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Marine geology and geophysics of the western South Orkney Plateau, Antarctica: Implications for Quaternary glacial history, tectonics, and paleoceanography

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MARINE GEOLOGY AND GEOPHYSICS OF THE WESTERN SOUTH ORKNEY PLATEAU, ANTARCTICA: IMPLICATIONS FOR QUATERNARY GLACIAL HISTORY, TECTONICS, AND PALEOCEANOGRAPHY

by

MARGARET JANE HERRON

A THESIS SUBMITTED
IN PARTIAL FULFILLMENT OF THE
REQUIREMENTS FOR THE DEGREE

MASTER OF ARTS

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SEPTEMBER, 1987

ABSTRACT

MARINE GEOLOGY AND GEOPHYSICS OF THE WESTERN SOUTH ORKNEY PLATEAU, ANTARCTICA: IMPLICATIONS FOR QUATERNARY GLACIAL HISTORY, TECTONICS, AND PALEOCEANOGRAPHY

Margaret J. Herron

Piston cores and single-channel seismic profiles were collected from the western South Orkney Plateau to investigate glacial history, survey the seismic stratigraphy, and test the feasibility of paleoceanographic interpretation as a site survey for O.D.P. Leg 113 drilling operations. Data reveal evidence for past grounded ice to 240 meters depth, and expanded floating ice cover over the entire plateau. Paleoceanographic interpretation is difficult because nearly 75% of slope cores are affected by sediment gravity flow. All dip-oriented seismic lines show large-scale slumping.

Surface sample textural data indicate that wind-driven currents are redistributing sediments in a predictable pattern to about 450 meters depth. Total grain size analyses are neccessary to differentiate ice-rafted-debris from other sands.

Seismic data support previous interpretations of a passive margin setting, and show up to three seismic sequences within sediment fill on the margin and plateau.

ACKNOWLEDGEMENTS

John Anderson provided the original ideas for this research, and has inspired and guided me throughout the course of the project. Comments and criticisms from the other members of my committee, particularly Rob Dunbar and Pete Vail, were valuable and much appreciated. H. C. Clark deserves special thanks for coming to my aid in a pinch.

The suggestions and cooperation from many of my friends and colleagues helped to make this research more productive as well as enjoyable. I particularly want to thank Doug Kennedy, Tom Griffith, Jill Singer, and "Laser" Liz Watkins. A special note of thanks goes to Marc Norman who unselfishly gave his time and expertise; and to Howard West who was my friend, basketball coach, and occasional spiritual advisor during the writing of this thesis.

I would also like to thank Peter Barker, who provided us with a bathymetric chart and seismic data to help plan the 1985 Deep Freeze cruise; and Davida Kellogg and David Harwood, who helped in dating the core samples.

A special word of appreciation is extended to Dennis Cassidy and his crew at the Florida State University Antarctic Core Facility, without whose generous assistance and attention to detail, working with the cores would be nearly impossible.

Finally, I want to thank my parents, whose support and encouragement has been unfailing and invaluable.

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CHAPTER 1. TECTONIC HISTORY AND SETTING

Introduction

The South Orkney Plateau is located at about 60° South latitude (figure 1), and is part of the South Scotia Ridge, a tectonically complex series of islands, submarine ridges and plateaus, which separates the Antarctic Plate from the smaller Scotia and Sandwich Plates (figure 2). The plateau is a microcontinental fragment which began separating from the northern Antarctic Peninsula along with the other North and South Scotia Ridge fragments during mid-Cenozoic (?) time (Barker and Dalziel, 1983; King, 1983; Thomson, et. al., 1983). The Powell Basin, which lies immediately west of the plateau, formed as a result of the separation of the peninsular fragments. Previous studies of the South Orkney Plateau/Powell Basin margin include a seismic refraction and sea floor magnetic study (Harrington, et. al., 1972), and a geophysical survey, including reflection seismic profiles of the entire plateau area (King, 1983). However, except for some dredging on margin highs (King, 1983) sediments of the South Orkney Plateau and its western margin had not been sampled until 1985, thus interpretations of the age or process of formation of the margin are mainly based on regional evidence from the Antarctic Peninsula and South America concerning the formation of the Scotia Ridge, and from the Scotia Sea.

Most existing passive margins are features left over from the breakup of Gondwanaland, which began in the late Triassic to early Jurassic (about 200 Ma ago) and in some parts of the world continues today. There is a broad range of ages of these passive margins (180 Ma to recent), but most are older than 65 Ma, since the major continental fragments were separated by that time. Other passive margins have been formed as basins are created by subsequent plate motions not related to the Gondwanaland breakup, such as the late Miocene opening of the Gulf of California (about 5 Ma ago). The western South Orkney Plateau margin is relatively young; it began to rift during the mid-Tertiary, about 35-40 Ma ago (Dalziel, 1983; King, 1983) and is not directly related to

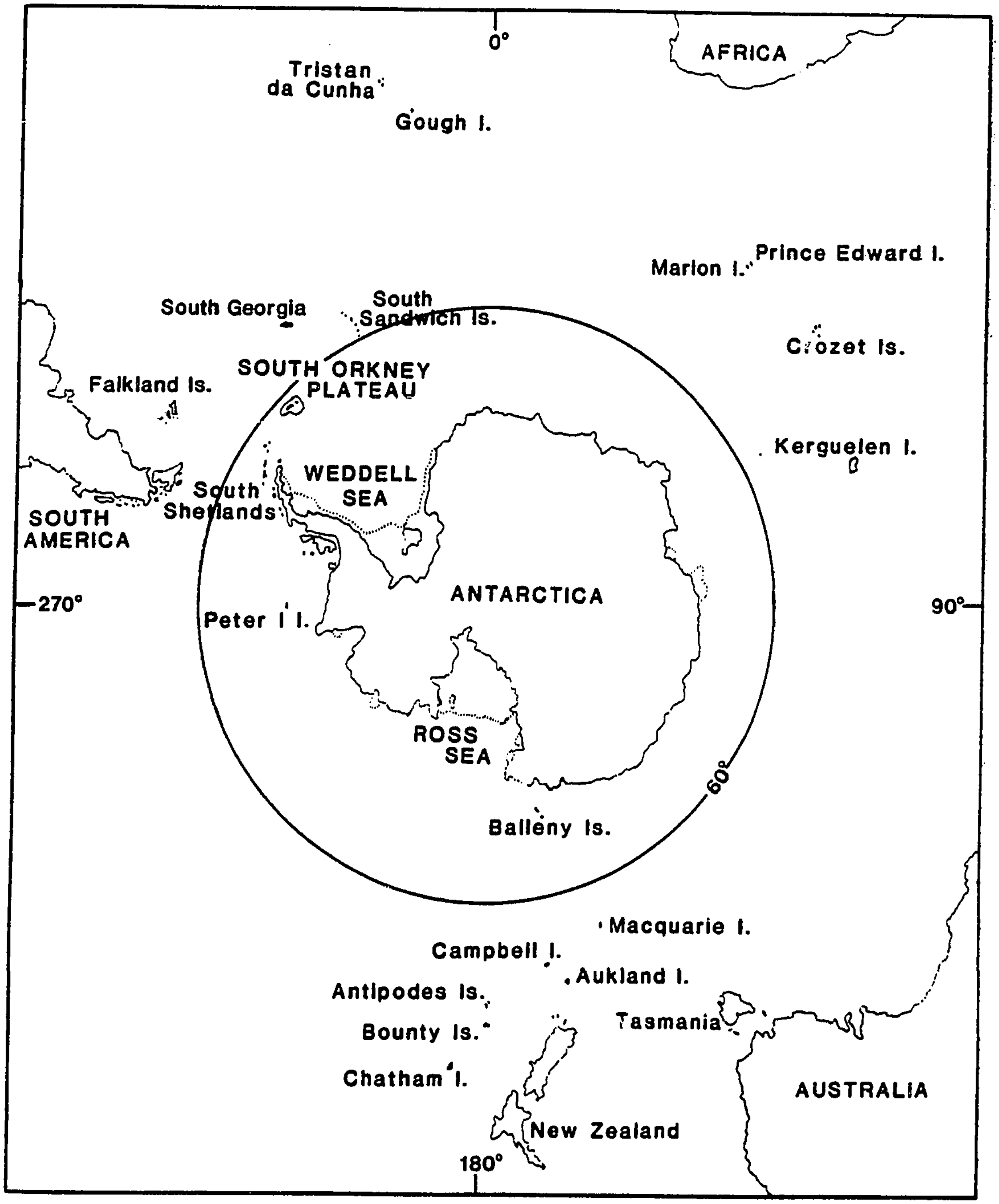
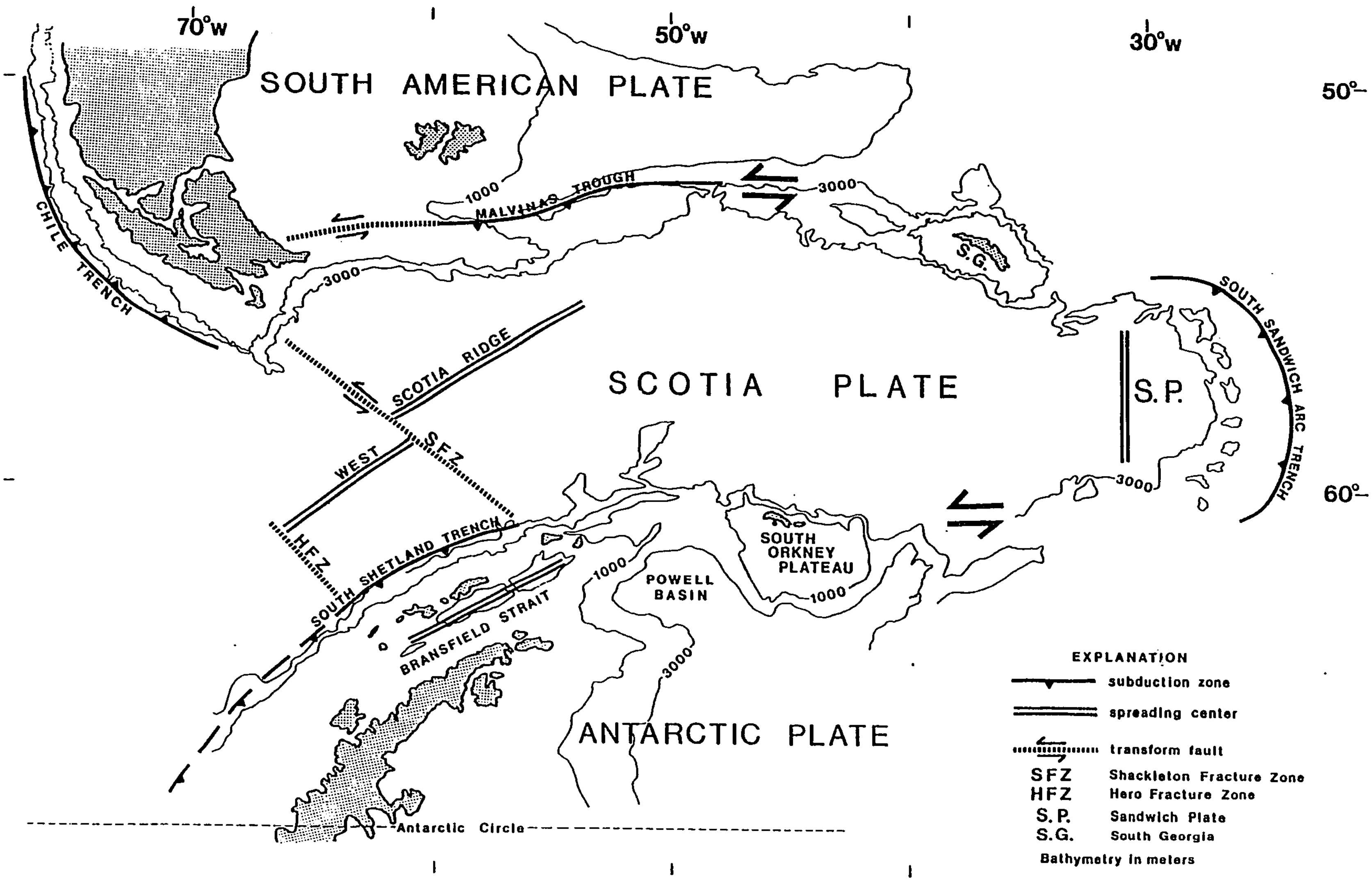


Figure 1. Regional location map showing the location of the South Orkney Plateau relative to the latitude of other Antarctic and sub-Antarctic islands, and relative to the Weddell Sea.

