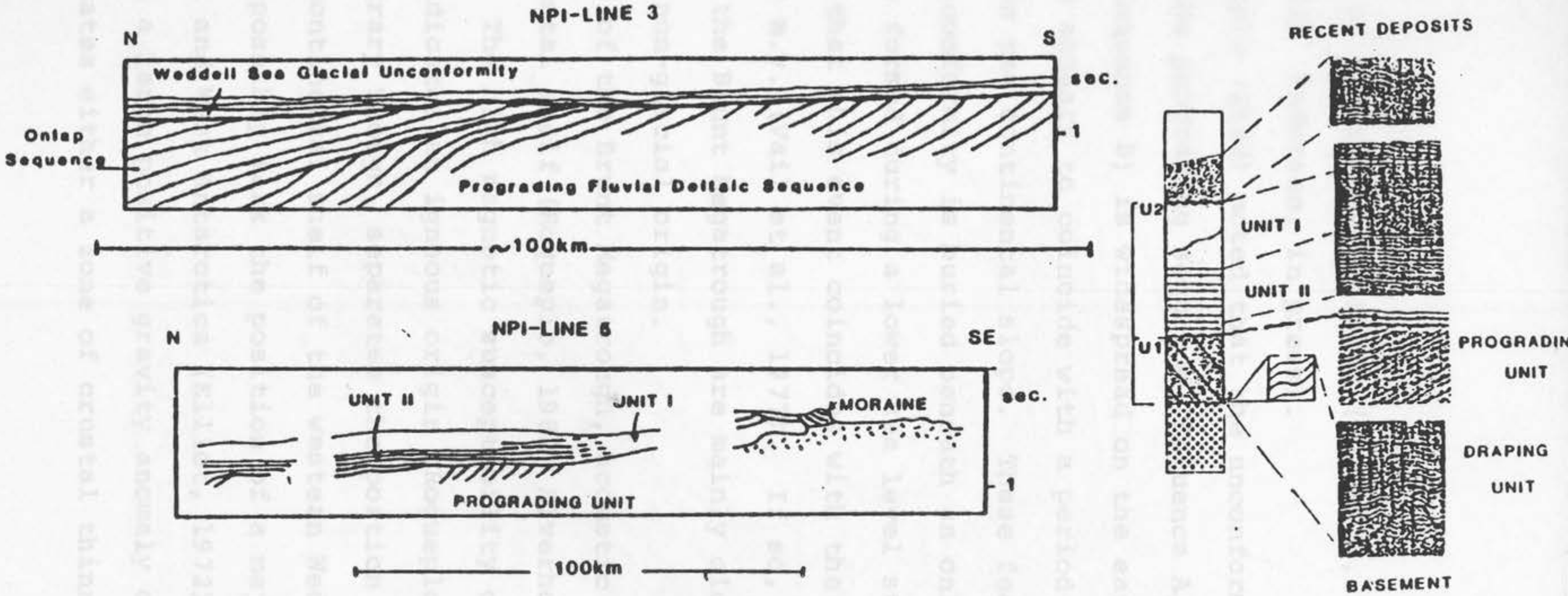


Figure 16. Seismic stratigraphy and representative interpreted seismic reflection profiles for the eastern Weddell Sea shelf(from Roqueplo,1982)

topography of the modern seafloor (Roqueplo, 1982; Elverhoi and Maisey, 1983; Anderson, in press).

Roqueplo (1982) noted that the unconformity ($U_1$) which separates the prograding sequence (Sequence A) from the onlap sequence (Sequence B) is widespread on the eastern shelf, relatively planar, and appears to coincide with a period of submarine canyon development on the continental slope. These features, plus the fact the unconformity is buried beneath an onlap sequence, implies that it was formed during a lower sea level stand. She further speculates that this event coincides with the world-wide eustatic event at 29 m.y. (Vail et al., 1977). If so, then the deposits which fill the Brunt Megatrough are mainly older than Oligocene, and are of non-glacial origin.

South of the Brunt Megatrough, acoustic basement is exposed on the continental shelf (Roqueplo, 1982; Elverhoi and Maisey, 1983) (Fig. 17). The high magnetic susceptibility of basement rocks in the area indicates an igneous origin (Roqueplo, 1982). A deep depression, Crary Trough, separates the portion of the shelf from the broad continental shelf of the western Weddell Sea. Crary Trough may possibly mark the position of a major fault system separating East and West Antarctica (Elliot, 1972). Behrendt (1962) did measure a large positive gravity anomaly over this feature, which indicates either a zone of crustal thinning or an intrusive body.

Seismic profiles across Crary Trough (Fig. 18) show acoustic basement outcropping on the eastern shelf, and westward dipping

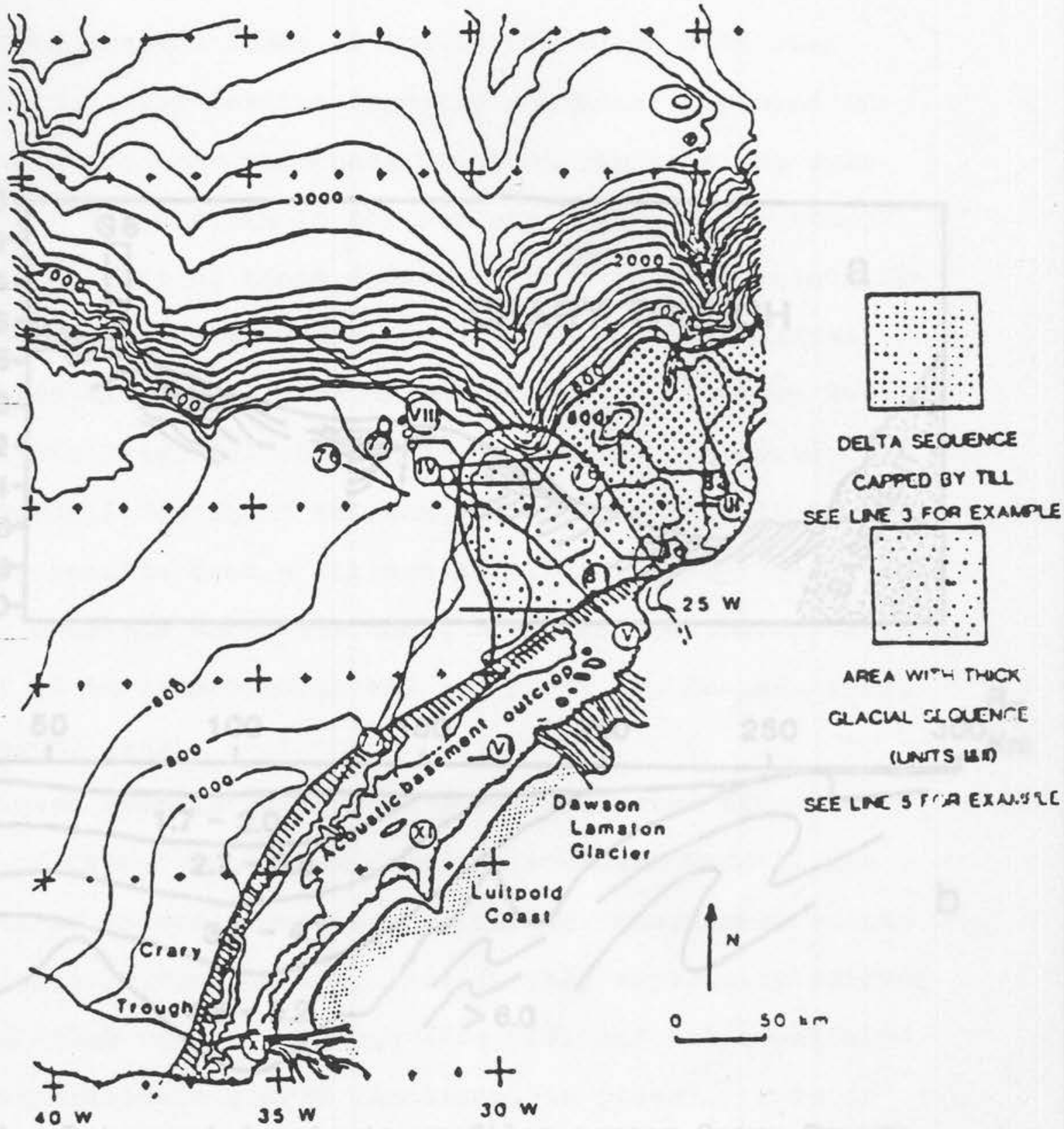


Figure 17. Distribution of major seismic facies in the eastern Weddell Sea (compiled from Norwegian data provided courtesy of Dr George Maisey).

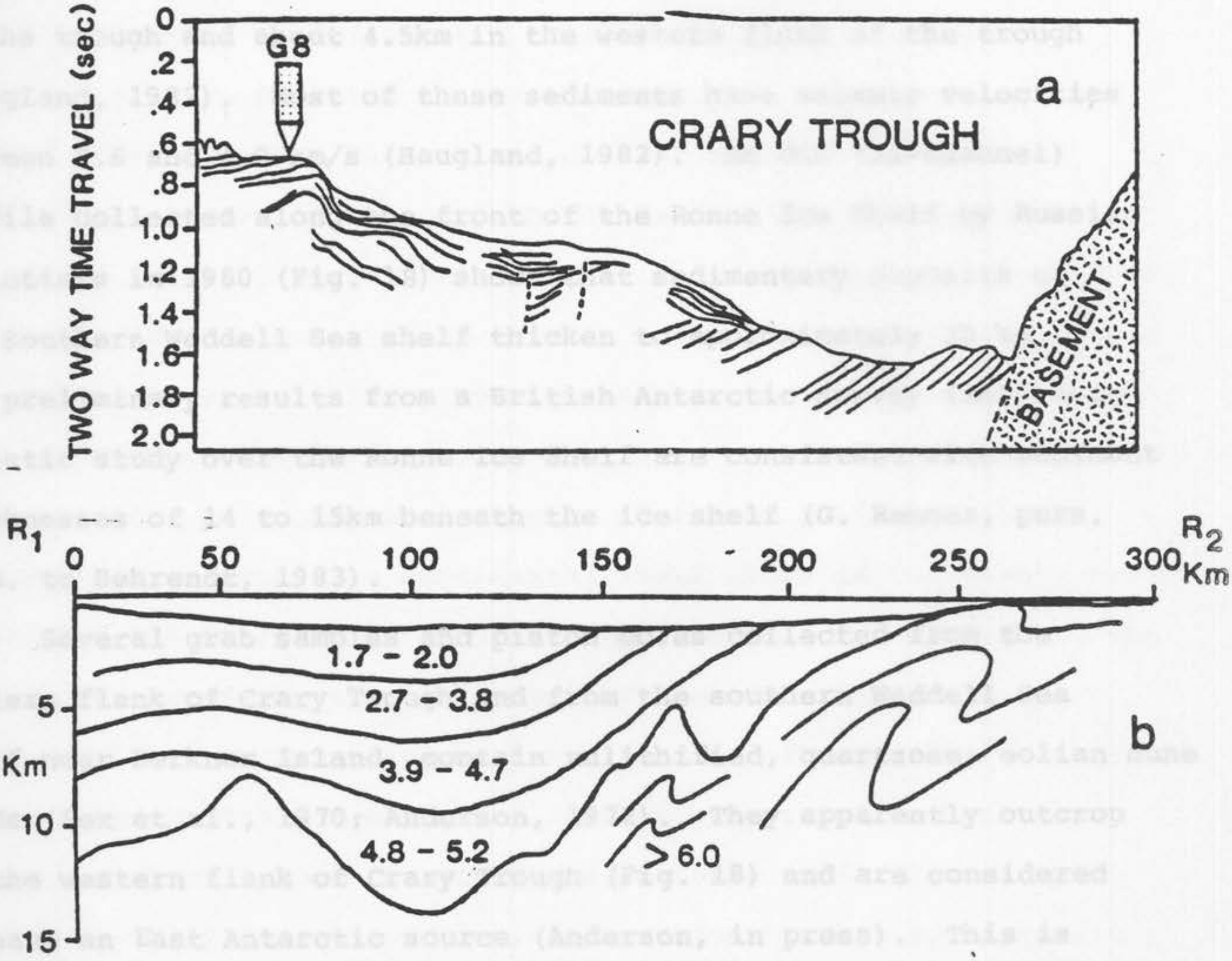


Figure 18. Interpreted seismic profiles across Crary Trough
a. Norwegian single channel profile (from Roqueplo, 1982)
b. Russian MCS profile (from Ivanov, 1983)

reflectors in the western flank of the trough which have been exposed by erosion. The results from two sonobuoys deployed in the trough show a sediment thickness of about 2km near the axis of the trough and about 4.5km in the western flank of the trough (Haugland, 1982). Most of these sediments have seismic velocities between 2.6 and 4.0 km/s (Haugland, 1982). An MCS (12-channel) profile collected along the front of the Ronne Ice Shelf by Russian sceintists in 1980 (Fig. 18) shows that sedimentary deposits of the Southern Weddell Sea shelf thicken to approximately 10 km, and preliminary results from a British Antarctic Survey (BAS) aeromagnetic study over the Ronne Ice Shelf are consistent with sediment thicknesses of 14 to 15km beneath the ice shelf (G. Renner, pers. comm. to Behrendt, 1983).

Several grab samples and piston cores collected from the western flank of Crary Trough and from the southern Weddell Sea shelf near Berkner Island, contain unlithified, quartzose, eolian dune sands (Rex et al., 1970; Anderson, 1972). They apparently outcrop on the western flank of Crary Trough (Fig. 18) and are considered to have an East Antarctic source (Anderson, in press). This is based on an absence of volcanic material in these sands. Also, the westward dipping reflectors of the Crary Trough region indicate that the continental shelf located east of Berkner Island was accreted from East Antarctica. Dramatic difference in the thickness of sediment deposits on the continental shelf of the eastern Weddell Sea implies that major structural elements intersect the shelf and are responsible for these differences (Anderson, in press).

As in the Ross Sea, fluvial deltaic sedimentation was occurring on the Weddell Sea continental shelf during what is believed to have been the early glacial history of the region, hence more temperate glacial conditions are implied (Anderson, in press). Major deltas were situated in the area of the Brunt Megatrough and west of Crary Trough. Deltaic and glacial marine sedimentation ended with a major advance of both the East and West Antarctic ice sheets onto the eastern continental shelf (Anderson et al., 1980; Elverhoi, 1982; Anderson et al., 1983). The shelf was deeply eroded during this event creating a modern seafloor unconformity ("Weddell Sea Glacial Unconformity") (Roqueplo, 1982; Elverhoi and Maisey, 1983).

To date, no geophysical results have been published on the western Weddell Sea. The continental shelf there is relatively broad (averaging 300 km in width) and is covered by sea ice throughout the year, hence access by ship is extremely limited. The shelf is situated within an extensive back-arc terrain of the Palmer Magmatic Arc, and has probably accumulated a relatively thick sedimentary sequence,derived from this arc, since Jurassic time (Elliot, 1983). Thick post-early Jurassic volcaniclasic deposits outcrop extensively along the entire length of the western Weddell Sea coast (Latady Formation, Laudon et al., 1983) and undoubtedly extend seaward beneath the continental shelf of the western Weddell Sea.

Antarctic Peninsula-Bellingshausen Sea Region

The tectonic evolution of the Antarctica Peninsula - Scotia Arc has been recently reviewed in a number of papers (Barker, et al., 1982 Dalziel, 1981, 1982, 1983; Dalziel and Elliot, 1982; DeWit, 1977; Norton, 1982; Thomson et al., 1983). The region's development has been dominated by subduction, which dates back to the Early Mesozoic, and possibly to Late Paleozoic (Dalziel, 1983). During its early development, the Bellingshausen continental margin was an active margin, and fore-arc and back-arc basins have flanked the peninsula since Late Jurassic time (Elliot, 1983). Oblique subduction of the Aluk Ridge crest, from west to east, occurred during Late Cretaceous through Early Miocene time (Herron and Tucholke, 1976; Weissel et al., 1977), so the active margin was gradually transformed to a passive margin as the ridge-crest was consumed and the locus of magmatism was shifted to the north and east. Bransfield Strait is a relatively recent (less than 2.0 m.y.) spreading center (Weaver et al., 1982; Dalziel, 1983).

Marine geophysical surveys of the region were first carried out in the Bransfield Strait and included gravity and magnetic surveys (Griffiths et al., 1964; Davey, 1972) and seismic refraction measurements (Cox, 1964; Ashcroft, 1972; Watters, 1972). Single channel sparker profiles were obtained from the southern end of the Bransfield Strait during the USCGC Glacier Deep Freeze 81 Expedition (Anderson and Myers, 1981). The Bellingshausen margin was surveyed during the U.S. Eltanin Cruise 43, R/V Vema Cruise 1806, and R/V Conrad Cruise 1503, but only single channel data were acquired during these cruises and these surveys were mainly restricted to the deeper part of the margin (Tucholke and Houtz, 1976). During the 1980-81 field season, the Japanese Research Center obtained multichannel seismic data in the Bellingshausen Sea, including one line that extended onto the continental shelf near Adelaide Island.

The results of the early BAS surveys showed the Bransfield Basin to contain between 2.5 and 3.0 kilometers of sediment resting on oceanic crust (Cox, 1964; Davey, 1972; Ashcroft, 1972), while the shelf north of the South Shetland Islands has upwards of 5.5 to 6.0 kilometers of sediments underlying it (Ashcroft,1972, Davey, 1972), (Fig. 19). Without multichannel seismic data, little can be said about the seismic stratigraphy in these areas. Single channel seismic records from the Bransfield Strait (Deep Freeze 81 data) show acoustic basement exposures at relatively shallow water depths (less than approxiately 600 meters) at the western end of the Bransfield Basin. The relatively thick sediment fill of the basin implies rapid sedimentation rates, given the young age (~2 m.y.) of this feature.

Birkenmajer (1983) recognizes three major unconformities within the Plio-Pleistocene section of King George Island which he attributes to episodic tectonic activity. The oldest of these unconformities occurs in Early Pliocene time and perhaps reflects the initial rifting of the basin. The second occurs in the Middle Pliocene section and is associated with the formation of acidic stratocone volcanics. The uppermost unconformity probably spans the lower Pleistocene and is of glacial origin.

The multichannel line acquired during the 1980/81 Japanese survey (Fig. 20) shows a basement high situated near the shelf edge. This feature is interpreted as a paleo-island arc, and unformably resting on it is a thick, seaward dipping accretionary sequence, which represents passive margin development in the area (Kimura, 1982). In this area, the Aluk Ridge was subducted beneath the peninsula

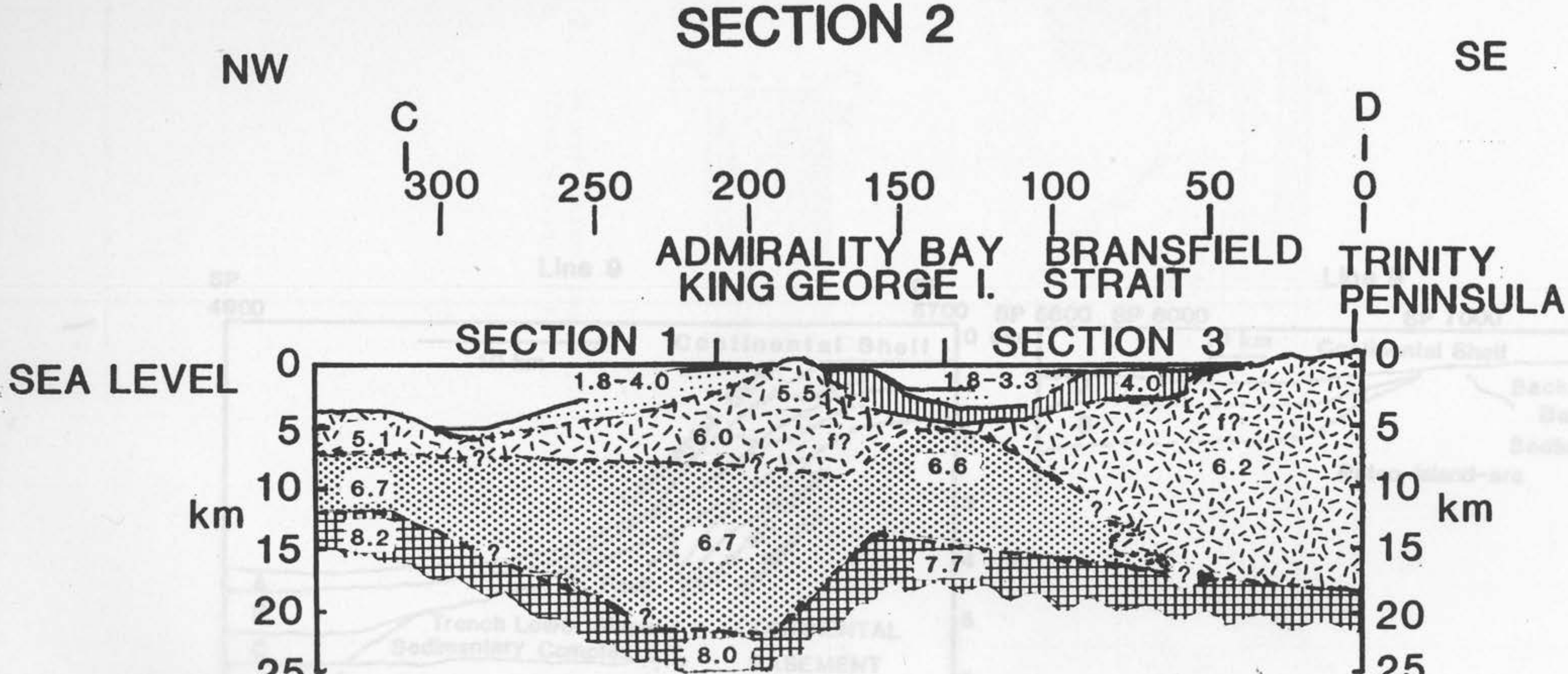


Figure 19. Interpreted seismic refraction profile across Bransfield Strait (from Ashcroft, 1972).

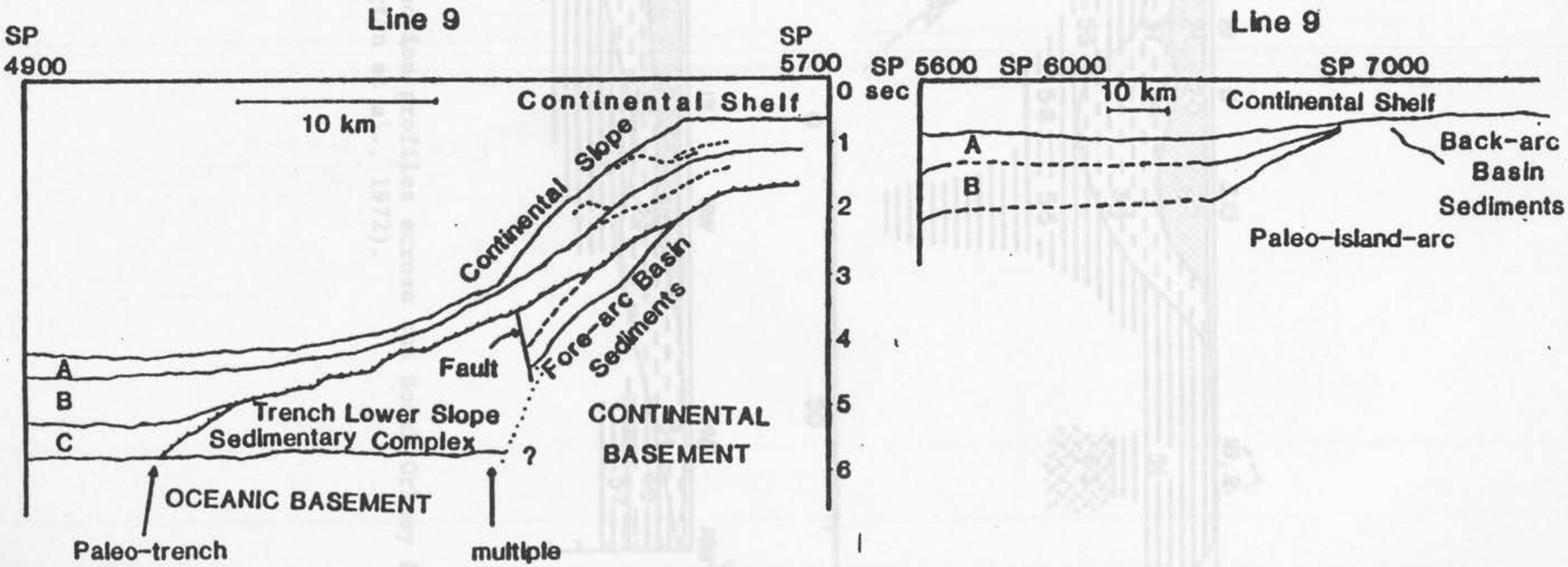


Figure 20. Interpreted seismic reflection profile across the Bellingshausen continental margin (from Kimura, 1982)

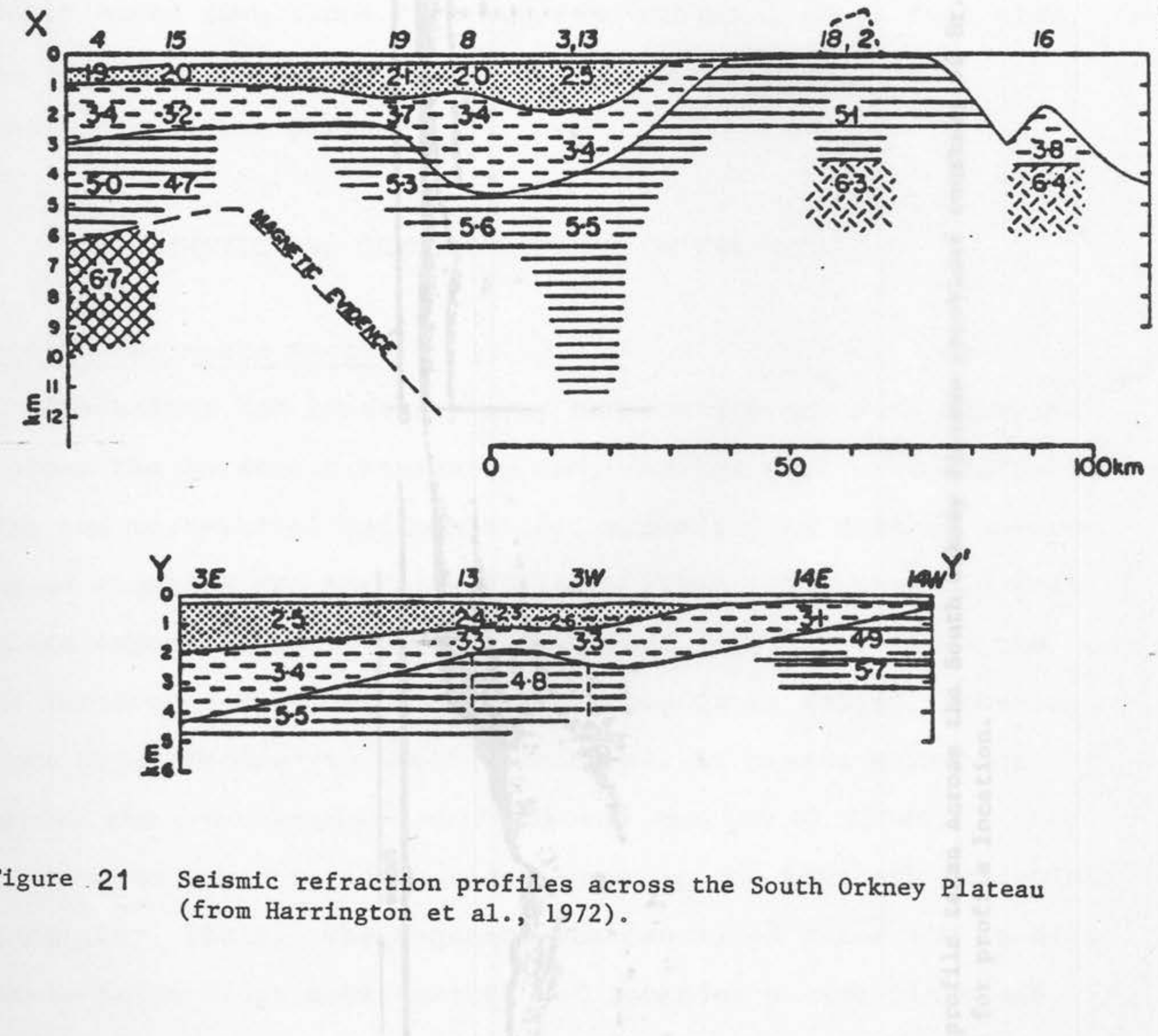


Figure 21 Seismic refraction profiles across the South Orkney Plateau (from Harrington et al., 1972).

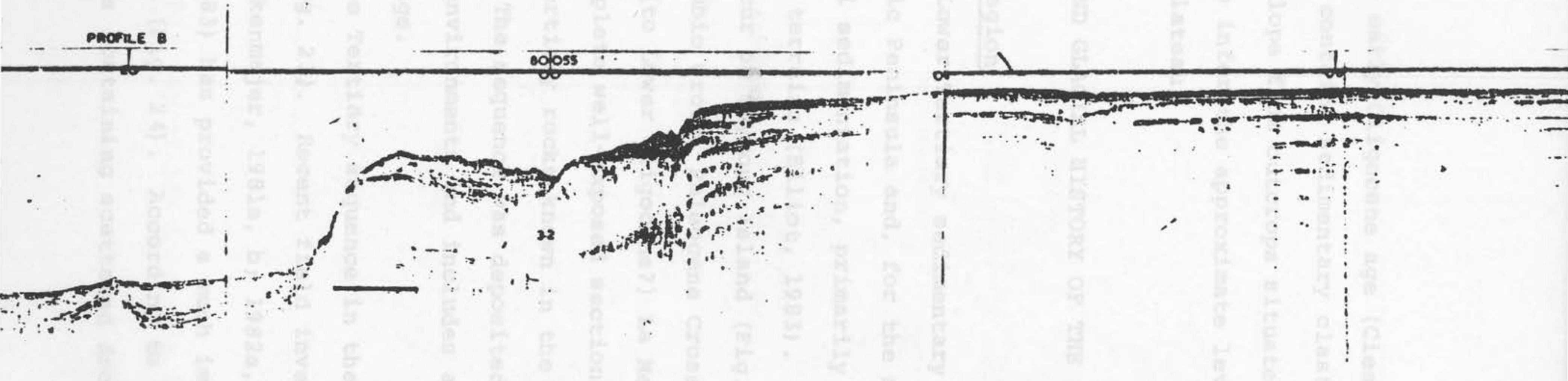


Figure 22 Single channel profile taken across the South Orkney Plateau (provided courtesy of Dr. Peter Barrett). See Figure 5.28 for profile location.

clay of late Eocene - early Oligocene age (Ciesielski and Jones, 1979). Because this deposit contains sedimentary clasts and has probably moved down slope from outcrops situated above this site, it is not possible to infer the approximate level of these deposits within the plateau.