Figure 2. Tectonic setting of the Scotia Ridge region (after Dalziel, 1983), showing major active tectonic features. Dashed lines indicate inactive features. Bathymetric contours at 1000 and 3000 meters are included to delineate the submarine components of the ridge.


70°W
50°W
30°W
50°
60°
SOUTH AMERICAN PLATE
SCOTIA PLATE
ANTARCTIC PLATE
CHILE TRENCH
MALVINAS TROUGH
S.G.
S.P.
SOUTH SANDWICH ARC TRENCH
SCOTIA RIDGE
WEST
S.F.Z.
HFZ
SOUTH SHETLAND TRENCH
BRANSFIELD STRAIT
POWELL BASIN
SOUTH ORKNEY PLATEAU
1000
3000
Antarctic Circle
EXPLANATION
subduction zone
spreading center
transform fault
SFZ Shackleton Fracture Zone
HFZ Hero Fracture Zone
S.P. Sandwich Plate
S.G. South Georgia
Bathymetry in meters

the breakup of Gondwanaland. The margin has developed through the rifting stage and probably the early part of the drifting stage, yet tectonic and structural features of the passive margin can be easily seen on shallow penetration seismic data because sediment cover on the margin is thin. Thickness of the sediment cover ranges from near zero to a few hundred meters, due to (1) the relatively young age of the margin, (2) the presence of strong marine currents (indicated by lags observed in margin cores) which prevent deposition of a large component of the available sediment, and (3) limited sediment supply to the margin because of the absence, for probably at least the last 20 Ma, of a large positive land mass, and because of the polar climate in which stream erosion does not play a major role in sediment supply. Thus, low energy (high frequency) seismic waves are able to penetrate in some areas to "basement" (the base of the rifting sequence). Comparison of data from the Gulf of Aden and the Gulf of California, two other young passive margin settings, with data from the western South Orkney Plateau margin provides a reference for discussion of the origin of the Powell Basin and the relative stage of development of the passive western margin.

Pre-Middle Jurassic rocks of the Scotia Ridge region consist of a metamorphic complex of greenschist-blueschist to amphibolite facies and a lower grade (Zeolite to Prehnite-pumpellyite facies) metamorphosed sedimentary rock group (the Trinity Peninsula Group and its supposed equivalents which include the Greywacke-Shale Formation in the South Orkneys). These rocks, usually refered to as "basement", were formed by subduction-accretion in a forearc basin setting which was located on the Pacific margin of Gondwanaland before breakup of the supercontinent in the Late Triassic-Early Jurassic (figure 3). Exact location and orientation of the parts of the Antarctic Peninsula and southern Scotia Ridge in pre-Jurasic time is still unclear (Dalziel, 1984), however facies interpretation, tectonic fabric, and structural style of rocks in the peninsula and Scotia Ridge areas suggest the interpretation shown in figure 4 from Dalziel (1984). The

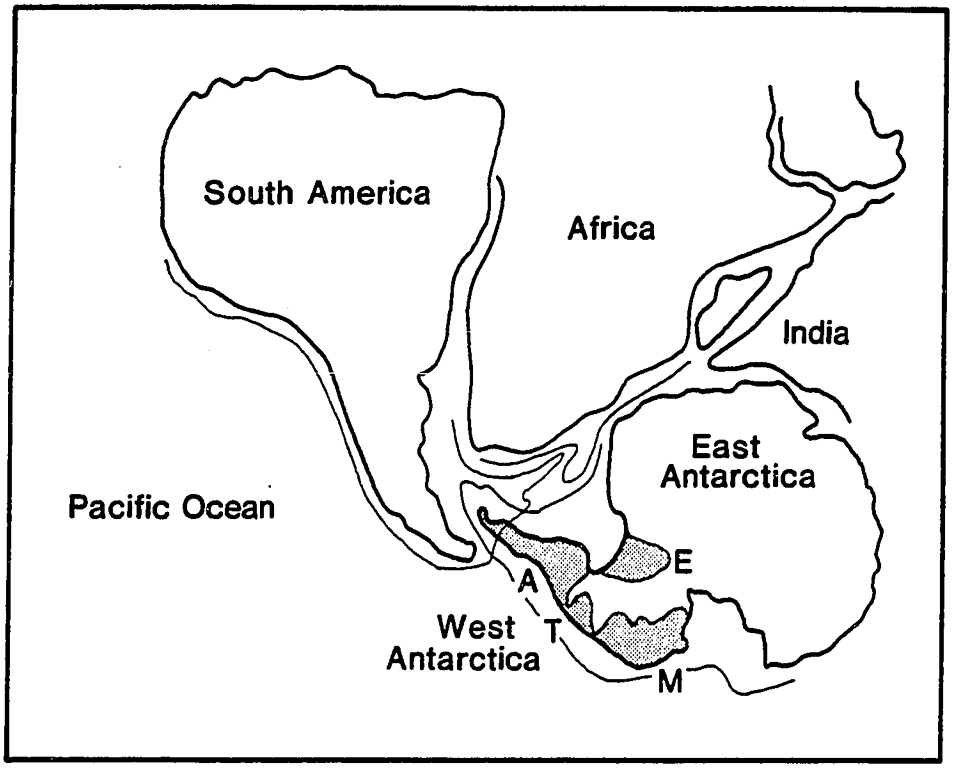


Figure 3. Reconstruction of Gondwanaland [Norton and Sclater, 1979] and main crustal blocks of West Antarctica [after Dalziel and Elliot, 1982]. A - Antarctic Peninsula; E - Ellsworth Mountains; M - Marie Byrd Land; T - Thurston Island-Eights Coast (from Dalziel, 1984). The location and orientation of the Antarctic Peninsula and Scotia Ridge crustal segments in the reconstruction is not clear and thus is purposely left as an overlap.

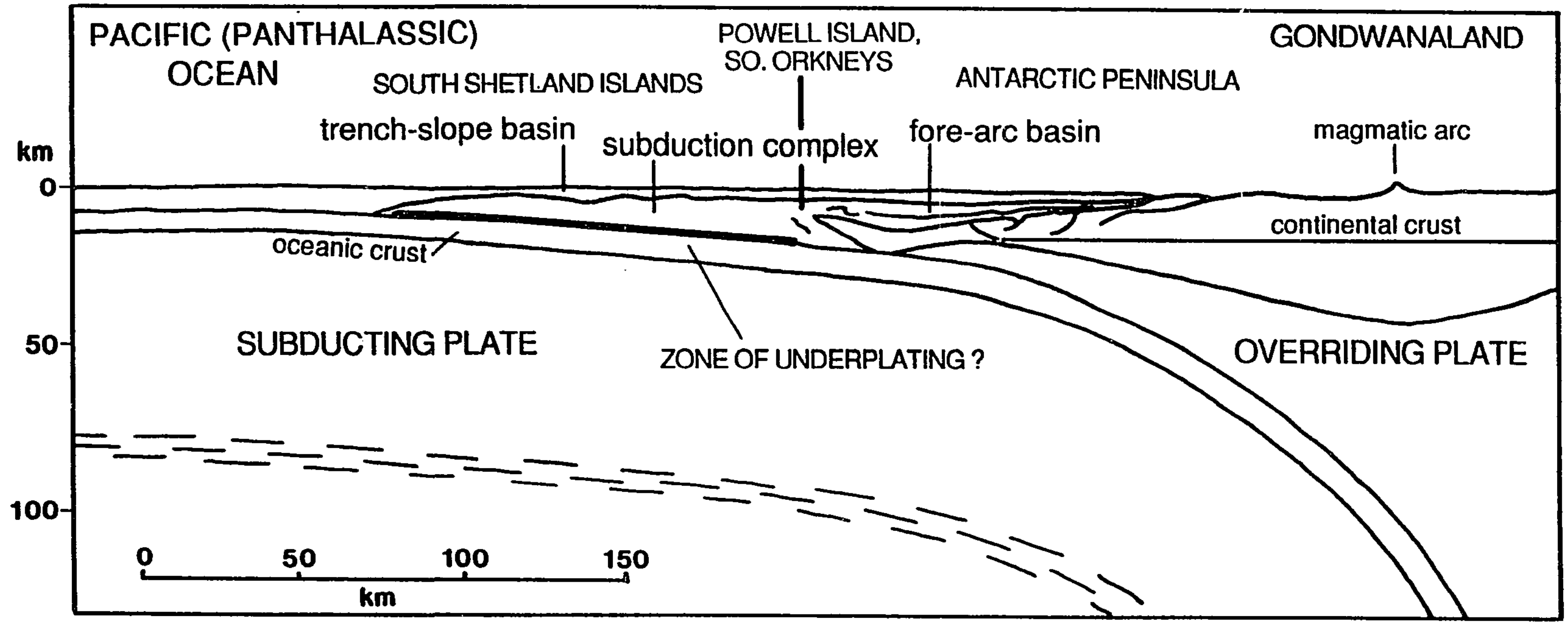


Figure 4. Interpretive cross section through the Antarctic Peninsula region prior to Gonwanaland break up [based on a forearc model by Hamilton, 1979] (from Dalziel, 1984). Approximate locations of the South Shetland Islands, the South Orkneys (Powell Island), and the Antarctic Peninsula are shown relative to the components of the fore-arc setting. Possible underplating is suggested as the mechanism which created the polyphase tectonite fabrics and high pressure metamorphic assemblages in parts of the the southern Scotia Ridge (Dalziel, 1984).

structural styles of the metamorphic complex and sedimentary sequences (described in detail by Dalziel, 1984) are characteristic of the products of subduction accretion and forearc sedimentation respectively. The metamorphic complex contains many elements of oceanic affinities and was partly formed in a fairly high P/T environment, representing the products of discontinuous subduction accretion in two or more distinct phases. The initial breakup of Gondwanaland is recorded in the Scotia Ridge region as Middle to Upper Jurassic age volcanic and sedimentary sequences unconformably overlying the Paleozoic and Lower Mesozoic "basement". Extensive calc-alkaline igneous and volcaniclastic rocks of Late Jurassic to Cretaceous age in the Scotia Ridge region imply that subduction-related igneous activity continued thoughout the fragmentation of Gondwanaland (Dalziel, 1983). Late Mesozoic and Cenozoic low-temperature metamorphic rocks present in the Scotia Ridge region represent another, later episode of uplift perhaps related to fracture zone tectonics along the Shackleton and Hero Fracture Zones. Structures in both the early Mesozoic and late Mesozoic-Cenzoic metamorphic terranes suggest underplating or subcretion to a forearc wedge as the mechanism of deformation and associated metamorphism (Dalziel, 1984).