## CLIMATIC AND GLACIAL HISTORY OF THE REGION

### Antarctic Peninsula Region

Cretacious and Lower Tertiary sedimentary deposits crop out all along the Antarctic Peninsula and, for the most part, reflect marine and terrestrial sedimentation, primarily in deltaic environments of magmatic arc terrains (Elliot, 1983). The best and most complete exposures occur on Seymour Island (Fig. 23). Here the upper Cretaceous Marambio Group, Paleocene Cross Valley Formation, and the Upper Eocene (to Lower Oligocene?) La Meseta Formation comprise the most complete well-exposed section of Upper Cretaceous to Lower Tertiary rocks known in the Southern Hemisphere (Zinsmeister, 1982). The sequence was deposited primarily in delta plain-to-delta front environments and includes a rich plant and animal fossil assemblage.

The most complete Tertiary sequence in the region occurs on King George Island (Fig. 23). Recent field investigations by Polish scientists (Birkenmajer, 1981a, b; 1982a, b; 1983; and Birkenmajer et al., 1983) has provided a much improved stratigraphic sequence for this area (Fig. 24). According to their work, plant fossil bearing deposits containing scattered dropstones


Figure 23. Geographic map of the Antarctic Peninsula(from Thomson et al. 1983)

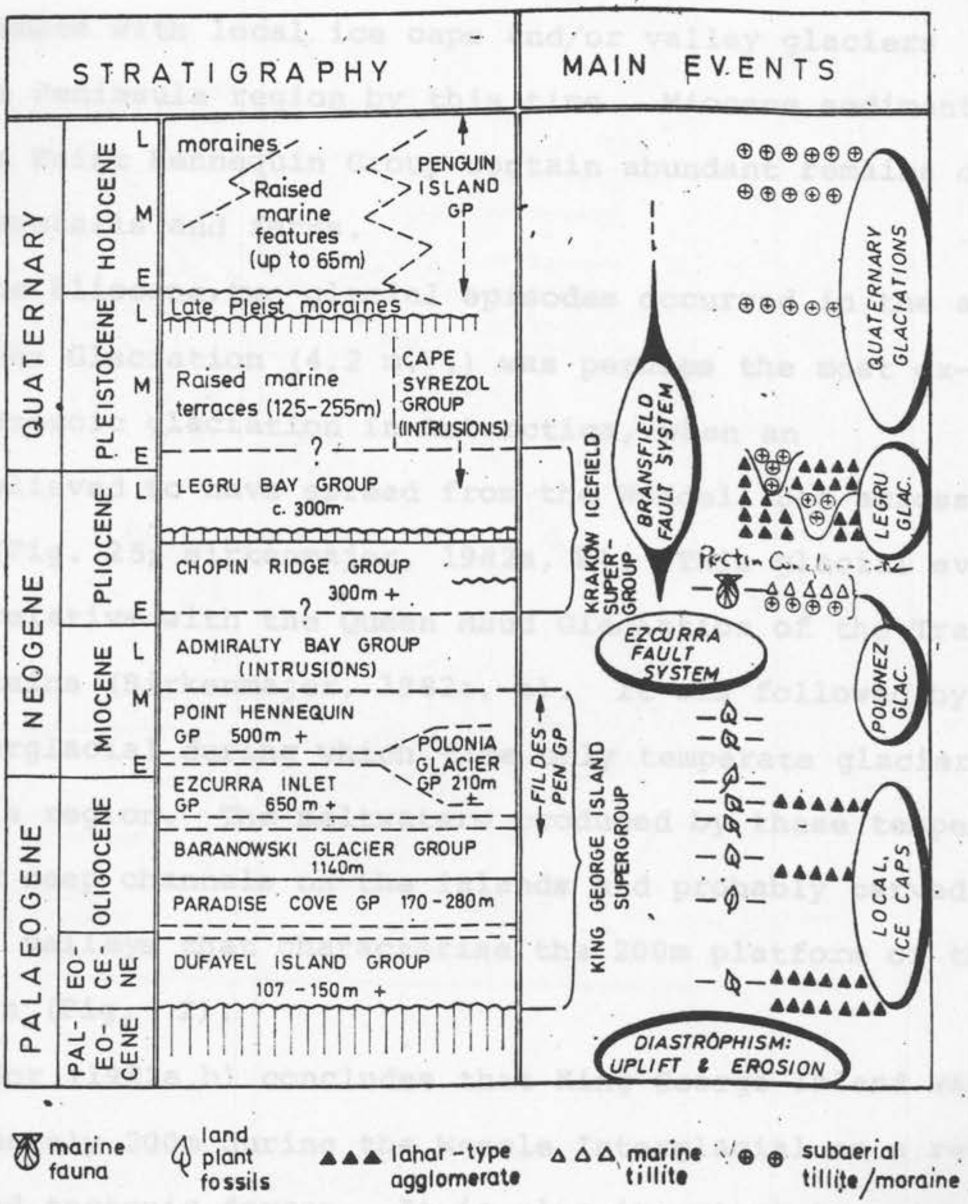


Figure 29. Stratigraphy of King George Island (from Birkenmajer, 1982)

may be as old as Eocene, and certainly Oligocene age (Dufayel Island Group, Paradise Cove Group, and Baranowski Glacier Group) and indicate a temperate climate with local ice caps and/or valley glaciers situated in the Peninsula region by this time. Miocene sedimentary deposits of the Point Hennequin Group contain abundant remains of Nothofagus, horsetails and ferns.

During the Pliocene, two glacial episodes occurred in the area. The older Polonez Glaciation (4.2 m.y.) was perhaps the most extensive late Cenozoic glaciation in Antarctica, when an ice sheet is believed to have spread from the Weddell Sea across the peninsula (Fig. 25; Birkenmajer, 1982a, b). This glacial event is perhaps correlative with the Queen Maud Glaciation of the Transantarctic Mountains (Birkenmajer, 1982a, b). It was followed by the Wesele Interglacial during which time only temperate glaciers existed in the peninsula region. The meltwaters produced by these temperate glaciers eroded deep channels on the islands and probably carved the stream-like valleys that characterise the 200m platform of the Bransfield Basin (Fig. 2).

Birkenmajor (1982a,b) concludes that King George Island was raised approximately 200m during the Wesele Interglacial as a result of isostatic and tectonic forces. It is also important to note that the submerged valleys of the 200m platform may connect with submarine canyons of the Bellingshausen margin; the heads of these canyons are presently centered near the 200 meter isobath. During Pliocene time the submarine fans fed by these canyons experienced

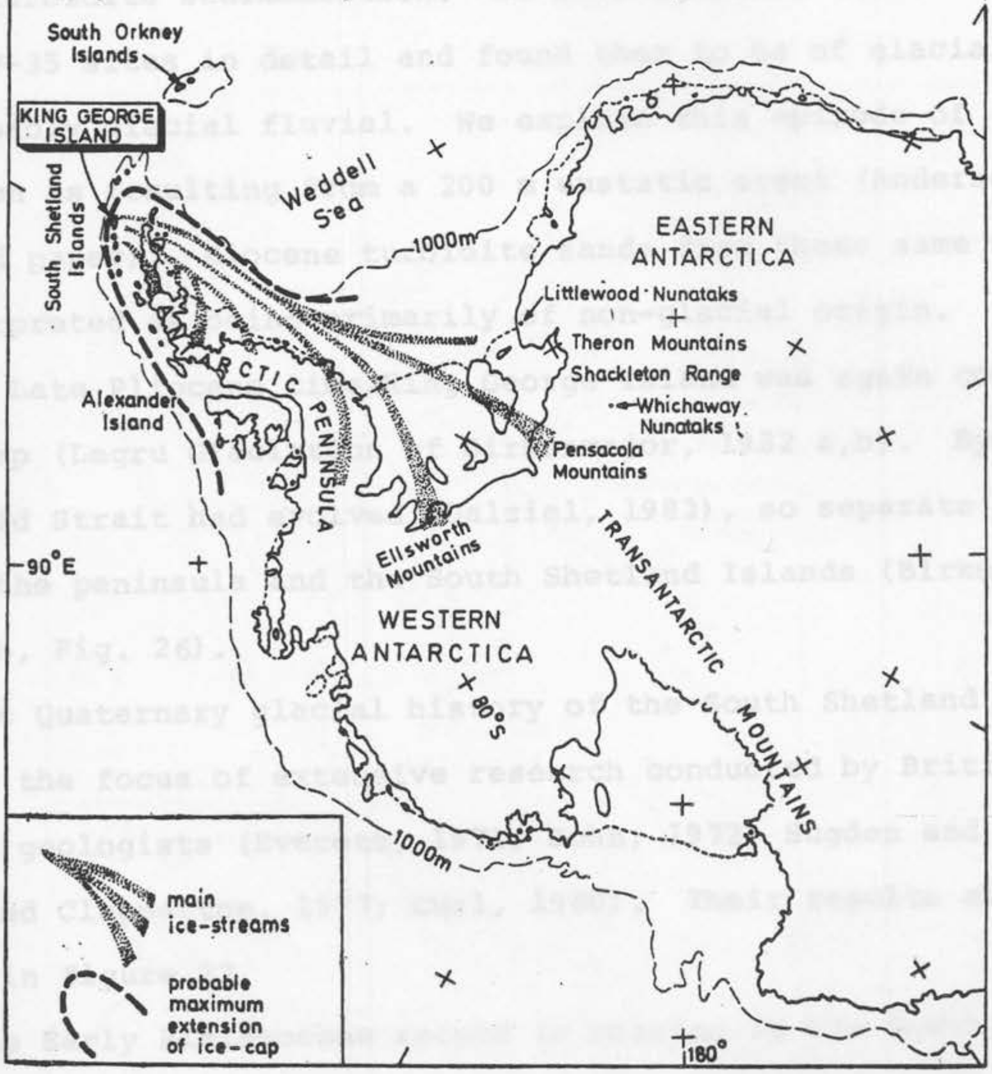


Figure 25. Glacial setting during the Polonez Glaciation
(from Birkenmajer, 1982)

renewed turbidite sedimentation. We have examined turbidite sands from DSDP-35 sites in detail and found them to be of glacial origin, probably glacial fluvial. We explain this episode of fan reactivation as resulting from a 200 m eustatic event (Anderson et al, submitted paper). Miocene turbidite sands from these same sites are interpreted as being primarily of non-glacial origin.

In Late Pliocene time, King George Island was again covered by an ice cap (Legru Glaciation of Birkenmajor, 1982 a,b). By this time the Bransfield Strait had evolved (Dalziel, 1983), so separate ice caps covered the peninsula and the South Shetland Islands (Birkenmajor, 1982 a, b, Fig. 26).

The Quaternary glacial history of the South Shetland Islands has been the focus of extensive research conducted by British and American geologists (Everett, 1971; John, 1972; Sugden and John, 1973; Sugden and Clapperton, 1977; Curl, 1980). Their results are summarized in figure 27.

The Early Pleistocene record is missing in the South Shetland Islands, so our knowledge of this important time interval is very poor. During the Late Pleistocene, two major glacial episodes (Illinoian nad Wisconsin Glaciations) and one major interglacial episode (Sangamon Interglacial) are recorded on the islands. During the older glacial episode an ice cap approximately 250 X 65 km in extent covered the islands and adjacent marine platform (Fig. 28, Sugden and John, 1973). In the later glacial episode separate ice caps covered the islands of the region; (Everett, 1971; Sugden and

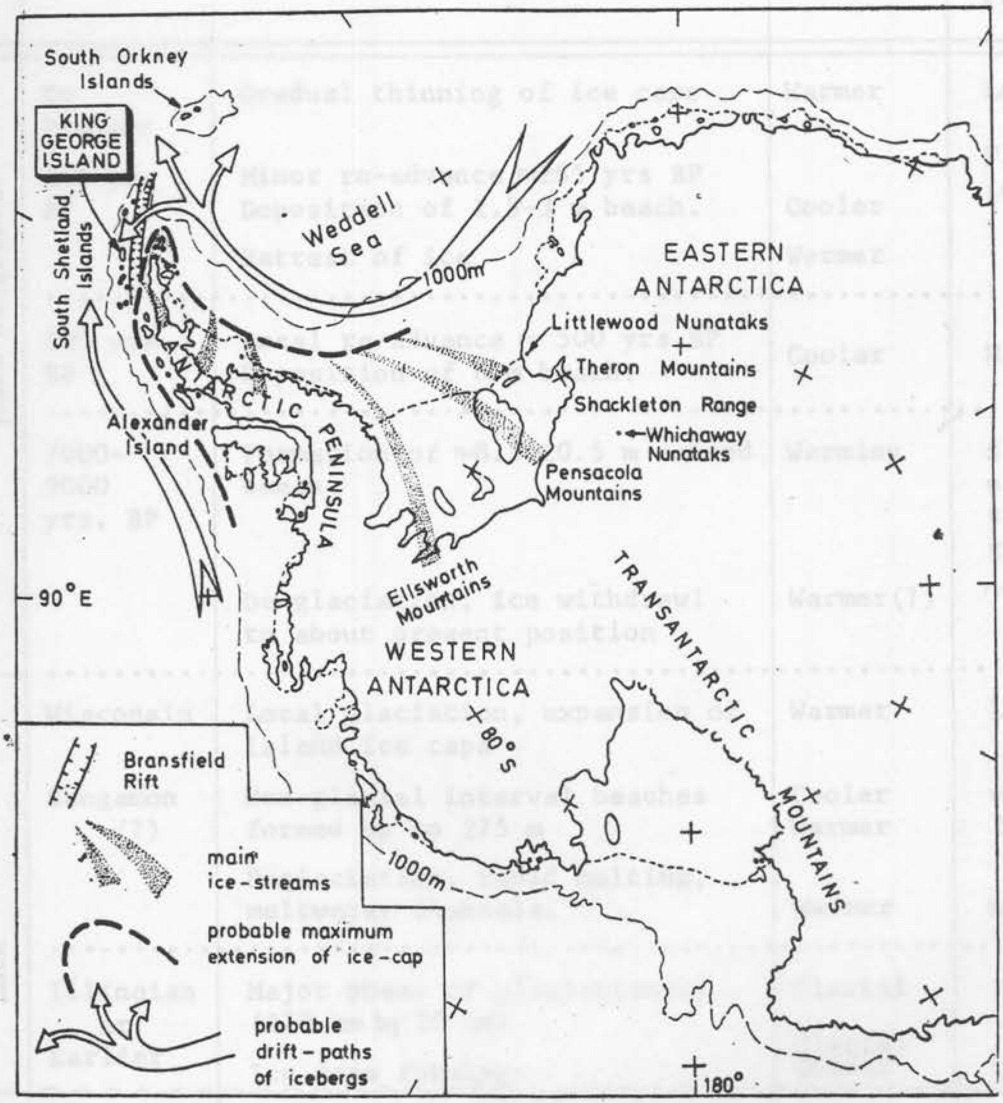


Figure 26. Glacial setting during the Legru Glaciation (from Birkenmajer, 1982)

| Period and Epoch | | | Age | Suggested Events | Climate Indicated | Sea level from the Present |
|---|---|---|---|---|---|---|
| QUATERNARY | Recent | Late Neoglacial | To Present | Gradual thinning of ice caps | Warmer | Lowering with Fluctuations |
| | | | 265 yrs BP | Minor re-advance ≈265 yrs BP<br>Deposition of 2.5-3 m beach. | Cooler | |
| | | | | Retreat of ice | Warmer | |
| | | | 500 yrs. BP | Local re-advance ≈ 500 yrs.BP<br>Deposition of 6 m beach. | Cooler | Halt(?) |
| | | | 7000-9000 yrs. BP | Formation of ≈8.5-20.5 m raised beach. | Warming | Standstill or transgression. |
| | | | | De-glaciation, ice withdrawl to about present position | Warmer(?) | ≈45-55 m |
| | Pleistocene | Late | Wisconsin | Local glaciation, expansion of island ice caps | Warmer | Lowering |
| | | | Sangamon (?) | Non-glacial interval beaches formed up to 275 m | Cooler<br>Warmer | up to 275 m |
| | | | | Deglaciation, rapid melting, meltwater channels. | Warmer | Higher |
| | | | Illinoian or Earlier | Major phase of glaciation(s) (270 km by 70 km) | Glacial | -100 m (?) |
| | | | | Ice caps forming. | Glacial<br>Colder | Lower |
| | | Early | | No record. | Glacial? | |
| TERTIARY | Plio. | | | Development of moraine surfaces and platforms above 55 m | Cooler | ±100 m<br>300 m<br>Fluctuating. |
| | Mio. | | | Vegetative cover | | |
| | Oli. | | | Falling and volcanic activity. | Temperate or warmer (?) | Numerous fluctuations. |
| | Eoc. | | | Andean Orogeny | | |

Figure 27. Climatic events in the Antarctic Peninsula(from Curl,1980)

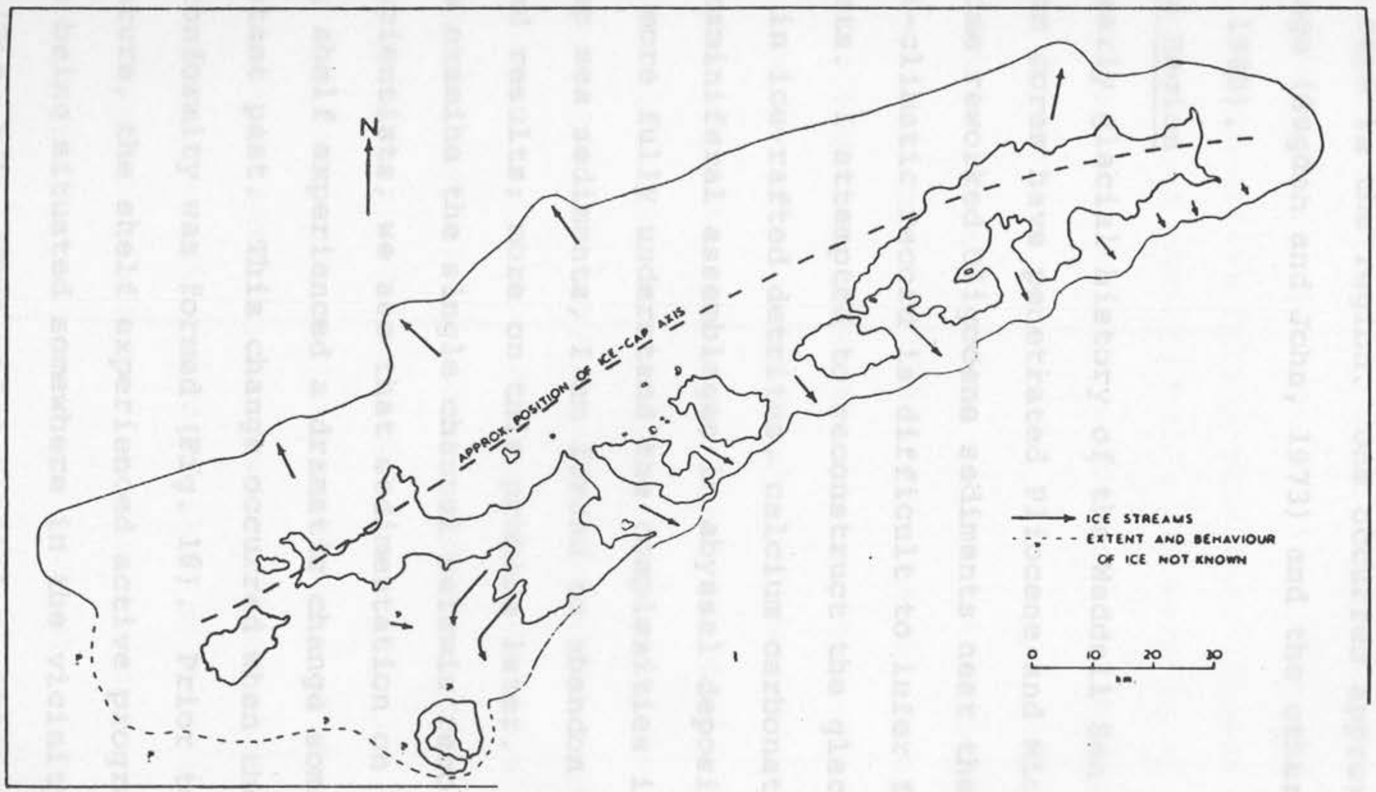


Figure 28 A reconstruction of the ice cap of the maximum glacial phase in the South Shetland Islands, based on erosional landforms. The seaward limits of the ice cap are assumed to have been determined by the 100 fathom (185 m) line. (Reproduced by courtesy of the British Antarctic Survey) (from Sugden and Clapperton, 1980).

John, 1973; Curl, 1980).

During Recent time there have been two minor readvances of island ice caps in the region. One occurred approximately 500 to 600 years ago (Sugden and John, 1973) and the other around 265 years ago (Curl, 1980).

Weddell Sea Region

The early glacial history of the Weddell Sea is poorly resolved. A few piston cores have penetrated Pliocene and Miocene sediments, and even some reworked Oligocene sediments near the Maud Rise, however, the glacial-climatic record is difficult to infer from these deep sea sediments. I attempted to reconstruct the glacial record using variations in ice-rafted detritus, calcium carbonate content, and benthic foraminiferal assemblages in abyssal deposits (Anderson, 1972). Now that I more fully understand the complexities involved in interpreting deep sea sediments, I am forced to abandon much of my earlier concepts and results; more on this problem later.

If we examine the single channel seismic records collected by Norwegian scientists, we see that sedimentation on the Weddell Sea continental shelf experienced a dramatic change sometime in the not too distant past. This change occurred when the Weddell Sea Glacial Unconformity was formed (Fig. 16). Prior to the formation of this feature, the shelf experienced active progradation, with a large delta being situated somewhere in the vicinity of Brunt Megatrough (Fig. 17). Thus, if a glacial maritime setting existed at this time it was a temperate one, with meltwater streams, not glaciers, delivering sediments to the sea.

This rapid shelf progradation probably took place on a shelf which was situated at more normal shelf depths (<180 m deep). This is implied by the eustatically controlled downlap - onlap geometry of delta sequences (Fig. 16) and the fact that the Weddell Abyssal Fan was apparently active during this time (Anderson, in press). Presently the canyons that fed this fan were isolated on the upper slope, their heads having been eroded during the glacial erosional event.

Based on our understanding of the Antarctic Peninsula glacial record, this situation could have existed throughout Miocene time when temperate vegetation existed on the South Shetland Islands. The glacial regime of the region changed dramatically as the ice sheet advanced onto the continental shelf, lowering the shelf by erosion and isostatic downwarping to create the present deep (500m), irregular topography that exists today (Anderson, in press). The tills that were deposited on the shelf during this glacial maximum (maxima) were clearly derived from ice flowing from both East and West Antarctica (Anderson et al, 1983; Fig. 29).

It is far easier to explain an advance of the ice sheets, especially the East Antarctic terrestrial ice sheet, onto the shelf if the shelf is subaerially exposed than to have the ice sheet advance onto a marine platform. I believe that this glacial advance occurred during the Pliocene and was probably triggered by a glacial eustatic drop in sea level resulting from build-up of both northern and southern hemisphere glaciers. This is based on changes in the

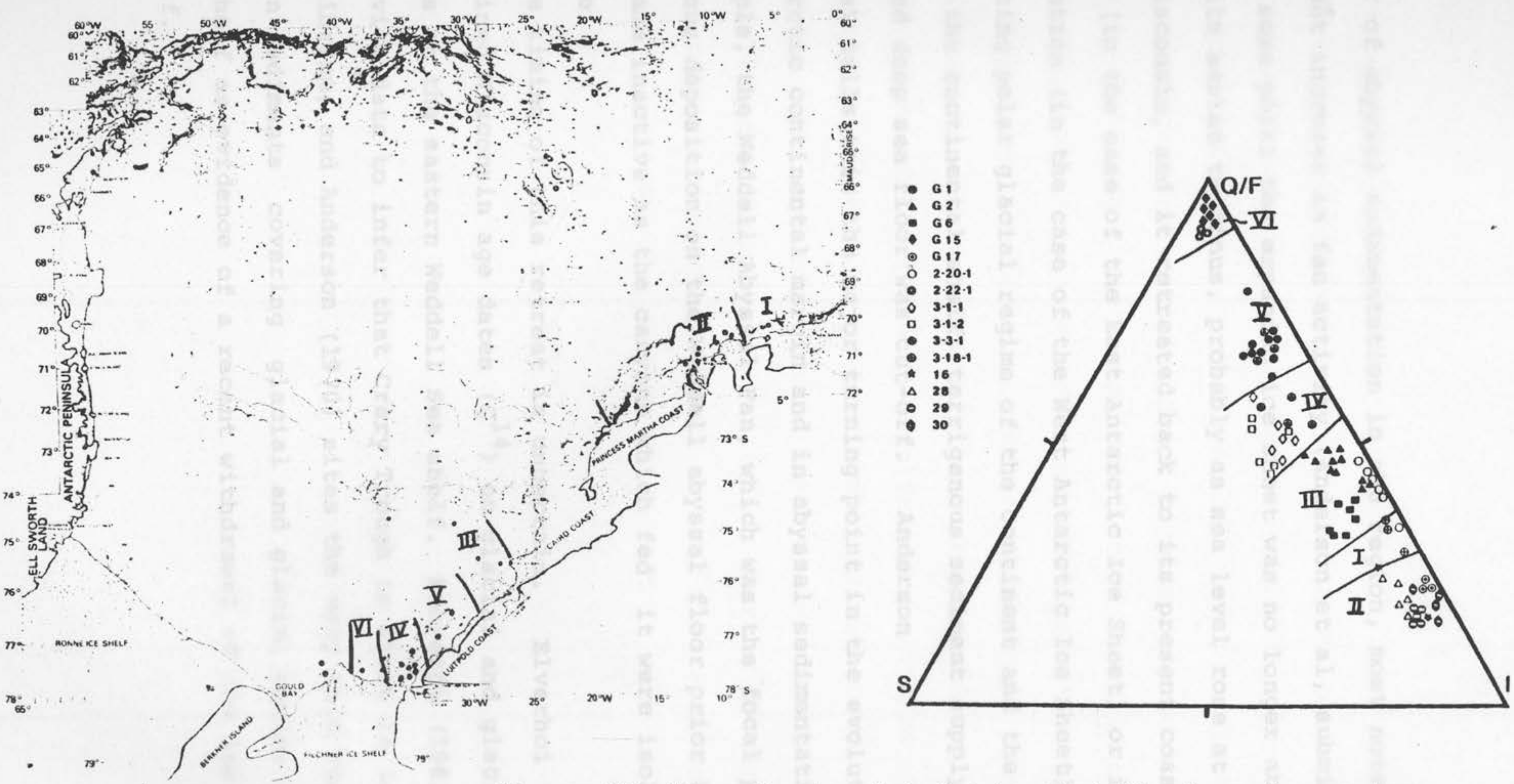


Figure 29. Mineralogic plot for basal tills from the eastern Weddell Sea. Six till provinces are recognized whose distribution is shown on the adjoining map. Q/F=Quartz/Feldspar, I=Igneous rock fragments, S=Sedimentary rock fragments.(from Andrews, in preperation)

character of abyssal sedimentation in the region, most notably an apparent increase in fan activity (Anderson et al, submitted).

At some point the expanded ice sheet was no longer able to sustain its marine terminus, probably as sea level rose at the end of the Wisconsin, and it retreated back to its present coastal position (in the case of the East Antarctic Ice Sheet) or ice shelf configuration (in the case of the West Antarctic Ice Sheet). Given the existing polar glacial regime of the continent and the great depth of the continental shelf, terrigenous sediment supply to the shelf and deep sea floor was cut-off. Anderson (in press) calls this the major turning point in the evolution of the Antarctic continental margin and in abyssal sedimentation. For example, the Weddell Abyssal Fan, which was the focal point of terrigenous deposition on the Weddell abyssal floor prior to this time, became inactive as the canyons which fed it were isolated on the slope.

The timing of this retreat is uncertain. Elverhoi (1982) has obtained Wisconsin age dates ($C^{14}$) on glacial and glacial marine sediments on the eastern Weddell Sea shelf. Behrendt (1962) has used gravity data to infer that Crary Trough is still in isostatic disequilibrium, and Anderson (1970) sites the very thin veneer of modern sediments covering glacial and glacial marine sediments on the shelf as evidence of a recent withdrawal of the ice sheet from the shelf.

Bellingshausen Basin

Four sites were drilled on the Bellingshausen continental rise and abyssal floor during DSDP Leg 35. (Fig. 30). Turbidity currents played an active sedimentologic role in delivering terrigenous sediments to these sites during Miocene time, making it difficult to interpret the pelagic and hemipelagic record. By Pliocene time the influx of terrigenous sediments to these sites became more variable, which probably reflects glacial eustatically controlled fluctuations in sea level and supply of terrigenous sediments to submarine canyons of the region. Significant quantities of ice-rafted debris began reaching these sites in Miocene time, but an extensive ice cover probably did not exist in the region until late middle Miocene (Tucholke et al, 1976). During Pliocene and Quaternary time there were apparently several glacial fluctuations (Tucholke et al, 1976).

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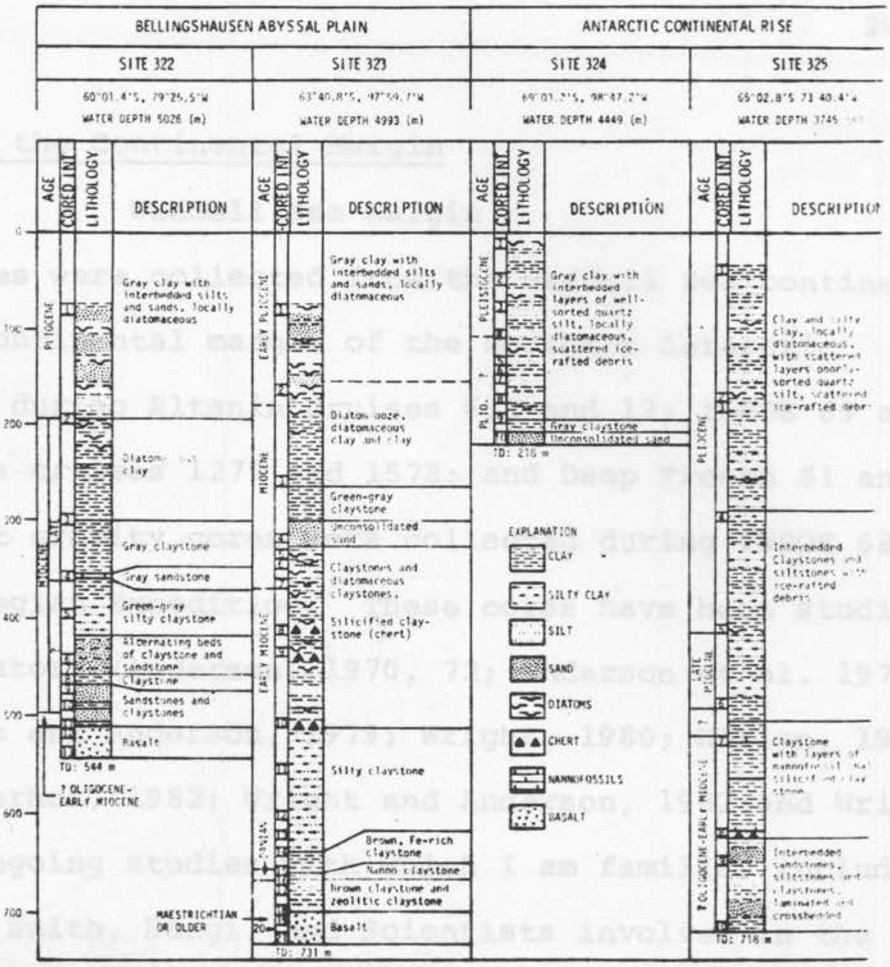


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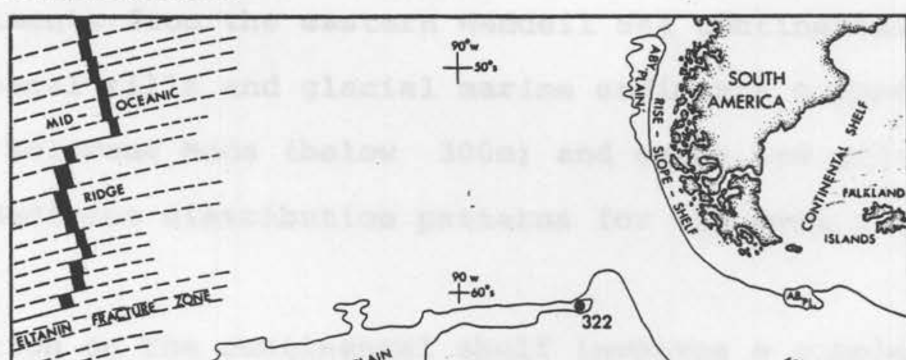



*Figure 1. Generalized physiography of the Southeast Pacific Basin and location of Leg 35 Sites (after Heezen and Tharp, 1972).*

Figure 30. DSDP Leg 35 site locations and core descriptions (from Hollister and Craddock, 1976).