Several lines of evidence support the theory that the Scotia Ridge was formed during the late Cenozoic from remnants of the formerly continous Antarctic-Andean Cordillera. Lower Cretaceous rocks from South Georgia are very similar lithologically and structurally to rocks on the Pacific side of Tierra del Fuego. Also, the Late Cretaceous-Eocene Andean orogeny appears to be recorded in South Georgia as well as in southern South America. Thus, separation of the parts of the Scotia Arc occurred after the early Late Cretaceous (Dott, 1976). Regionally, stratigraphic continuity and evidence for continuing subduction on the Pacific side of the Cordillera implies a more or less intact Antarctic-Andean Cordillera until at least mid-Cenozoic time. Stratigraphic evidence, in the form of new sedimentation patterns and scattered late Cenozoic basaltic volcanism in Patagonia and the

Antarctic Peninsula, indicates a mid-Cenozoic tectonic discontinuity (Dott, et. al., 1982; Dott, 1976). Average Cenozoic sea floor spreading rates for the southern Pacific and Atlantic basins are 5 - 10 cm/yr (Herron, 1974). Given these rates, 20 - 40 Ma are required to move South Georgia from its original position adjacent to Tierra del Fuego to its present position, therefore separation occurred at least 20 Ma ago (Dott, 1976). In addition, magnetic anomalies in the western and central Scotia Sea are less than 30 Ma old and indicate the opening of the Drake passage between 29 and 23.5 Ma (Barker, 1972b; Barker and Burrell, 1977). Deep sea drilling data also suggest inception of Antarctic Circumpolar Current flow in Oligocene or Miocene time (Craddock and Hollister, 1976).

Spreading on the eastern arm of a former triple junction just west of the present Scotia Sea probably caused the initial segmentation of the cordillera (Dott, 1976; Herron, 1974). Subsequent motion on transform faults related to the spreading arm resulted in eastward displacement of segments of the North and South Scotia Ridge and the formation of the Powell Basin.

Present Tectonic Setting

Three principal active spreading centers influence the tectonics of the Scotia Ridge area today (figure 2). Rapid back-arc spreading west of the South Sandwich Island Arc causes subduction of the South American Plate beneath the Scotia Sea and defines the small Sandwich Plate. The West Scotia Ridge, which created much of the Scotia Plate, lies along a northeast trend within Drake Passage, offset by the Shackleton and Hero Fracture Zones, and continues to be a very slow active spreading center (Dalziel, 1983). The Bransfield Strait spreading center is much younger than the other two (1-2 Ma old), but is spreading rapidly to create a back-arc basin immediately west of, and extending into the area of the South Scotia Ridge.

Major transform faults form the North and South Scotia Ridges. Motion between the South American and Antarctic Plates is divided between the two ridges (Forsyth, 1975) but probably not evenly (Dalziel, 1983). Small amounts of seismicity in the area show that the faults continue to be active today (Forsyth, 1975). Various fracture zones, all trending west/northwest (including the Shackleton and Hero Fracture Zones) cut the western part of Drake Passage.

Four subduction zones exist within the Scotia Ridge area, (1) the Chile Trench, on the west side of southern South America, (2) the South Shetland Trench, (3) the South Sandwich Arc Trench, and (4) the Malvinas Trough, along the north side of the North Scotia Ridge (Dalziel, 1983).

Geology of the South Orkney Islands and South Scotia Ridge

The islands of the Scotia Ridge are all of continental origin except for the South Sandwich Islands, which comprise an active intraoceanic island arc - a relatively new feature of the Scotia Ridge. Magnetic anomaly data indicate that the present South Sandwich Islands sit on oceanic crust formed within the last 8 Ma (Barker, 1972a). The rest of the Scotia Ridge islands have been on continental crust since at least Triassic time (Dalziel, 1982; 1983) when they were being formed as part of the pre-Mid Jurassic forearc (South Orkney Islands) and back arc (South Georgia) basins on the Pacific margin of Gondwanaland (Dalziel, 1984; Dott, et. al., 1982).

The "basement" rocks on the South Orkney Islands consist of two main groups (1) highly deformed greenschist to amphibolite facies rocks of the Scotia metamorphic complex, and (2) the Greywacke-Shale Formation, deformed sequences of sandstone and turbidite facies (shales) metamorphosed to the prehnite-pumpellyite facies. Age of these rocks is not precisely known. A regional unconformity separates them from overlying Middle Jurassic to lower Cretaceous and younger strata, providing an upper boundary on their age. The best paleontologic evidence for the age of the Greywacke-Shale Formation is the discovery of a late Triassic (Carnian to Norian) radiolarian fauna from Scapa Rock (figure 5), a small island consisting entirely of chert (Dalziel, et. al., 1981). No direct evidence exists for field relations between the chert and rocks of the other islands, however, from the location of Scapa Rock amidst islands formed exclusively of the Greywacke-Shale Formation, and bedding surfaces in the chert parallel to those in the greywacke and shale, Dalziel, et. al. (1981) infer a correlation and a probable genetic relationship, either sedimentary or tectonic, between the chert and the Greywacke-Shale Formation. The metamorphic complex of the South Orkney Islands is lithologically and structurally similar to some of the metamorphic rocks of Elephant and Clarence Islands (Thomson, 1974). Regionally, the metamorphic complex of the southern Scotia Ridge consists of two contrasting terranes: (1) a lower temperature assemblage, blueschist and greenschist facies, on Smith, northern Elephant, and Clarence Islands, and (2) a higher temperature assemblage, albite-epidote-amphibolite and amphibolite facies, on southern Elephant, Aspland, Eadie, and O'Brien Islands in the South Shetlands and on Coronation, Signy, and Powell Islands in the South Orkneys.

A basic geologic map of the South Orkney Islands is shown in figure 6 (after Dalziel, et. al., 1981). The western islands, Coronation, Signy, Moe, and Inaccessible Islands are primarily composed of terrane 2 of the Scotia metamorphic complex; the Spence Harbour Conglomerate also crops out on easternmost Coronation Island (Matthews and Mailing, 1967; Thomson, 1968;1974). Laurie Island and Saddle and Weddell Islands in the east, consist entirely of rocks of the Greywacke-Shale Formation (Thomson, 1973; Dalziel, et. al., 1981). Powell and Fredricksen, and the smaller islands that lie between Laurie and Coronation Islands, have outcrops of the metamorphic complex and of the Greywacke-Shale Formation, as well as a conglomerate unit containing late Jurassic-early Cretaceous fauna and flora, probably correlative with the Spence Harbour Conglomerate (Dalziel, et. al., 1981). On Powell Island the Greywacke-Shale Formation structurally

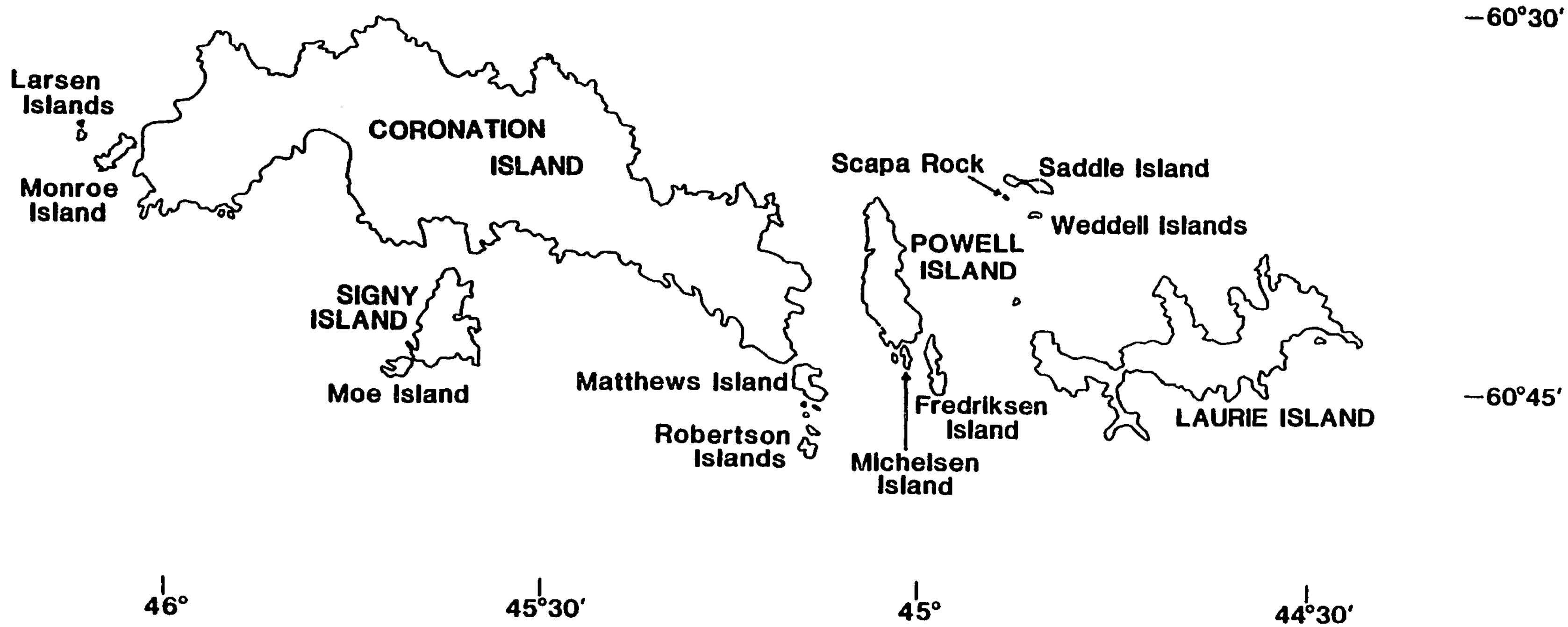


Figure 5. Map showing locations of all larger islands and rocks in the South Orkney Island Group. The Inaccessible Islands lie about 20 miles west of the western end of Coronation Island at approximately 46°40' West.