Sedimentation on the Continental Margin

Weddell Sea Margin

Piston cores were collected from the Weddell Sea continental margin and the continental margin of the northern Antarctic Peninsula region during Eltanin cruises 6,7 and 12; IWSOE 69 and 70; Islas Orcadas cruises 1277 and 1578; and Deep Freeze 81 and 82. A number of short gravity cores were collected during IWSOE 68 and the 1977-78 Norwegian Expedition. These cores have been studied by several investigators (Anderson, 1970, 72; Anderson et al. 1979, 80, 82, 83a, b; Kurtz and Anderson, 1979; Wright, 1980; Harlan, 1981; Fisco, 1982; Elverhoi, 1982; Wright and Anderson, 1982 and Wright et al. 1983). Ongoing studies with which I am familiar include those of Singer, Smith, Baegi, and Scientists involved in the recent (1983-84) Polarstern expedition.

Cored sediments from the eastern Weddell Sea continental shelf include relict basal tills and glacial marine sediments capped by a thin layer of Holocene Muds (below 300m) and sands and gravels (above 300m). Sediment distribution patterns for the area are shown in figure 31.

Sedimentation on the continental shelf involves a complex interplay of glacial, oceanographic, and mass flow processes. Presently, marine currents, particularly impinging geostrophic currents, and mass flow processes are the main sedimentary agents, however, glacial sedimentation clearly dominated at sometime in the not too distant past (Anderson et al. 1979, 1980, 1982a, b, 1983a, b;

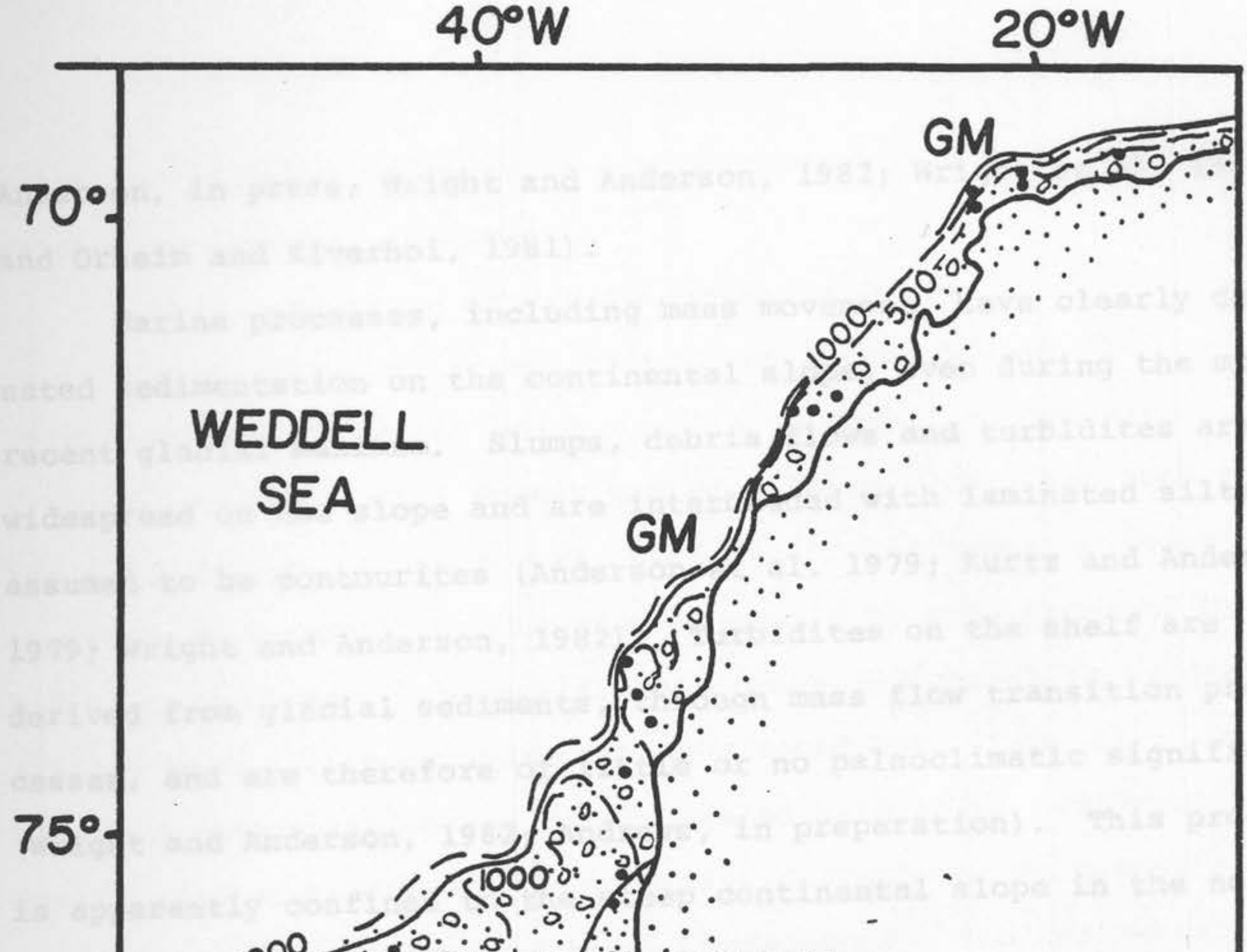



Figure 31. Sediment distribution pattern for the eastern Weddell Sea continental shelf(from Anderson et al. 1983).

Anderson, in press; Wright and Anderson, 1982; Wright et al. 1983; and Orheim and Elverhoi, 1981).

Marine processes, including mass movement, have clearly dominated sedimentation on the continental slope, even during the more recent glacial maximum. Slumps, debris flows and turbidites are widespread on the slope and are interbedded with laminated silts assumed to be contourites (Anderson et al. 1979; Kurtz and Anderson, 1979; Wright and Anderson, 1982). Turbidites on the shelf are derived from glacial sediments, through mass flow transition processes, and are therefore of little or no paleoclimatic significance (Wright and Anderson, 1982; Andrews, in preparation). This process is apparently confined to the steep continental slope in the northeastern Weddell Sea.

Cores from the southern Weddell Sea slope penetrated interbedded laminated silts (contourites) and diamictons (debris flows). The absence of transitional flow deposits in this area is attributed to the more gentle slope (Wright and Anderson, 1982).

In the northeastern Weddell Sea, geostrophic currents impinge on the upper slope, scowering it to produce sands (traction current deposits) and gravelly sands (lag deposits). This process and mass movement have probably played active roles in slope sedimentation in the Weddell Sea for some time.

The Weddell Sea continental rise is mainly floored by laminated silts with small but variable concentrations of ice-rafted debris and calcium carbonate. Paleoglacial and paleo-oceanographic interpretation of these deposits is complicated, as discussed in the chapter on abyssal sediments.

Northern Antarctic Peninsula Region

Piston cores collected during Deep Freeze 81 and 82 (Fig. 32) are presently being studied in detail by two Rice graduate students, Jill Singer and Mike Smith. They are both in the early stages of their work, so I will not attempt to describe their initial results. Both studies should be well underway by the end of this summer. In general, the Bransfield Basin is presently filling with siliceous sediments at a rapid rate (Fig. 33). This biogenic sedimentation was likely masked by glacial sedimentation during glacial maxima and by turbidity current and meltwater sedimentation during glacial minima. Consequently, the sedimentary record of climatic change may be quite conspicious. Keep in mind that sedimentation rates have probably been high, so a high resolution record for at least the last 2 million years likely exists.

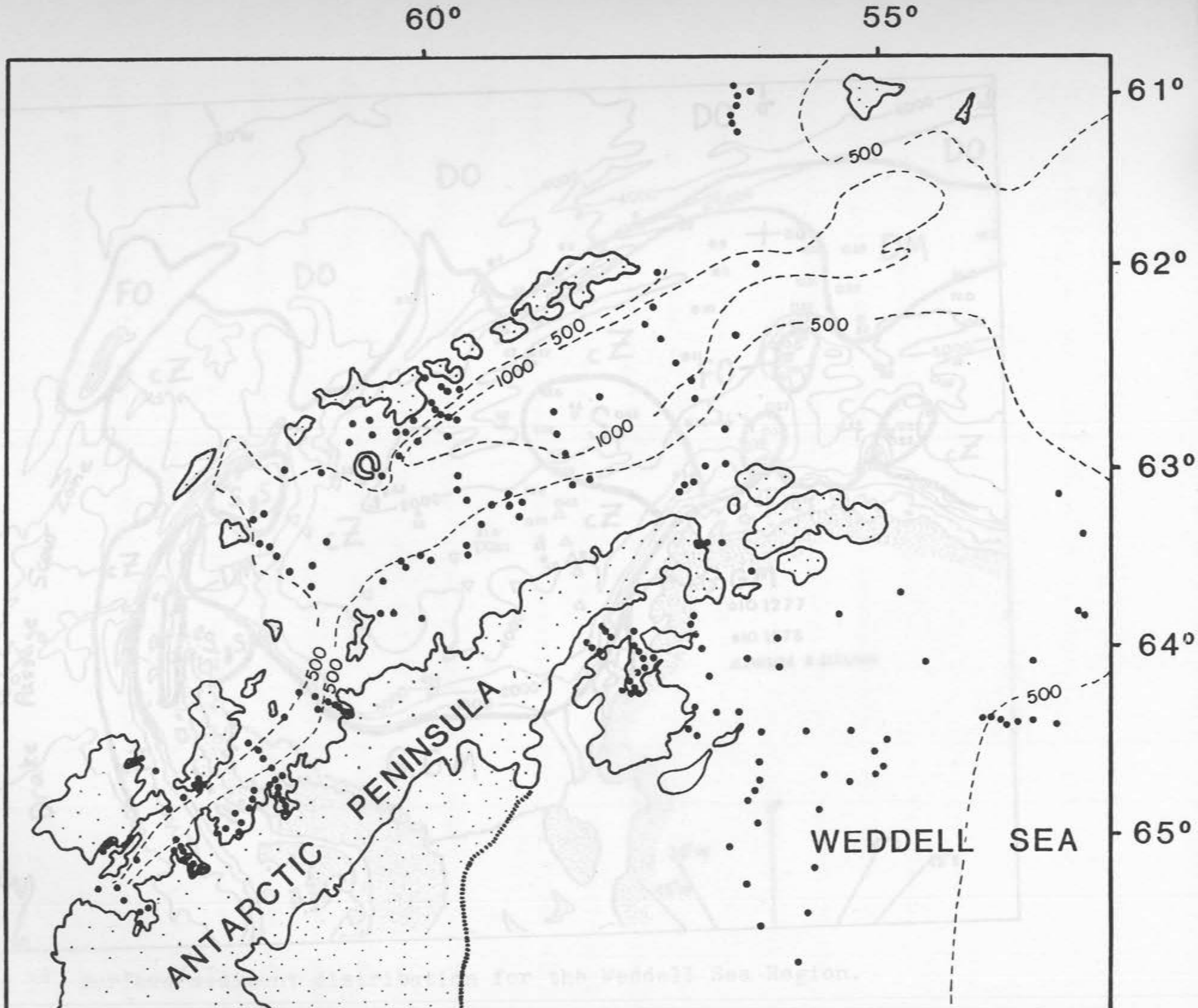



Figure 32. Deep Freeze 81 and 82 piston core locations

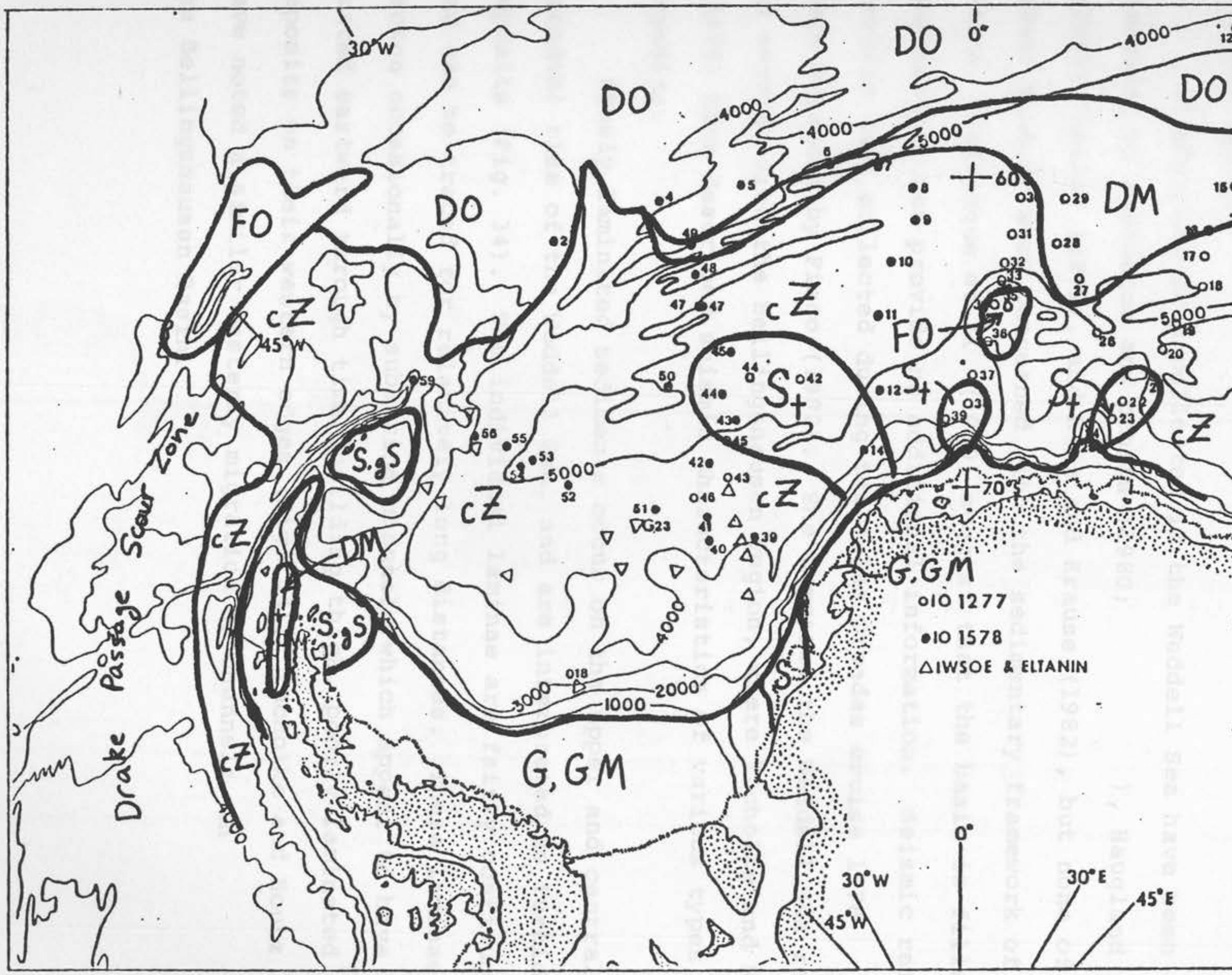



Figure 33. Surface sediment distribution for the Weddell Sea Region.

## Sedimentation on the Continental Rise-Abyssal Floor

### Seismic Studies

Geophysical data collected in the Weddell Sea have been examined by LaBrecque and others (1980;          ), Haugland (1982), Maisey (1979), and Hinz and Krause (1982), but none of these studies were concerned with the sedimentary framework of the basin. LaBrecque et al. (1980) suggest that the basin is filled with turbidites, but provide no additional information. Seismic reflection profile data collected during the Islas Orcadas cruise 1578 were examined by Fisco (1982). She compared the Weddell Sea records to records from the Bellingshausen region, where Tucholke and Houtz (1976) have described seismic characteristics of various types of deposits.

Finely laminated sediments occur on the upper and central continental rise of the Weddell Sea, and are interpreted as turbidite deposits (Fig. 34). The individual laminae are fairly continuous, and can be traced for relatively long distances. These laminae are broken occasionally by submarine channels which appear to have migrated eastward through time, building thick, poorly laminated levee deposits on their western edges (Fig. 34). Tucholke and Houtz (1976) have noted a similar easterly migration of channels in the Bellingshausen Basin.

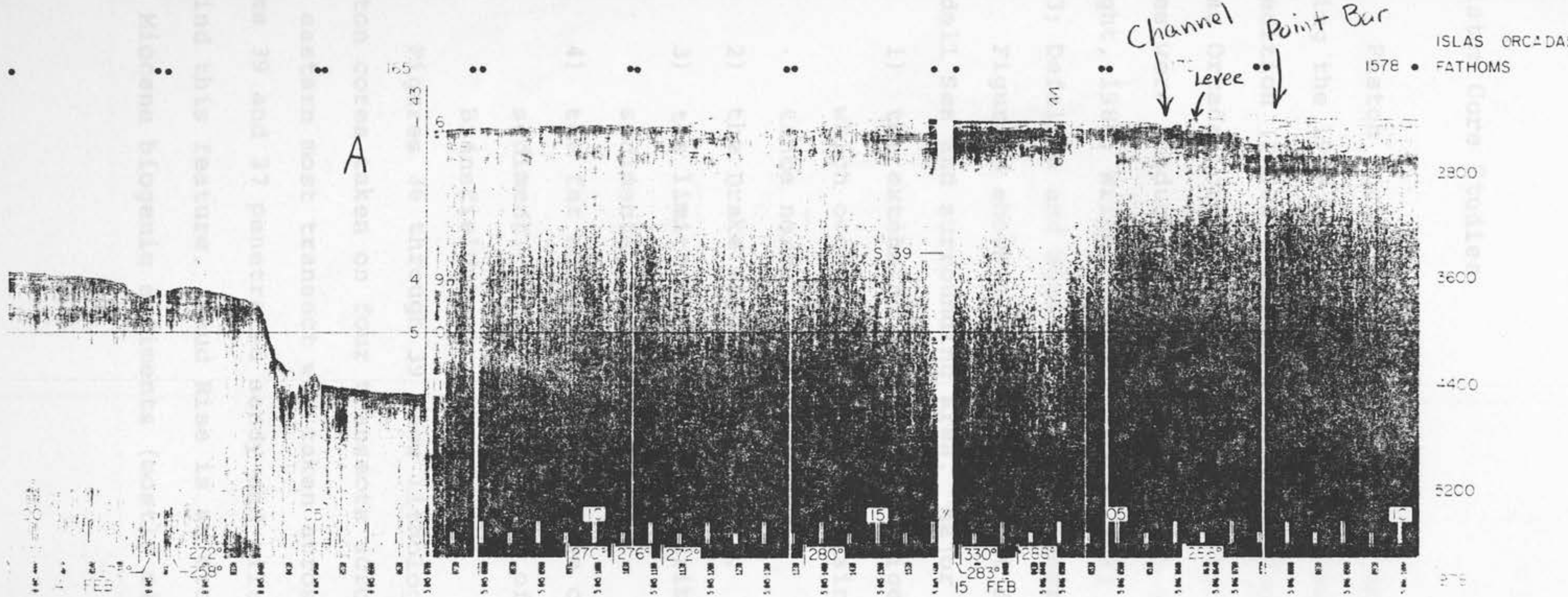



Figure 34. Seismic reflection profiles collected during Islas Orcadas Cruise 1578 showing laminated deposits presumed to be turbidites. A channel and associated point bar and levee are also shown. Profile provided courtesy of Dr. John La Brecque.

Piston Core Studies

Piston coring of the Weddell Sea abyssal floor was conducted during the 1969 and 1970 International Weddell Sea Oceanographic Expedition (IWSOE), during Eltanin cruises 7 and 12, and during Islas Orcadas cruises 1277 and 1578 (Fig. 35). Studies of these cores were conducted by several workers (Anderson, 1972, 1975a, b; Wright, 1980; Wright and Anderson, 1982; Fisco, 1982; Wright et al, 1983; Defelice and Wise, 1980; and Ledbetter and Ciesielski, 1982).

Figure 33 shows a surface sediment distribution map for the Weddell Sea and surrounding area. Major features of this map are:

1) the extensive region of terrigenous silts and clays which occupies the entire basin and extends some distance north,
2) the Drake Passage Scour Zone.
3) the limited and shallow distribution of calcareous sediments, and
4) the far northern distribution of siliceous biogenic sediment, with the exception of those that fill the Bransfield Basin.

Figures 36 through 39 show lithologic descriptions for piston cores taken on four transects across the Weddell Basin. The eastern most transect was taken across Maud Rise. Cores 39 and 37 penetrated sandy and silty turbidites ponded behind this feature. Maud Rise is an eroded feature with Pliocene and Miocene biogenic sediments (mostly siliceous) buried beneath

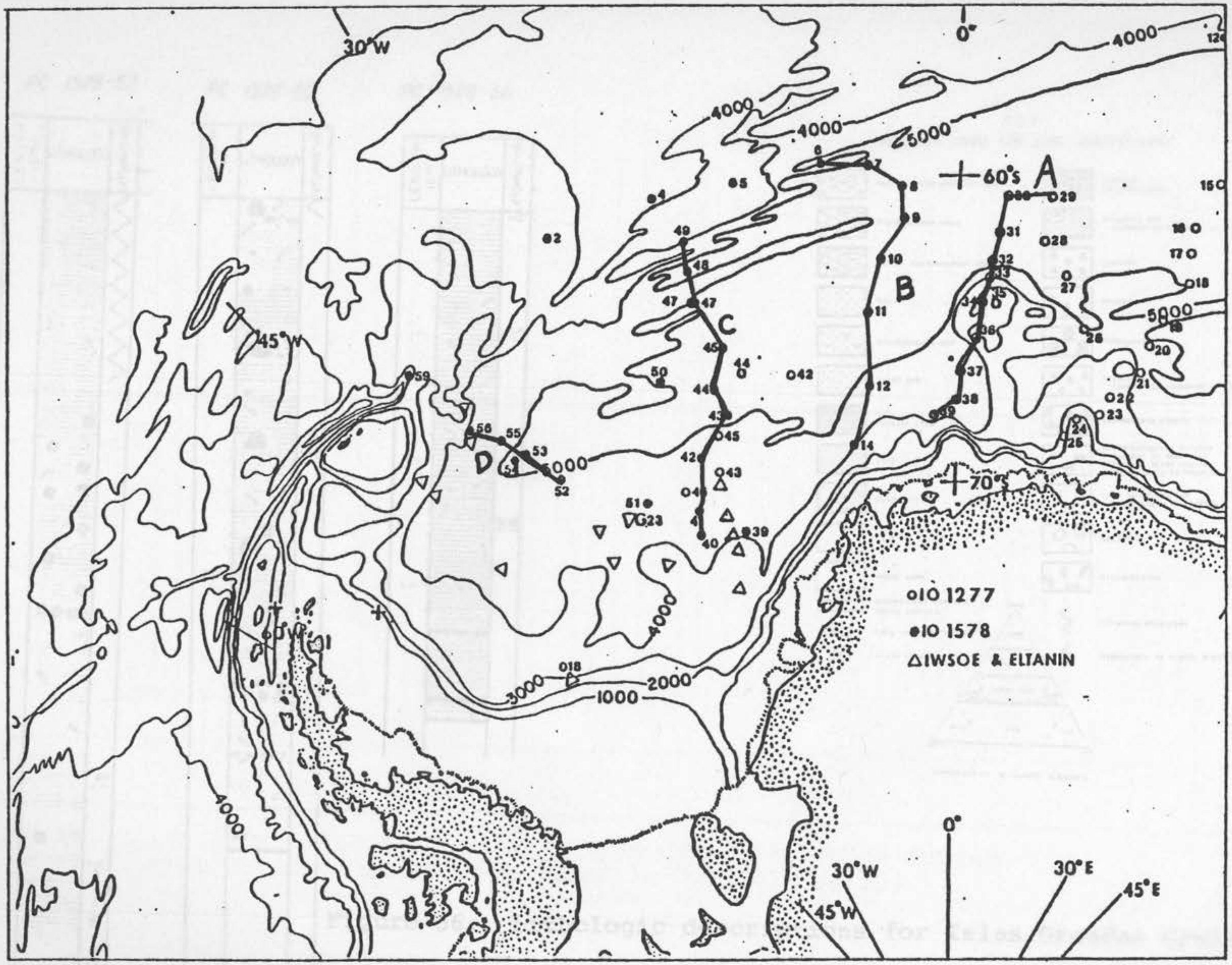
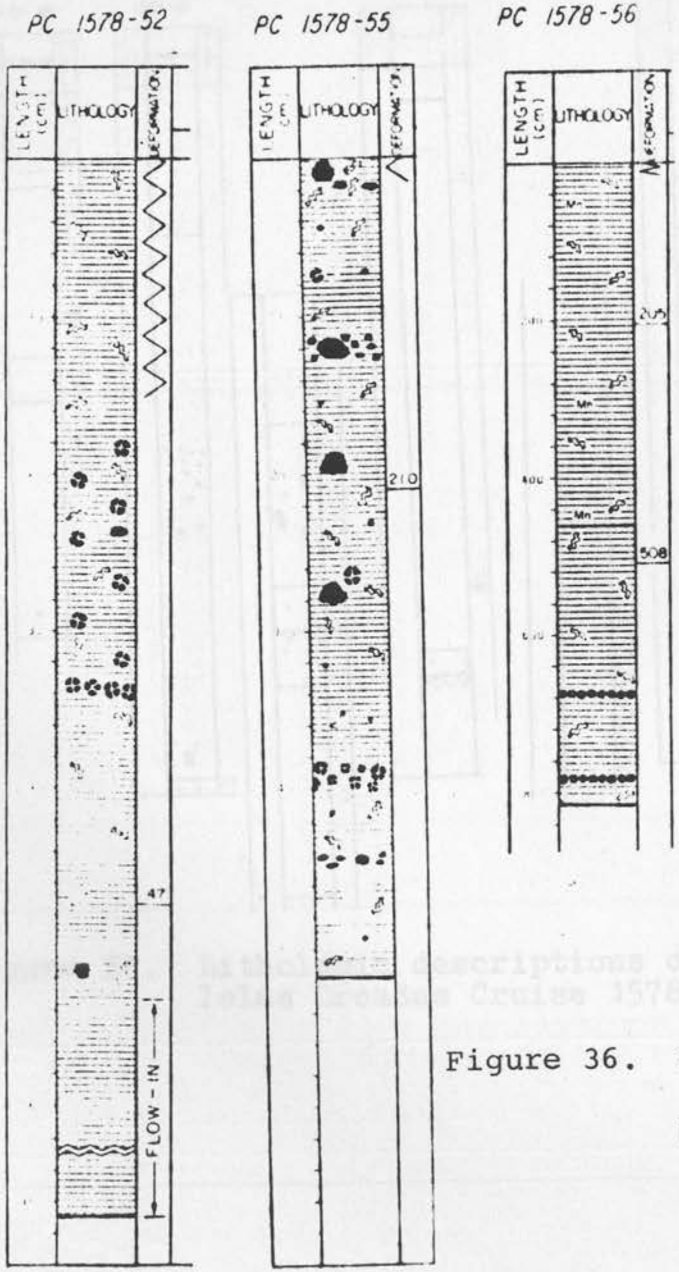



Figure 35. Piston core locations for the Weddell Sea.



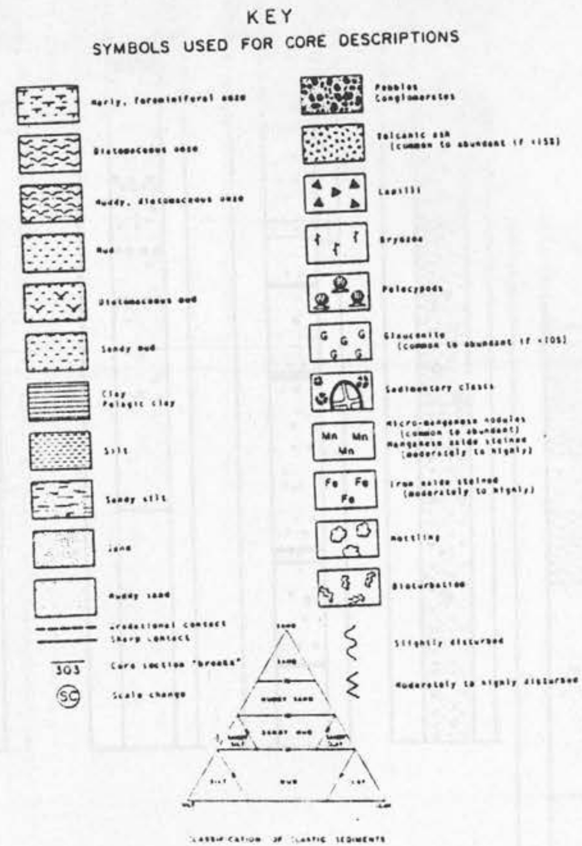




Figure 36. Lithologic descriptions for Islas Orcadas Cruise 1578 piston cores (profile D of Fig. 35). Use same key for figures 36 through 38 (from Cassidy et al., 1979, 1980).