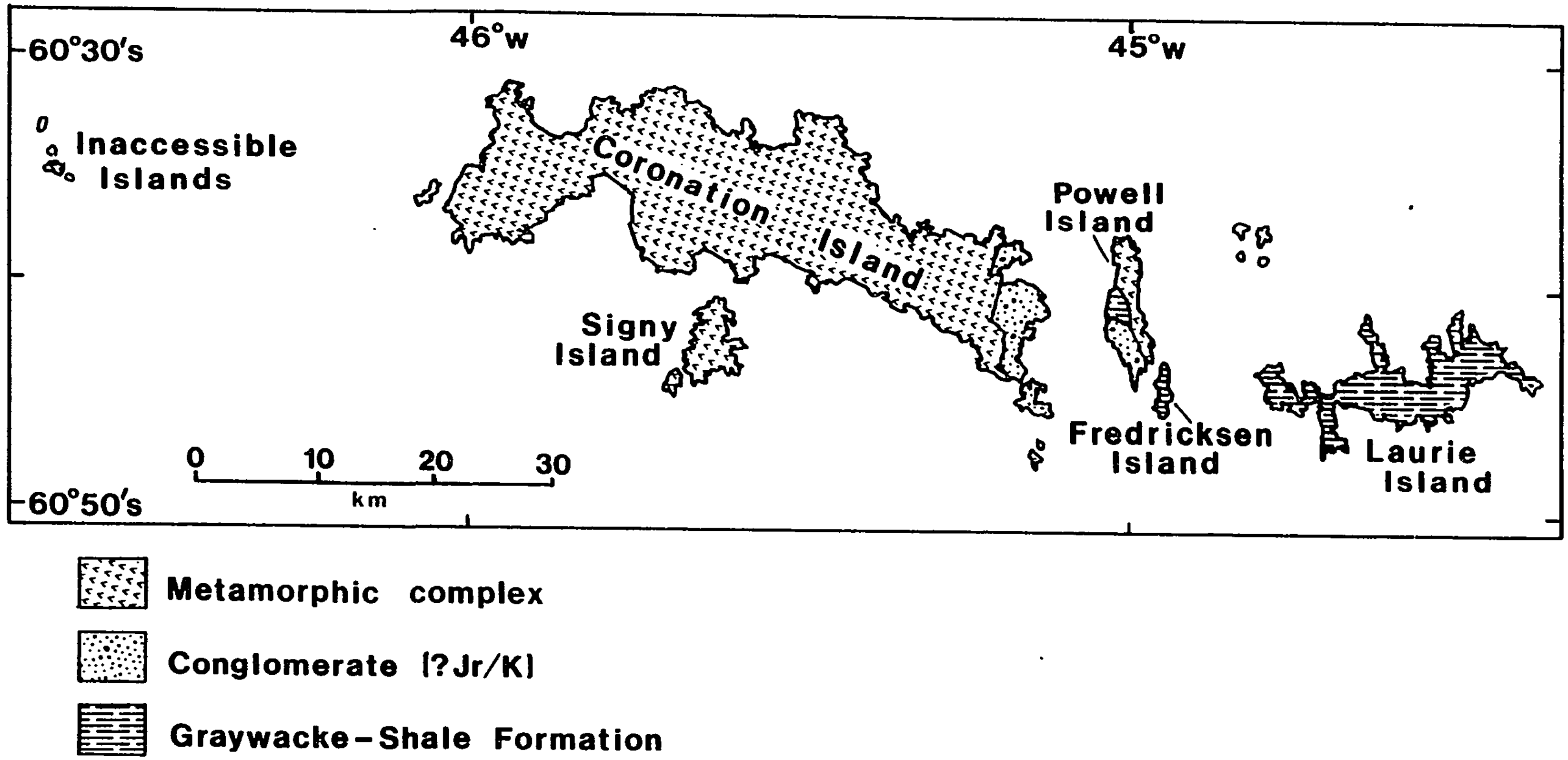


Figure 6. Geologic map of the South Orkney Islands showing the three major rock types found on the islands (after Dalziel, 1982). The Inaccessible Islands consist of metamorphic complex rocks.

overlies the metamorphic complex on a tectonic contact (Dalziel, 1984), no other contacts between the metamorphic and the sedimentary sequences of the Scotia Ridge "basement" rocks have been found, thus the relationship between the two major divisions of the "basement" is unknown. The conglomerate unit unconformably overlies the metamorphic rocks of Coronation Island, and on Powell Island is in fault contact with the Greywacke-Shale Formation and contains clasts of the greywacke and shale.

Petrology of the South Orkney Islands

On Coronation Island, the metamorphic rocks are primarily quartzo-feldspathic schists which have been subdivided into three main types (Thomson, 1974): (1) thinly laminated quartz-albite-biotite-muscovite-schists, the most common type on Coronation Island, (2) porphyroblastic albite-quartz-biotite-schists, common only at Olivine Point on the southern coast of Coronation Island, rare elsewhere, and (3) flaggy quartz-albite-biotite-muscovite-chlorite-schists, typical on the eastern end of the island. Other rock types found on Coronation Island are semi-micaceous schists, mica schists, phyllites and phyllonites, greenschists, hornblende schists, and marbles. Altered dolerite dykes intrude both the metamorphic and sedimentary sequences in a few locations on the southern coast of Coronation Island, and at least one cuts the early Cretaceous Spence Harbour Conglomerate on Matthews Island (Thomson, 1974). Predominant rock types found on Signy Island are garnetiferous quartz-mica-schists and maca-garnet-schists intercalated with para-amphibolites (mostly hornblende-schists). The greater abundance of marbles and amphibolites distinguishes the metamorphic complex of Signy Island from that of Coronation Island, and implies that the original sedimentary rocks were deposited in different enviroments on the two islands (Thomson, 1968).

The Greywacke-Shale Formation crops out primarily on Laurie Island and the smaller islands between Laurie and Powell Island; scattered outcrops occur on Powell

Island. In outcrop, the sedimentary sequences are rhythmically bedded medium- and fine-grained sandstones, siltstones, mudstones, and shales all affected by dynamic metamorphism (Thomson, 1973). The sandstones were referred to as greywackes by earlier authors (Pirie, 1905; Matthews, 1959) due to their high matrix content (60-75%). However, most actually plot as arkoses or sub-arkoses using Folk's (1954) classification; few plot as true greywackes (Thomson, 1973).

The conglomerates on Coronation, Robertson, Powell, Chistoffersen, and Michelsen Islands are petrologically similar, and probably time equivalent, although they are not correlatable in the field due to discontinous outcrops and paucity of fossils. The conglomerates are typically of pebble or cobble grade with clasts ranging in size from granules to over 17 cm embedded in a grey, muddy sandstone matrix. The most commonly occurring clast lithologies are orange-brown or buff sandstone, grey sandstone, and vein quartz.

Approximate relative percentages of the major rock types found on the islands were calculated from Marr's (1935) estimates of the areas of the islands and the island group as a whole (table 1) and from Dalziel's (1982) map of the general geology of the islands (figure 6). Metamorphic complex rocks (schists and amphibolites) make up about 70% of the outcrop on the islands, the Greywacke-Shale Formation makes up approximately 22% and the Jurassic-Cretaceous conglomerates comprise the rest (about 8%). These percentages are relavent to the investigation of the source of sediments deposited on the plateau.

Structure of South Orkney Island rocks

The metamorphic complex on the South Orkney Islands has undergone complex polyphase ductile deformation. Except for Fredricksen Island, where an oceanic mélange containing exotic pillow lava and chert exists, no brittle or "mélange-type" deformation

TABLE 1. PERCENT ROCK TYPE ON SOUTH ORKNEY ISLANDS

Surface Area Of Islands

Island	Area *
Coronation	130 mi^2
Laurie	25 mi^2
South Orkney's (total)	175 mi^2

*estimated by Marr (1935).

Calculations

Metamorphic complex = approx. 90% of Coronation Island (117 mi^2) + Signy Island and northern Powell Island (approx. 10 mi^2) = 127 mi^2

Of remaining island area (not covered by metamorphic rocks) about half is Graywacke-Shale Fm. and half is Jr-K Conglomerates.

Graywacke-Shale Fm. = Laurie Island (25 mi^2) + (approx. 12 mi^2) = 37 mi^2

Jr-K Conglomerates = 11 mi^2

Percent Area Covered By Each Rock Type

Rock Type	Area**
Metamorphic complex	127 mi^2 = 73%
Graywacke-Shale Fm.	37 mi^2 = 21%
Jr-K sedimentary rocks (cgl)	11 mi^2 = 6%

**estimates based on areas covered by each rock type as shown on map by Dalziel (1982).

occurs anywhere in the South Orkney Islands and is rare elsewhere in the Scotia Ridge. Deformation in the sandstone and shale sequences (Greywacke-Shale Formation) is much milder, with generally simple folding, weakly developed cleavage, and ubiquitous preservation of bedding and primary structures. Regionally, the structural geometry of the Greywacke-Shale Formation is far too heterogeneous to relate directly to the Trinity Peninsula Group or its other supposed equivalents in the Antarctic Peninsula region. Structural features or fabric on the South Orkney Islands cannot be used to reconstruct the configuration of the Gondwanaland continental margin because the geometry of sea-floor spreading in the opening Powell Basin is not understood, and rotation of the South Orkney Block during Powell Basin formation is possible (Dalziel, 1984).

Origin and Characterization of the Powell Basin

The Powell Basin is generally characterized as a pull-apart basin; little else about the basin has been published. The geometry of the tectonic features implies a pull-apart origin, with the driving mechanism being the large transform fault system along the South Scotia Ridge (figure 2). However, there is some evidence for rotation of the block away from its original position (Dalziel, 1984), which suggests a more complex history of basin formation. Similarities between metamorphic facies and structural trends on the South Orkney and South Shetland Islands, and bathymetry (i.e. the 1000 m contour fit between the plateau and the Peninsula) suggest the reconstruction (figure 7) by Dalziel (1984), and imply that the South Orkney Plateau rotated in a clockwise sense away from the Antarctic Peninsula. King (1983) suggests an alternative reconstruction in which the South Orkney Block is translated along a 256° azimuth. This movement follows the trend of lineations seen on Seasat data from the Powell Basin and aligns the observed magnetic anomalies in the South Orkney Block and the Antarctic Peninsula. In order to reconstruct the

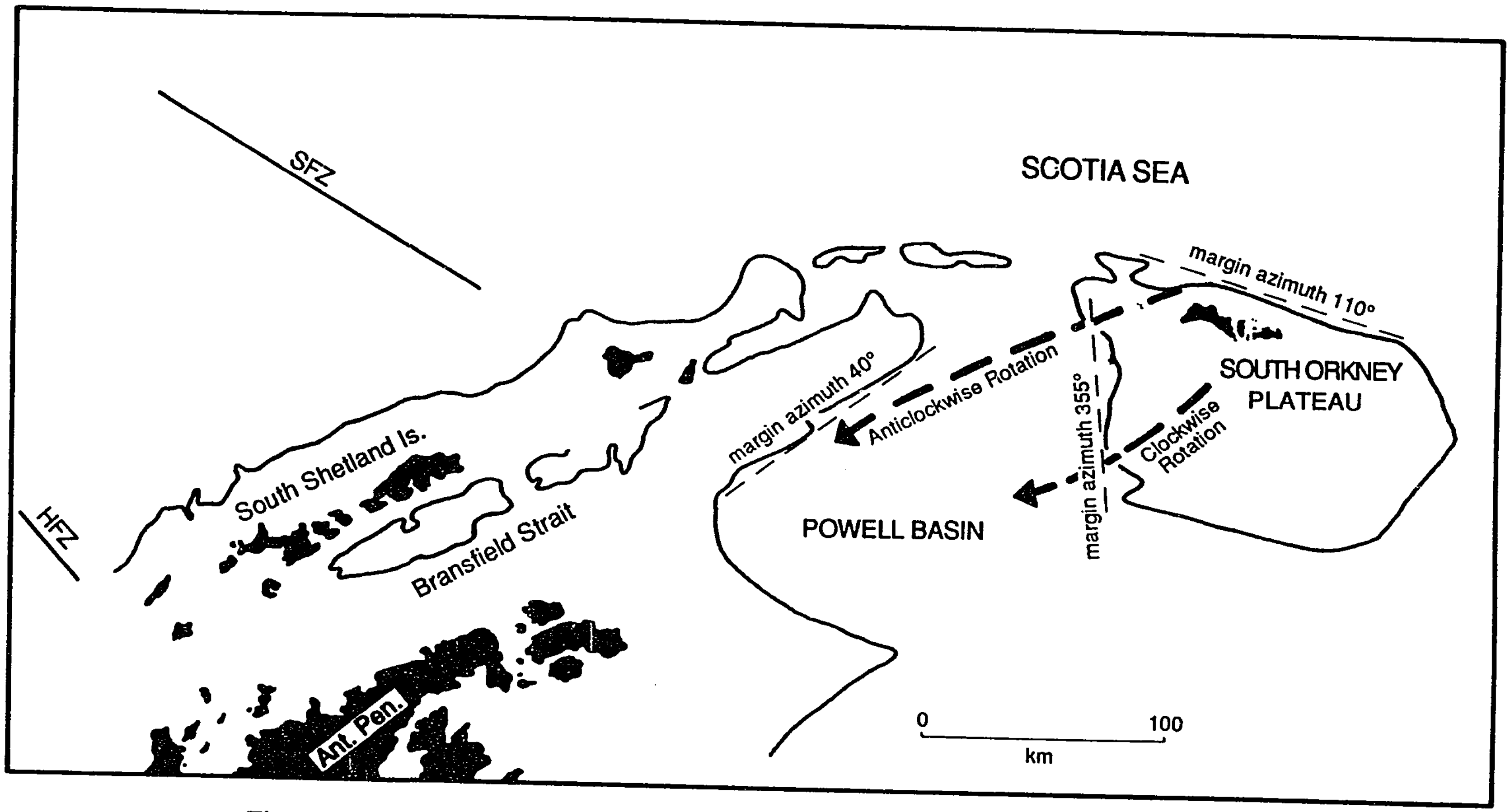


Figure 7. Suggested original (pre-Cenozoic ?) relationship of the South Orkney Islands platform and northern Antarctic Peninsula. Reconstruction is based on fit of the 1370 meter bathymetric contour, and on structural trends on the South Orkney Islands and Elephant, Clarence, and Gibbs Islands (from Dalziel, 1984). Two possible rotations which would place the South Orkney Block in suggested original positions are shown. The anticlockwise rotation is preferred.

continental fragments in this manner without substantial overlap, approximately 300 km of strike-slip movement of the South Scotia Ridge components west of the South Orkney Block is required, as well as some changes in the shape of the ridge (figure 8 a and b). Evidence which supports King's reconstruction includes the steep, linear southern margin of the South Scotia Ridge, which is characteristic of strike-slip faulting, numerous faults described in the area (Watters, 1972), and alignment of structural features on Elephant Island and Smith Island (King, 1983). Structures on Coronation Island, however, do not align in this reconstruction. There is very little data of any kind from the deep parts of the Powell Basin, thus evidence for or against the presence of a spreading ridge is sparse; oceanic crust is not known to be present anywhere in the basin. Ocean floor spreading in the Powell Basin is interpreted by King (1983) from seismic data which shows an unconformity overlain by depositional strata implying an episode of uplift and rapid transition to subsidence.

Magnetic and Gravity Surveys

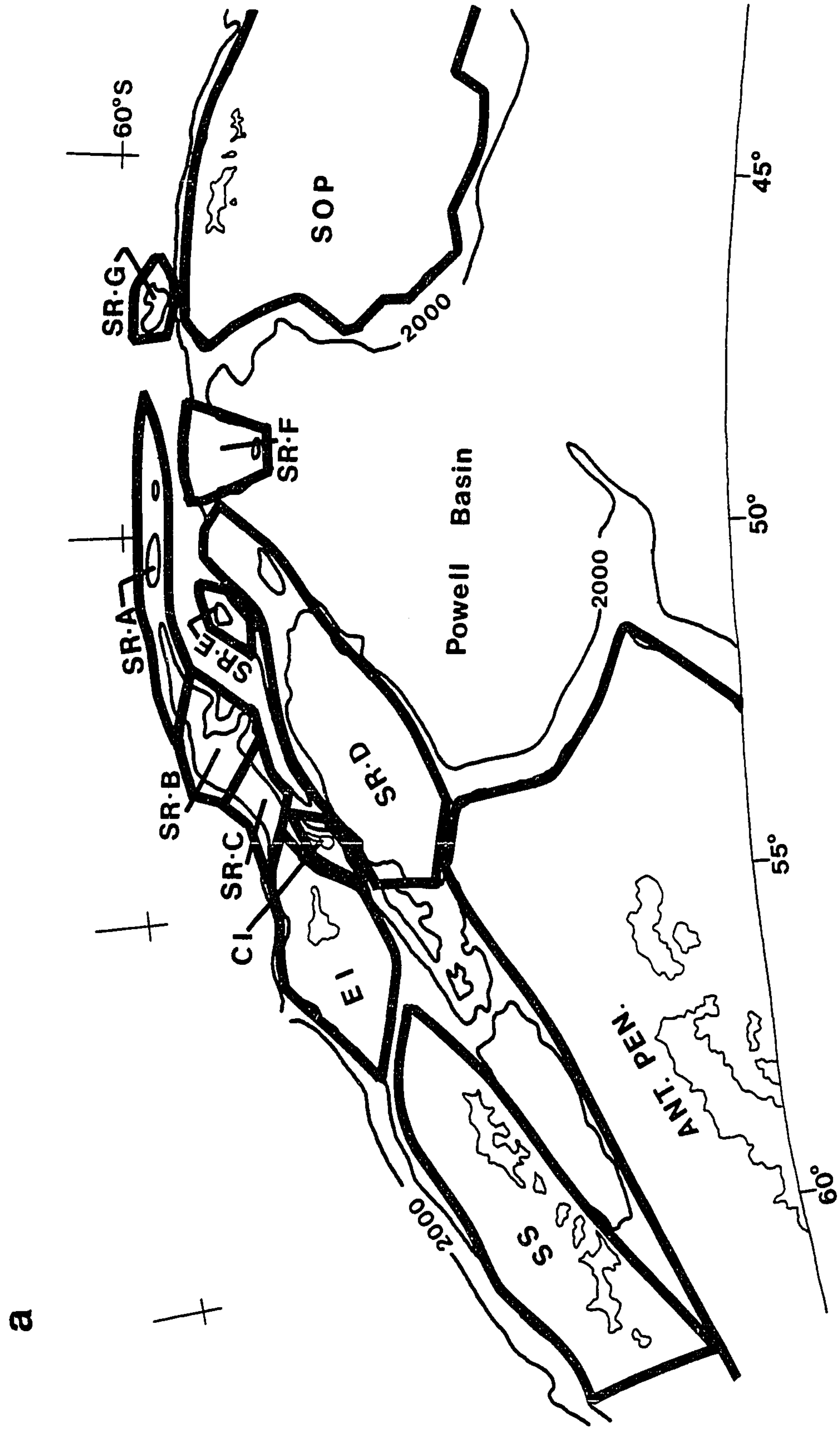
Magnetic anomaly data on the western margin of the plateau indicate an intrusive episode (figure 9). The magnetic high and increase in high frequency anomalies in this area could be related to anomalies associated with Tertiary dykes on Coronation Island and /or high frequency anomalies south of the Inaccessible Islands (King, 1983). Magnetic profiles extending into the Powell Basin show little variation from the base line value; no oceanic type anomalies appear in the basin. Trends of linear anomalies in the northern Antarctic Peninsula and the South Orkney Block appear to be truncated at the margins of the Powell Basin, implying break up of formerly continuous continental fragments.

Gravity anomaly data also show a western margin high coinciding with the magnetic high. A gravity high of approximately 50 mgal (King, 1983) on the edge of the plateau shelf corresponds to a bathymetric and structural high interpreted as a buried volcano

Figure 8. Present day locations and 30 Ma reconstruction of the elements of the South Scotia Ridge and the Antarctic Peninsula (after King, 1983). The South Orkney Plateau is translated along a 256° azimuth, parallel to lineations seen on Seasat data from the Powell Basin. Evidence for strike-slip faulting provides the basis for division of the South Scotia Ridge. SOP - South Orkney Plateau; EI - Elephant Island block; CI - Clarence Island block; SR-A through G - elements of the South Scotia Ridge; Ant. Pen. - Antarctic Peninsula block (considered fixed in the reconstruction).

a. Present day locations.

b. 30 Ma reconstruction.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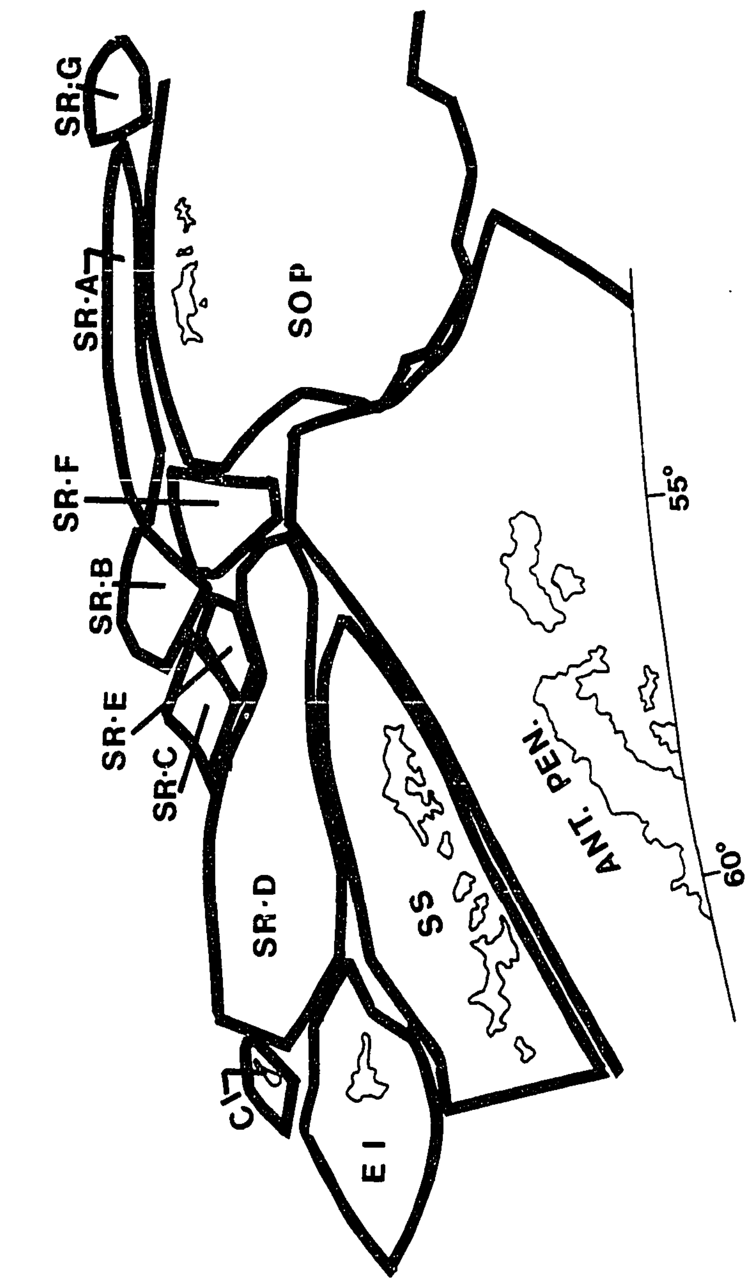