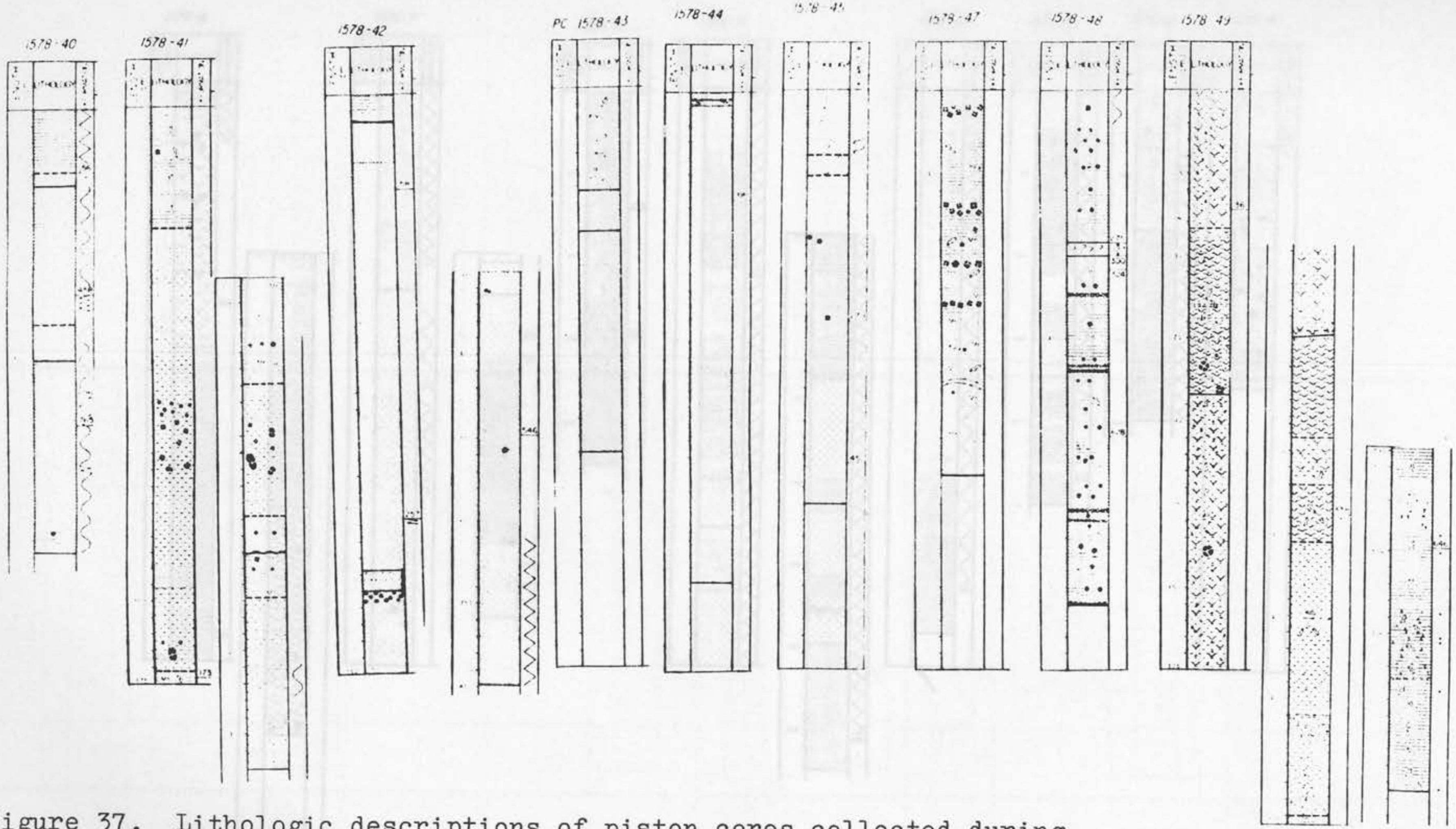



Figure 37. Lithologic descriptions of piston cores collected during Islas Orcadas Cruise 1578 (profile C of figure 35).

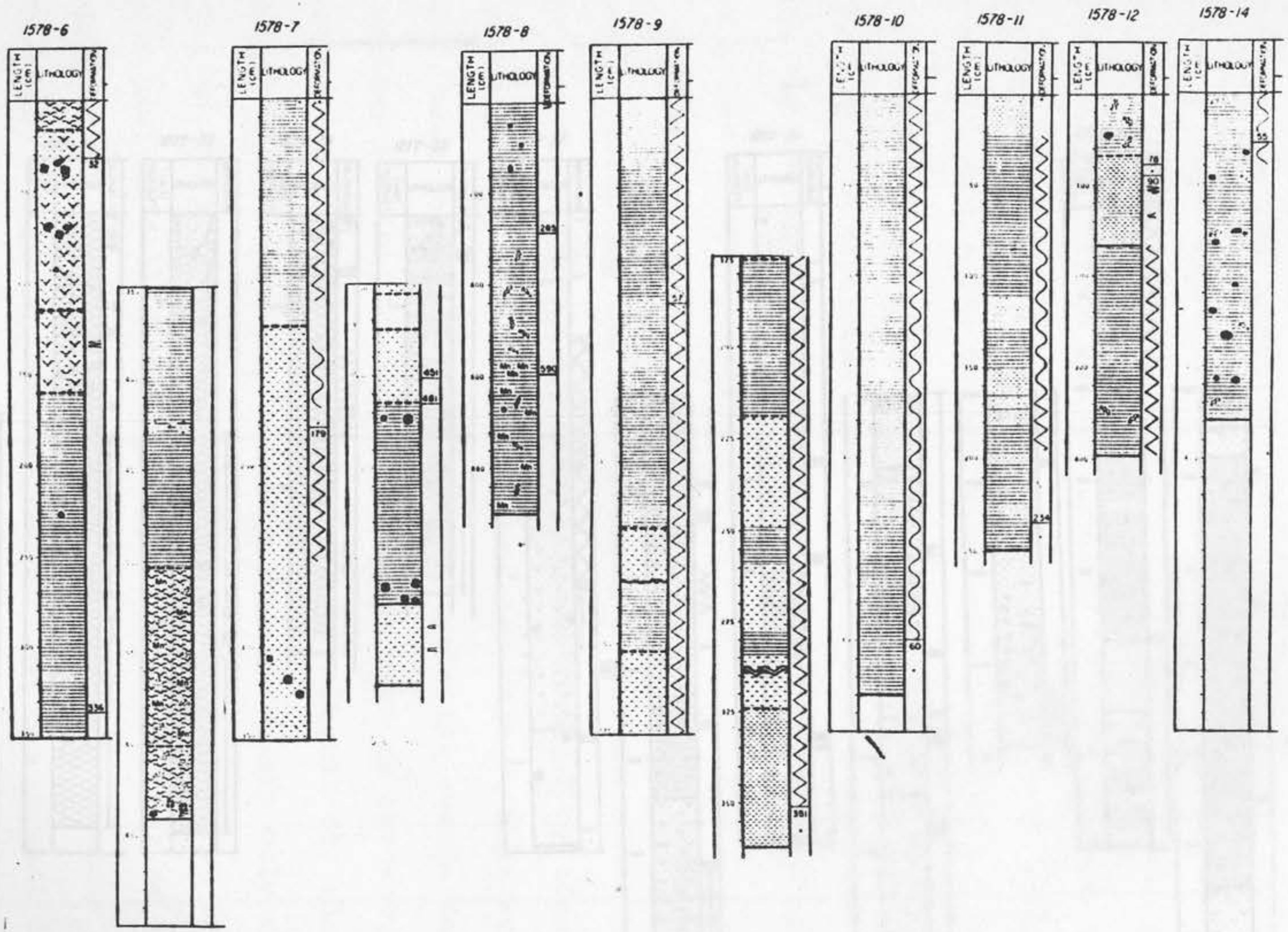



Figure 38. Piston core descriptions for cores collected during Islas Orcadas Cruise 1578 (profile B of figure 35).

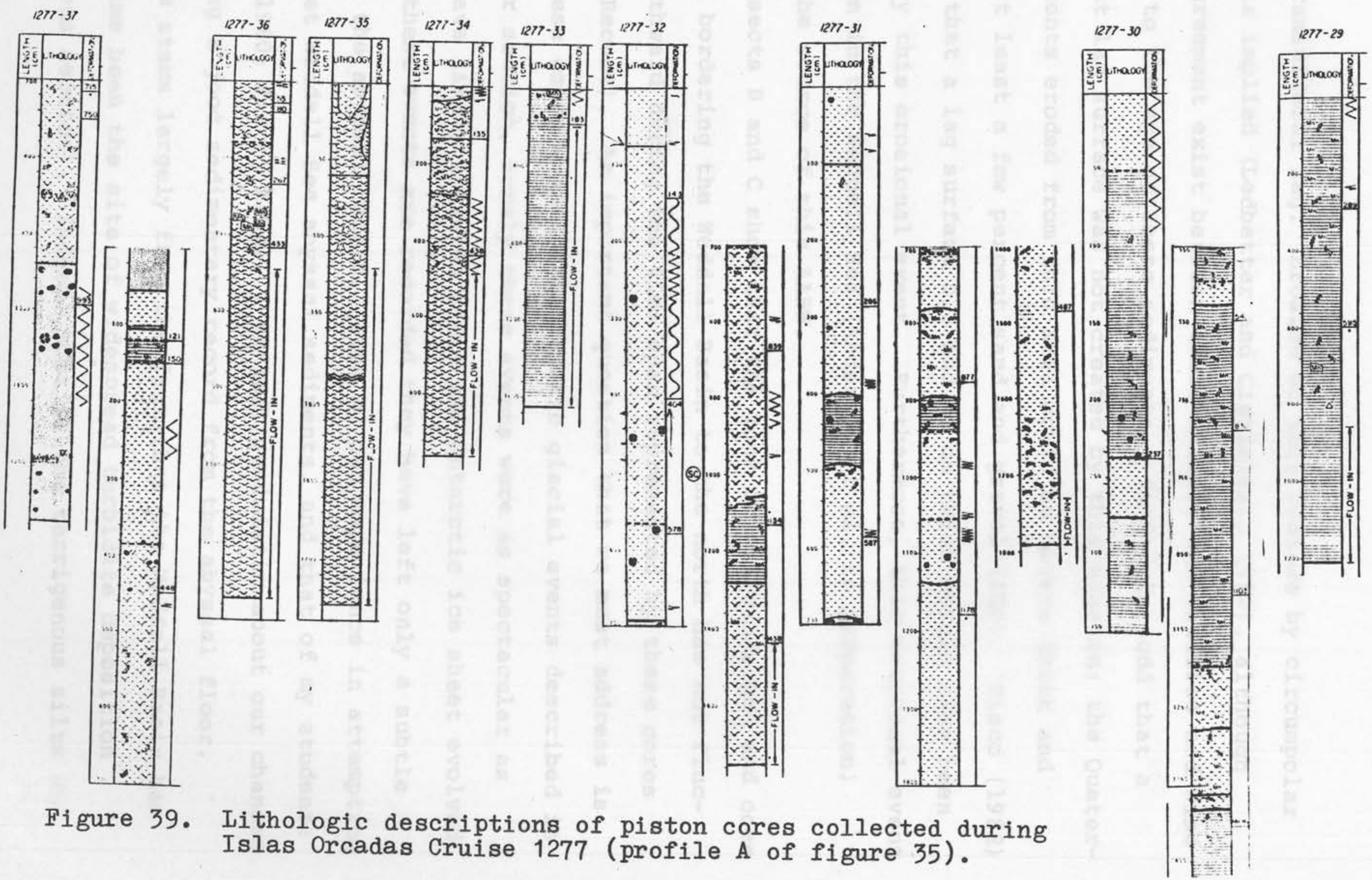


Figure 39. Lithologic descriptions of piston cores collected during Islas Orcadas Cruise 1277 (profile A of figure 35).

a thin foraminiferal lag. Erosion of this feature by circumpolar currents is implied (Ledbetter and Ciesielski, 1982), although some disagreement exist between these authors and Defelice and Wise (1980) as to the age of these sediments. It is also odd that a significant lag surface was not created by this erosion; the Quaternary sediments eroded from this area would be meters thick and contains at least a few percent sand and gravel (IRD). Fisco (1982) estimates that a lag surface 0.3 and 30 cm thick should have been produced by this erosional event. Furthermore, this erosional event is not seen in the Weddell Sea (Anderson et al. in preparation) which is the source of this AABW.

Transects B and C show that the zone of siliceous mud and ooze deposition bordering the Weddell Basin to the north has not fluctuated southward during the time span represented by these cores (Pliocent-Recent). An important question that we must address is whether these cores record the dramatic glacial events described in the earlier section, surely these events were as spectacular as any that have likely occurred since the Antarctic ice sheet evolved. If indeed these events are recorded they have left only a subtle imprint on the abyssal record. From my own experience in attempting to interpret Weddell Sea abyssal sediments, and that of my students (Harland, 1980; Fisco, 1982), I am left pesimistic about our chances of obtaining a good sedimentary record from the abyssal floor. The problem stems largely from the fact that the Weddell Basin has for some time been the site of widespread turbidite deposition (see previous section). Indeed, most of the terrigenous silts and clays penetrated in piston cores from the region were probably derived in this manner. Note the sedimentary clasts are common in cores from the region (Figs. 36-39).

Fisco examined Weddell Sea abyssal sediments in detail and constructed a list of criteria that can be used to distinguish fine-grained turbidites and debris flows from hemipelagic and pelagic sediments (Fig. 40). This requires careful, time-consuming work, but unless these distinctions are made we will not be able to diagnose glacial and paleo-oceanographic events from the deep sea sedimentary record.

| SEDIMENT TYPE | PELAGIC | HEMIPELAGIC | DEBRIS FLOW | SAND &SILT TURBIDITE | MUD TURBIDITE |
|---|---|---|---|---|---|
| SEDIMENT SOURCE | biogenic debris, chem. precipitation, windblown | biogenic debr. chem. precip. windblown, IRD terrigenous | any sediment type or source | terrigenous, biogenic, or chem. ppt. | terrigenous, biogenic, or chem. ppt. |
| TRANSPORT MECHANISM | settling through water column, growth or ppt. on bottom | settling through water, ppt., windbl., current transport | debris flow transport | turbidity current flow | turbidity current flow (turbid cloud) |
| SEDIMENT CHARACTERISTICS | unsorted silt and clay, large sizes from biota or chem. ppt., homogeneous, normal compaction (water-rich) | unsorted, all sizes, homoge. normal compaction (water-rich), larger grains usu. IRD | unsorted, all sizes, matrix greater than 20%, compacted, occasionally reversed grading, containing sedimentary clasts | graded, well sorted, sand to coarse silt sized, no IRD, usu. less than 10% clay component few clasts or lag at base | unsorted fine silt to clay sized sometimes more silt at base than at top, Fe-Mn micronods or $CaCO_3$ occasionally, very little or no IRD |
| BED FORMS | burrowed, homogeneous, or if no fauna on bottom, laminated | burrowed, homogeneous, or laminated if no fauna on bottom, ash laminae, dropstones | mottled, homog. or mixed look, sometimes evidence of a rigid plug, clasts in zones or scattered | usually massive, (infrequent par. lam, x-lam.) | usually laminated |
| basal CONTACTS | burrowed, gradational | burrowed, or gradational | sharp or burrowed, | sharp, erosive sometimes with lag or sed. clasts at base | sharp, erosive, with clasts, or graded |
| upper | sharp if eros., or burrowed & gradational | sharp if eros. or burrowed & gradational | sharp or burrowed | sharp or graded | sharp or graded &biot. |
| BED THICKNESS | any thickness | any thickness | 20-300 cm usually | 3-100 cm usually | 20-100 cm usually |
| SEDIMENTATION RATE | very low | low to medium variable terr. component | variable usu. medium | high | high |

Figure 40. Criterea for distingwishing mass flow deposits from pelagic and hemipelagic deposits (from Fisco,1982).

Two primary objectives in drilling the Weddell Sea will be to examine Antarctic Bottom Water flow history and the glacial record. These are worthy objectives, but we must concern ourselves with whether they are best achieved in the Weddell Basin or elsewhere.

The sedimentary record on the continent and continental shelf reveals that several major glacial-interglacial episodes occurred during the Plio-Pleistocene, yet the abyssal sediments of the Weddell Sea bear no conspicuous record of these events. Again, part of the problem lies in the fact that piston coring to date has been concentrated in the area of the Weddell Abyssal Fan where pelagic and hemipelagic sedimentation has been frequently interrupted by turbidite deposition. We have defined the limits of mass flow deposits using available piston cores (Fig. 41). The southern limits of the fan are poorly constrained due to inadequate core coverage; this is, in turn, due to perennial ice cover in this area.