b

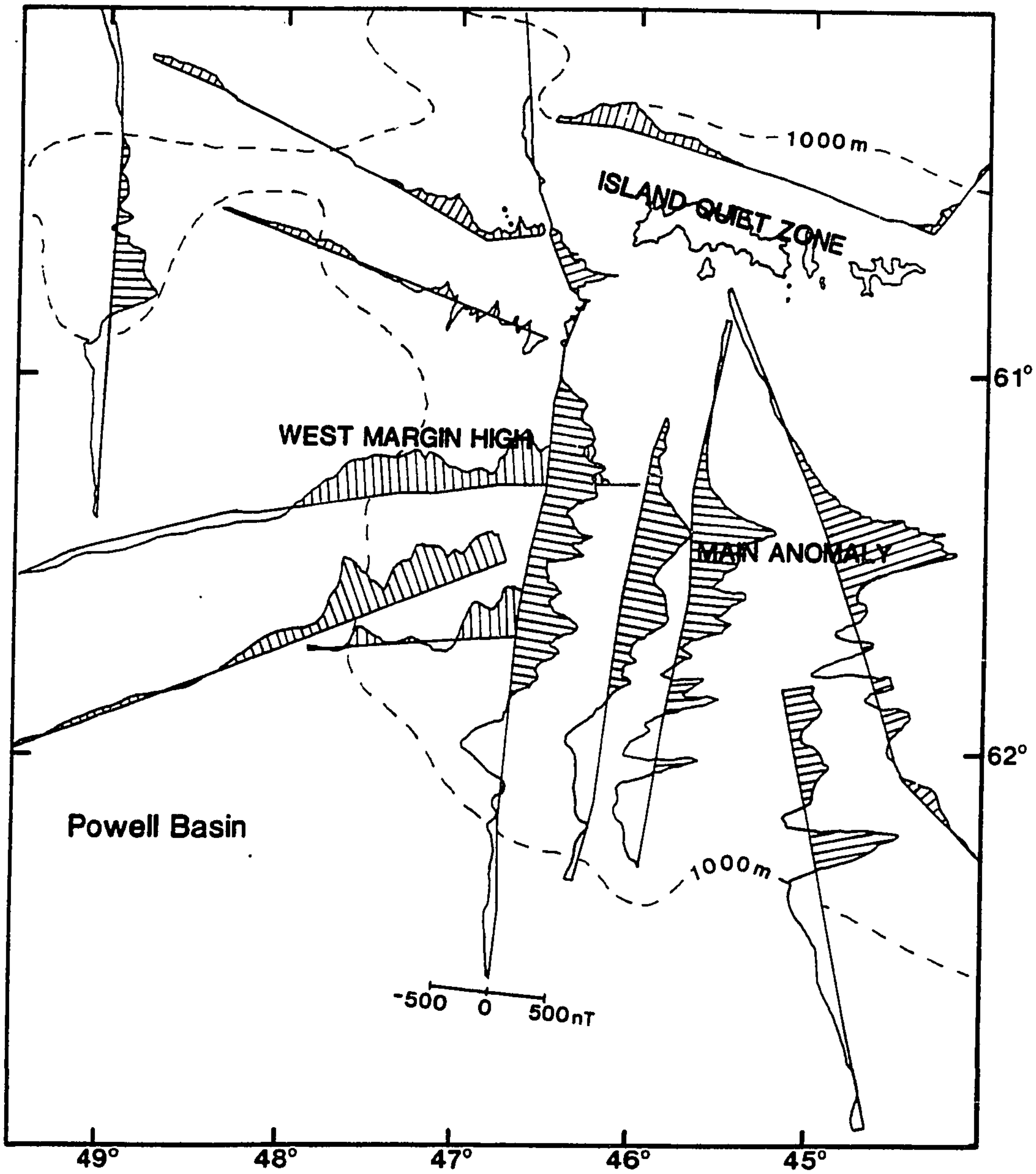


Figure 9. Magnetic anomaly profiles of the South Orkney Plateau and margins (from King, 1983). The WEST MARGIN HIGH corresponds to probable Tertiary igneous intrusive and extrusive(?) features on the passive margin. The MAIN ANOMALY is due to a granite-gabbro intrusive complex. The ISLAND QUIET ZONE suggests that the metamorphic and sedimentary rocks on the islands extend under the shelf in this area. No oceanic-type anomaly is seen in the Powell Basin profiles.

(figure 10). A second bathymetric high at the same relative position on the margin as the first is also interpreted as a buried volcanic feature. However, there are no gravity or seismic tracks over the second "cone", and magnetic data are not detailed enough to show that size of structure. Narrow zones of gravity lows occur at the base of the slope. Widely spaced anomaly values in the Powell Basin are low, averaging between 10 and 20 mgal (King, 1983).

Gravity modeling by King (1983) reveals a relatively thin continental crust beneath the South Orkney Plateau, ranging between 16 and 23 km thick. The Moho appears to slope gently under the western margin. A possible reason for the thinness of the crust is extension during rifting. The plateau's western margin shows evidence of rifting on seismic lines, the eastern margin may also have undergone a rifting event at around the same time, opening the Jane Basin. Modeling by King (1983) also shows a marked thinning of the crust in the center of the plateau, apparently related to the rifting event.

Seismic Surveys

Refraction seismic profiling interpreted by Harrington, et. al. (1972) gives some further information about the crustal structure and composition of the South Orkney block. Close to the islands, rocks with velocities near 5 km/sec are at or very near the sea floor (figure 11). These are interpreted (by Harrington) to include rocks of the metamorphic basement complex and the Graywacke-Shale Formation found on the islands. Further south on the plateau up to 4.5 km of sediments and sedimentary rocks (2 and 3.5 km/sec) cover the 5 km/sec basement in an east-west trending basin. The basin is truncated on the western edge of the plateau (as are the magnetic anomalies) implying rifting of the plateau from the peninsula after basin development. North-south striking faults seen on refraction lines displace the 2.0-3.5 km/sec interface on the western side of the plateau. Refraction data from the western slope of the plateau show a fairly steep gradient, sloping down into a

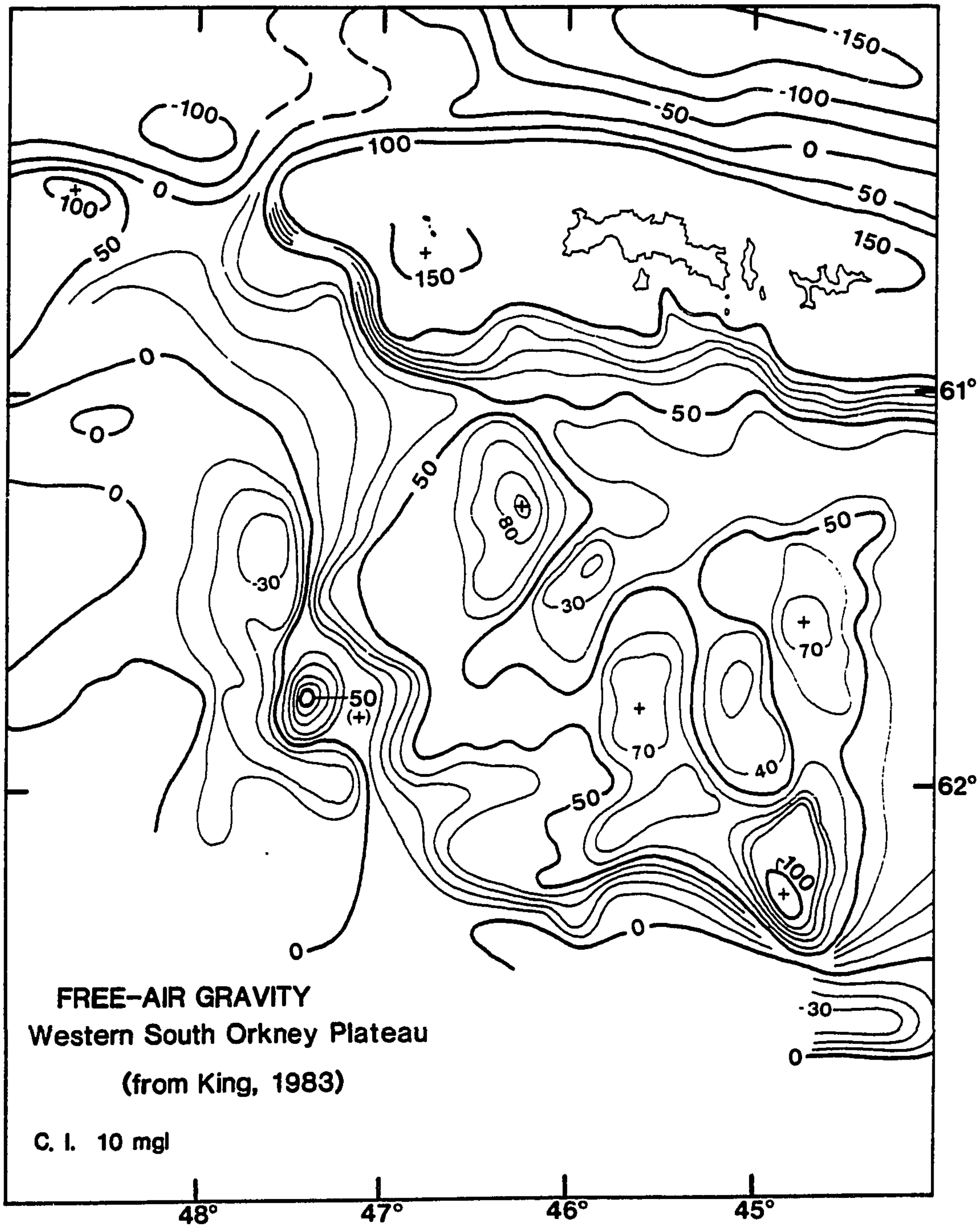
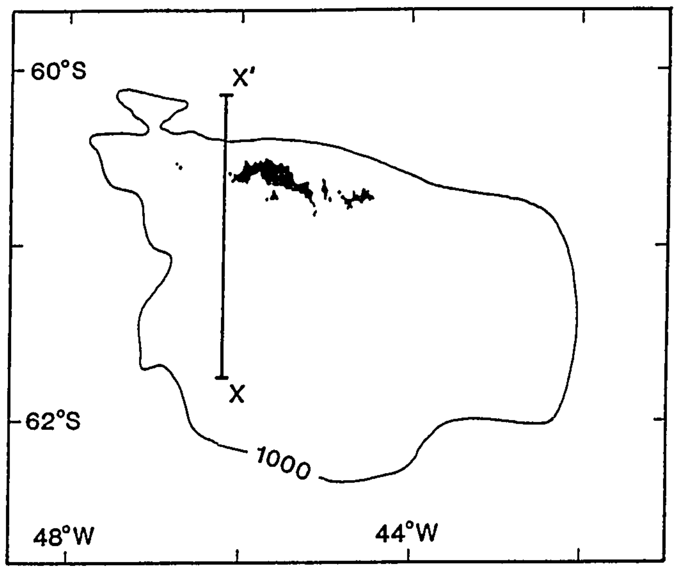
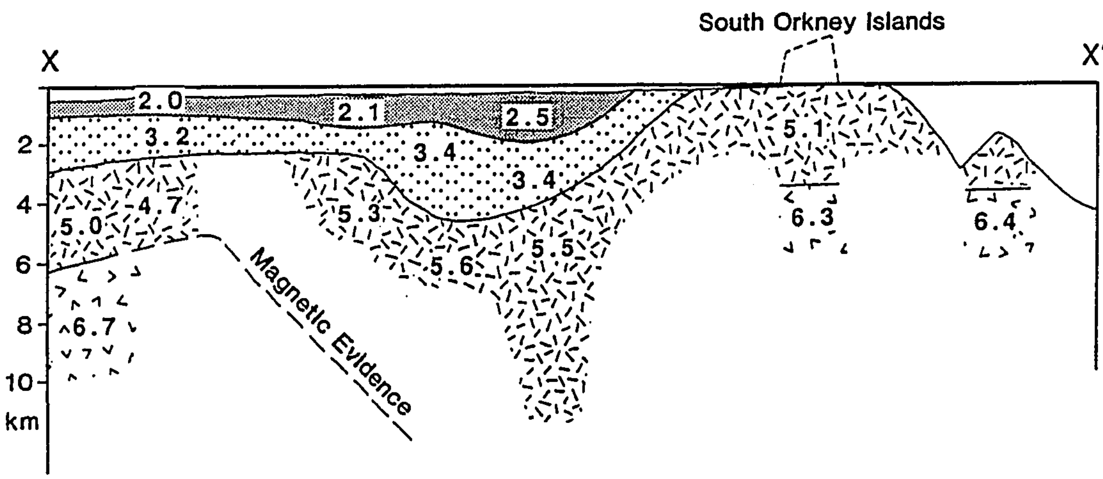


Figure 10. Free-air gravity anomaly - western South Orkney Plateau (from King, 1983). The positive anomaly at approximately 47° W and 62° S corresponds to the western margin positive magnetic anomaly and to a bathymetric high, which is interpreted by King (1983) as a volcanic feature.





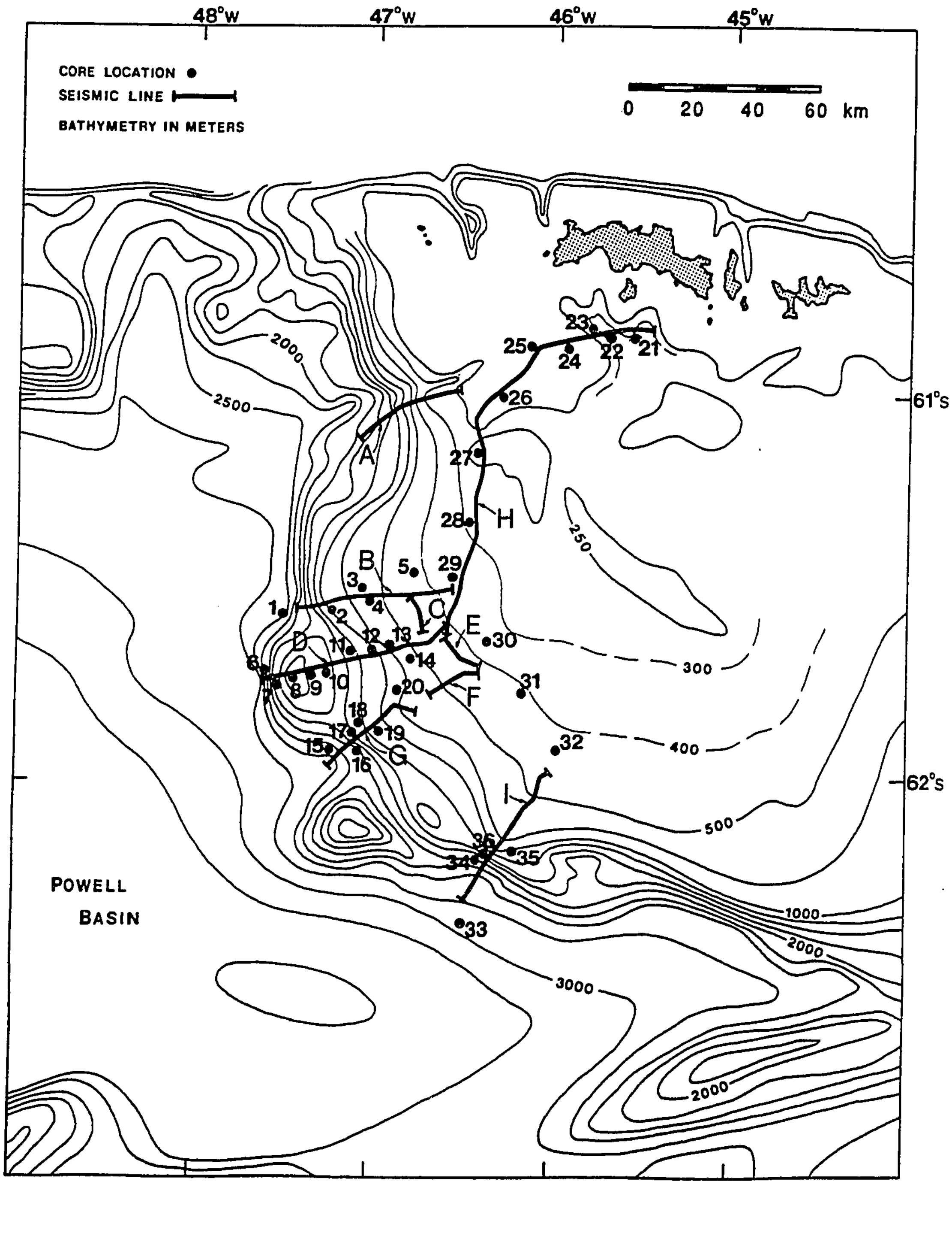
VELOCITY PROFILE

Figure 11. Seismic velocity cross section X - X' showing "basement" rocks (with velocities near 5 km/sec) and sediments overlying basement (with velocities between 2 and 3.5 km/sec) (from Harrington, et. al., 1972). "Basement" rocks crop out near the islands; elsewhere on the plateau, from 2 to 4 km of sediments overlie the basement. Velocities of sediments pentrated on Deep Freeze 85 seismic lines should be approximately 2 km/sec except near the islands (line SO-H), where sediments with velocities around 3.5 km/sec and "basement" rocks crop out.

sediment-filled basin; Harrington, et. al. (1972) describe the Powell Basin simply as a smooth, sediment-filled basin. However, refraction seismic data from the basin itself are limited to two short lines in the extreme northern Powell Basin. Crustal thicknesses measured from those data averaged 5.3 km (King, 1983). Direct evidence of oceanic crust or a spreading center is not present.

Reflection seismic profiles collected during Deep Freeze 1985 across the eastern Powell Basin margin (figure 12) also show features of a young passive margin and associated gravitational tectonics. Models of passive margin development have been described by several authors including Dewey and Bird (1970), Kinsman (1975), and Le Pichon and Sibuet (1981). A summary by Bally and Oldow (1986) describes three main phases of passive margin formation: (1) rifting phase, consisting of thermal uplift of the mantle, stretching and thinning of the lithosphere, and formation of half-grabens which begin to fill in with sediments; (2) drifting onset, in which continental lithosphere is actually separated and oceanic crust begins to be emplaced along a spreading ridge; and (3) main drifting phase, during which subsidence increases dramatically and margins typically accumulate thick, prograding sediment packages (figure 13). The eastern Powell Basin margin is characterized by normal block faulting (lines SO-D and SO-G, figures 14 and 15). Evidence of extensive slumping is seen on the steeper parts of almost every slope profile (figures 14, 15, 16, 17). King (1983) interprets half-graben development on the margin and two regional unconformities, one attributed to the initial rifting episode, and one to the onset of spreading and oceanic crust emplacement (the "break-up unconformity"), although no direct evidence of a spreading ridge exists. Seismic data also show the buried volcano structure discussed above under gravity anomalies (line SO-D, figure 14). Moderate amounts of sediment have accumulated on the margin. Thickest sediment packages are within basins formed by block faulting (eg. line SO-D figure 14), and are approximately 1/2 sec or 500-600 meters thick. Deep Freeze 85 seismic line SO-H

Figure 12. Bathymetry of the South Orkney Plateau showing locations of Deep Freeze 1985 core samples and seismic lines. Regional bathymetric data was made available courtesy of Dr. P. Barker. Bathymetry was recontoured to incorporate Deep Freeze 85 data.


48°W
47°W
46°W
45°W
CORE LOCATION
SEISMIC LINE
BATHYMETRY IN METERS
0 20 40 60 km
61°S
62°S
POWELL
BASIN
2000
2500
250
300
400
500
1000
2000
3000
2000
A
B
C
D
E
F
G
H
I
1
2
3
4
5
6
7
8
9
10
11
12
13
14
15
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30
31
32
33
34
35
36