The northwestern Weddell Sea was cored during Eltanin Cruises 7 and 12 and during Deep Freeze 82 (Fig. 32, 35). We have examined these cores and found them to contain fewer turbidites than cores collected from the northeastern Weddell Sea. Two cores (12-6 and 7-12) were selected for detailed analysis to see whether the Late Pleistocene glacial events that have been recorded in the South Shetland Islands (see Climatic and Glacial History section) are imprinted in the abyssal record (Fig. 42). The history of AABW flow out of the region is also being investigated. Both cores span the Brunhes magnetic epoch.

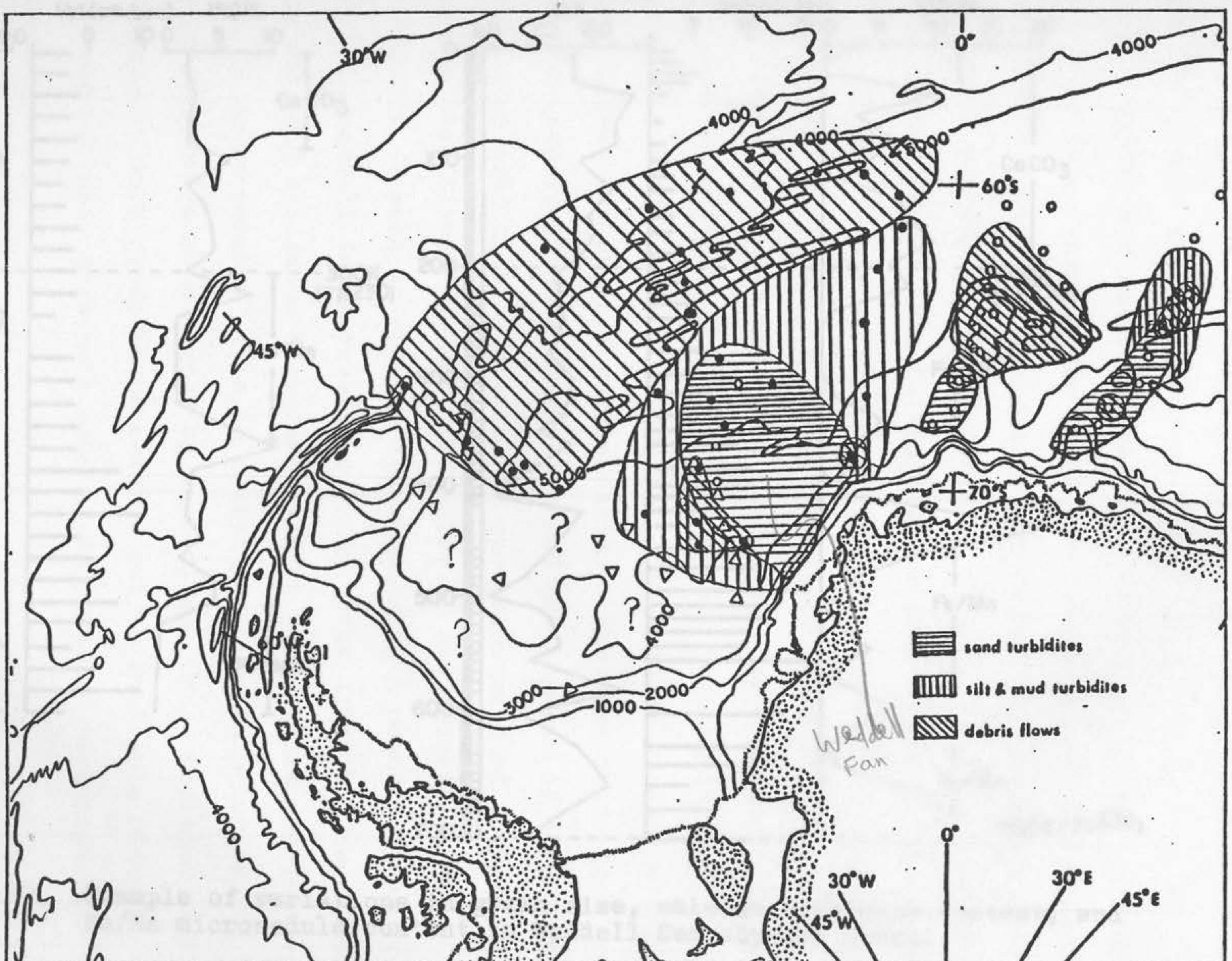



Figure **41** Distribution of mass flow deposits in the Weddell Sea (from Fisco, 1982).

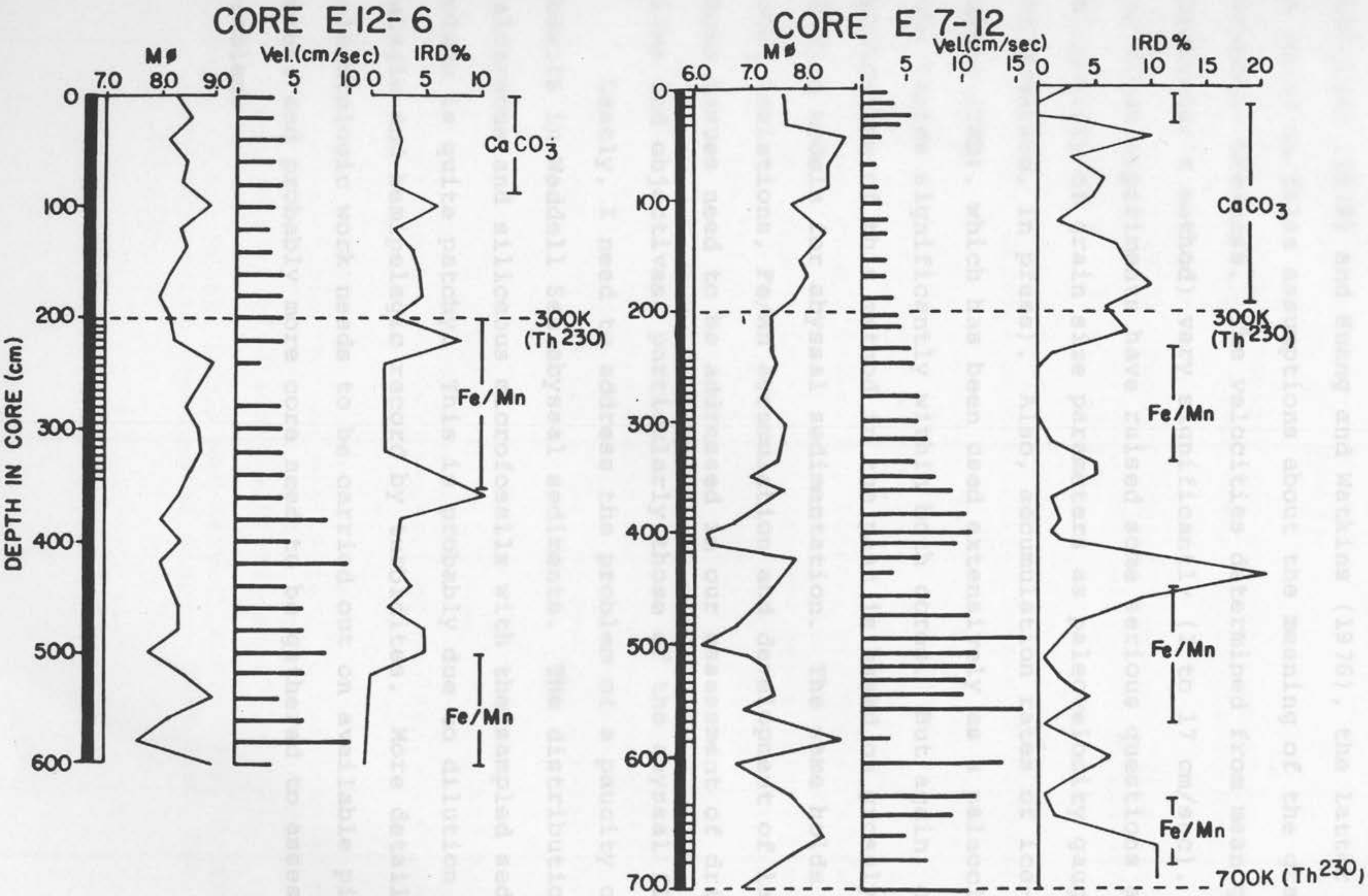



Figure 42. Example of variations in grain size, calcium carbonate content, and Fe/Mn micronodule content in Weddell Sea abyssal cores.

Our method for determining bottom water velocity from grain size data (Singer and Anderson, in press) differs from that of Ledbetter (1979) and Huang and Watkins (1976), the latter procedure is based on false assumptions about the meaning of the grain size parameter skewness. The velocities determined from mean grain size (Ledbetter's method) vary significantly (2 to 17 cm/sec). However, our flume experiments have raised some serious questions about the reliability of grain size parameters as paleovelocity gauges (Singer and Anderson, in press). Also, accumulation rates of ice-rafted debris (IRD), which has been used extensively as a paleoclimatic tool varies significantly within both cores. But again, our application of this method in the past is based on grossly oversimplified models for abyssal sedimentation. The same holds true for $CaCO_3$ variations, Fe/Mn accumulation and development of laminations. These issues need to be addressed in our assessment of drilling sites and objectives, particularly those of the abyssal floor.

Lastly, I need to address the problem of a paucity of microfossils in Weddell Sea abyssal sediments. The distribution of both calcareous and siliceous microfossils with the sampled sedimentary column is quite patchy. This is probably due to dilution of the pelagic and hemipelagic record by turbidites. More detailed micropaleontologic work needs to be carried out on available piston cores, and probably more core need to be gathered to assess this problem.

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PROPOSED DRILLING SITES

Location: Bransfield Basin

Objectives:
(1) To study the Quaternary glacial history of the Antarctic Peninsula
(2) To study the development of this basin
(3) To investigate geochemical process (short term diagenesis and petrogenesis)

Because of their relatively high latitude position, maritime setting, and relatively limited drainage basins, the valley glaciers of the Antarctic Peninsula have probably responded to climatic fluctuations which had little effect on the East and West Antarctic Ice Sheets. The manner in which marine sedimentation has responded to these changes has probably been far more dramatic than the responses of abyssal sediments, hence the sedimentary record should be more reliably interpreted. And lastly, sedimentation has apparently been quite rapid in the Bransfield Strait ($<1$, / $10^6$ yrs.$^{-1}$).

Land studies in the islands surrounding the Antarctic Peninsula have revealed a complicated glacial history for the region and require better chronostratigraphic control. A major objective in drilling the Bransfield Strait would be to acquire a high resolution record of the glacial history of the region, and thus the more subtle climatic history of the continent.

Because of its unique tectonic setting, the Bransfield Strait provides a unique setting in which to examine sedimentation within a rapidly evolving basin, and to confirm existing tectonic models. Preliminary studies (Rob Dunbar) have shown that the flux of organic carbon and silica to the basin is quite high. This coupled with the high heat flow in the sediments provides a unique setting in which to study early diagenesis of siliceous sediments and petrogenesis.

Location: Western Flank of the South Orkney Plateau (4 sites)

Objective: (1) To recover as complete a Neogene record as possible from nearly exposed sequences on the western flank of the Plateau. Problems of particular interest are the Neogene climatic record, and the origin of the South Orkney Plateau.

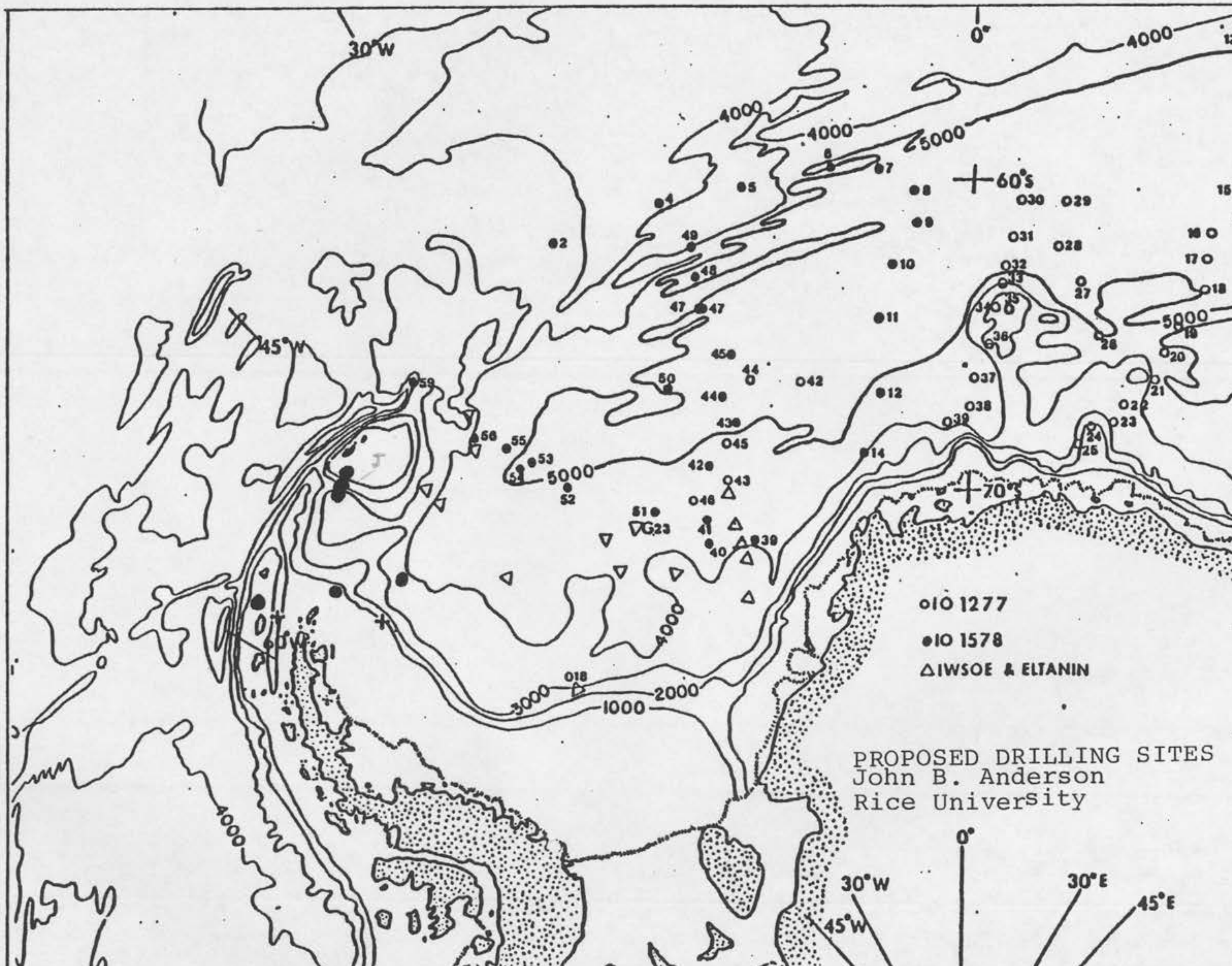
Location: Northwestern Weddell Sea Continental Shelf (possibly several short holes)

Objective: (1) To examine the Quaternary glacial history of the region and relate it to the results of land studies in the region. Test Birkenmajer's 1982 models, which are similar to Denton et al., 1982, for glacial grounding events in the region. This would be accomplished by drilling through basal tills, and associated unconformities and conducting mineralogic provinance analyses of these tills, and associated glacial marine sediments.

(2) To core outcrops in the area in an attempt to obtain a Neogene sequence.

Location: Northwestern Weddell Sea Continental Rise

Objective: To examine the deep-sea paleo-oceanographic record, specifically that of AABW production history (See text for discussion of problems with such studies).




PROPOSED DRILLING SITES
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