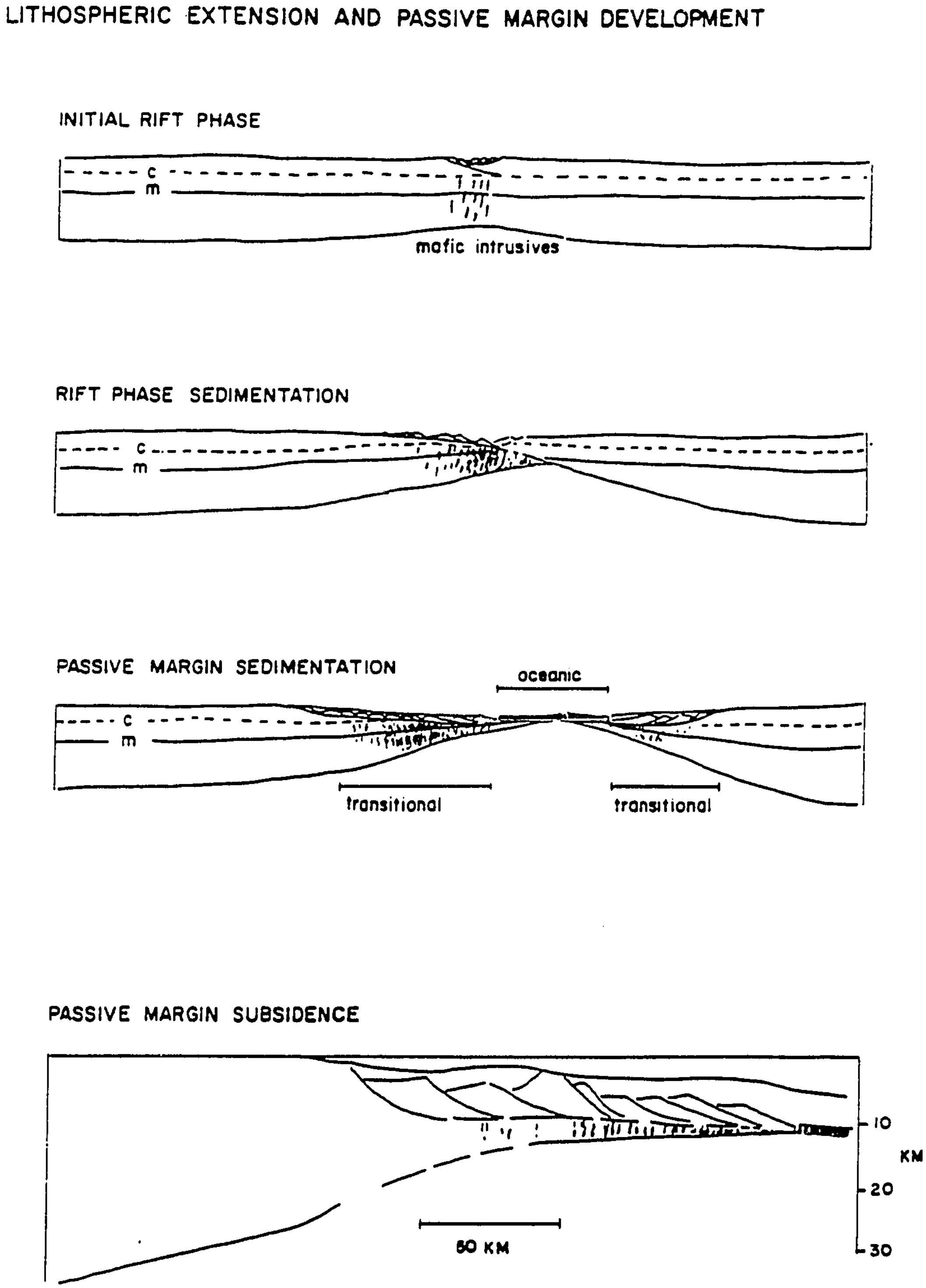


Figure 13. Schematic diagram of progressive lithospheric extension and the development of a passive margin (from Bally and Oldow, 1986).

Figure 14. Seismic Line SO-D, 4.6 kJ single-channel sparker profile - South Orkney Plateau/Powell Basin margin. Location on figure 12.

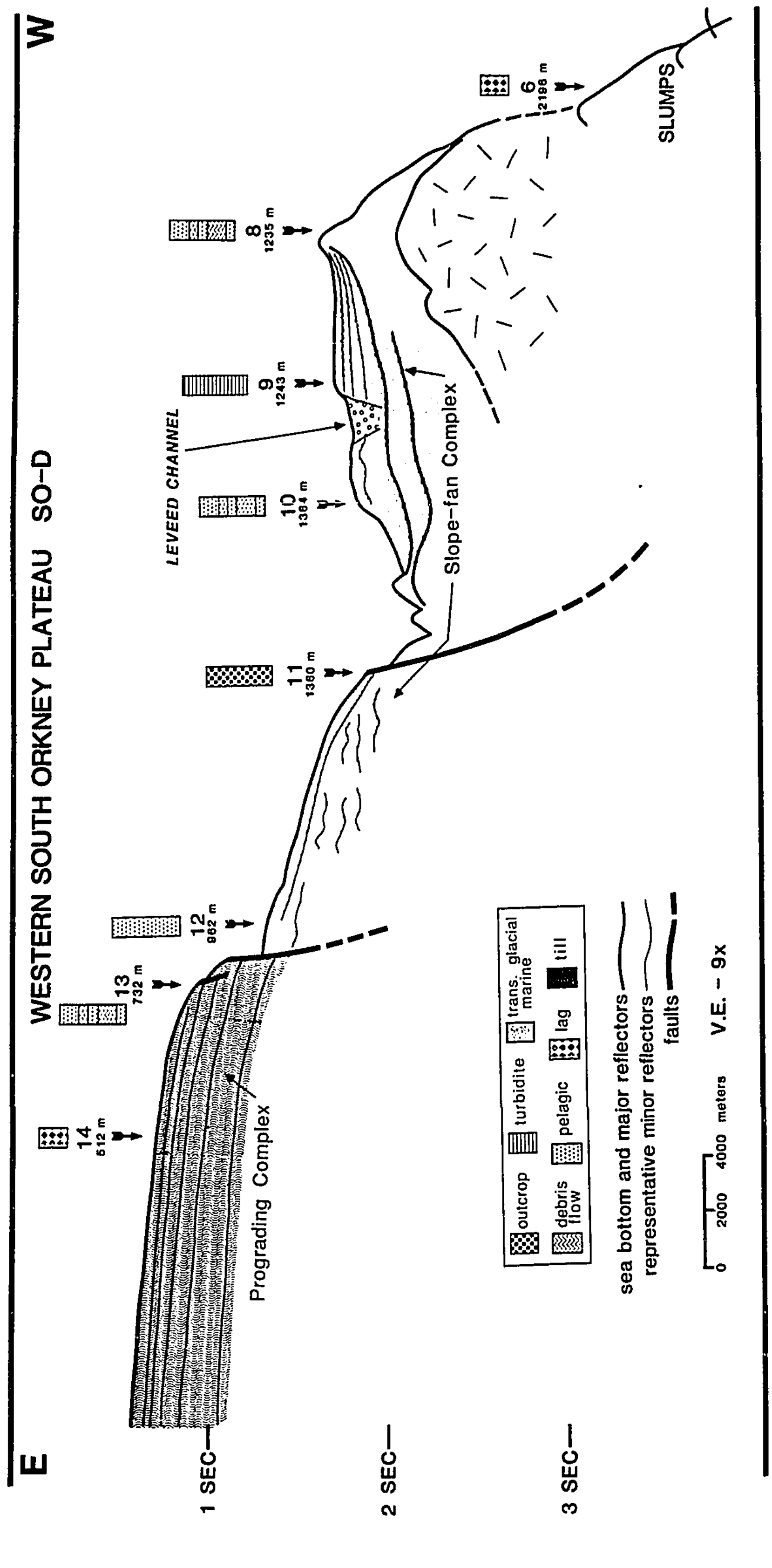
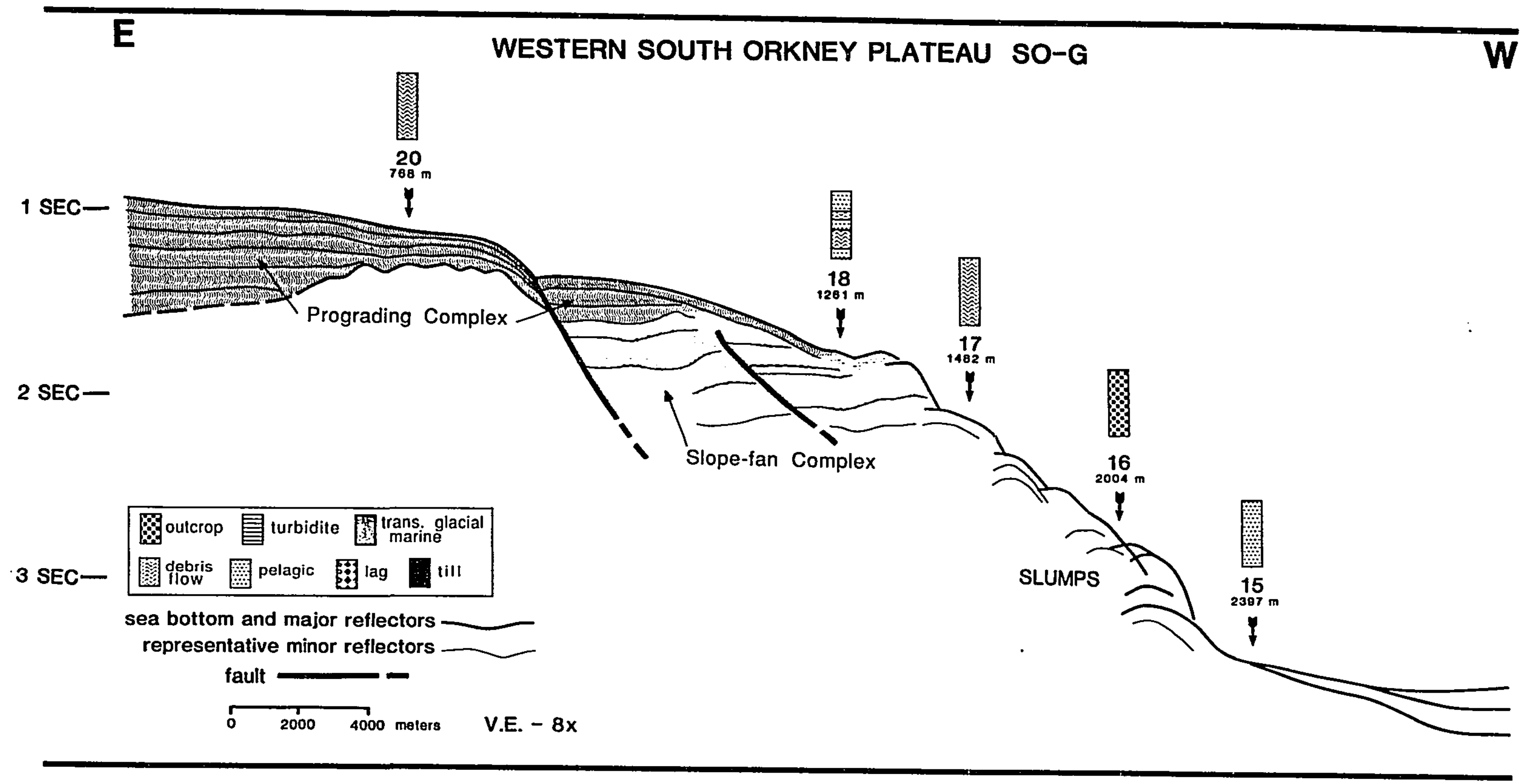

WESTERN SOUTH ORKNEY PLATEAU SO-D
E
W
1 SEC
2 SEC
3 SEC
14
512 m
13
732 m
12
982 m
11
1380 m
10
1364 m
9
1243 m
8
1235 m
6
2196 m
Prograding Complex
LEVEED CHANNEL
Slope-fan Complex
SLUMPS
outcrop
turbidite
trans. glacial marine
debris flow
pelagic
lag
till
sea bottom and major reflectors
representative minor reflectors
faults
0 2000 4000 meters
V.E. ~ 9x

Figure 15. Seismic Line SO-G, 4.6 kJ single-channel sparker profile - South Orkney Plateau/Powell Basin margin. Location on figure 12.



E
WESTERN SOUTH ORKNEY PLATEAU SO-G
W
20
768 m
18
1261 m
17
1482 m
16
2004 m
15
2397 m
1 SEC
2 SEC
3 SEC
Prograding Complex
Slope-fan Complex
SLUMPS
outcrop
turbidite
trans. glacial marine
debris flow
pelagic
lag
till
sea bottom and major reflectors
representative minor reflectors
fault
0
2000
4000 meters
V.E. - 8x

Figure 16. Seismic Line SO-A, 1 and 4.6 kJ single-channel sparker profile - South Orkney Plateau/Powell Basin margin. Location on figure 12.

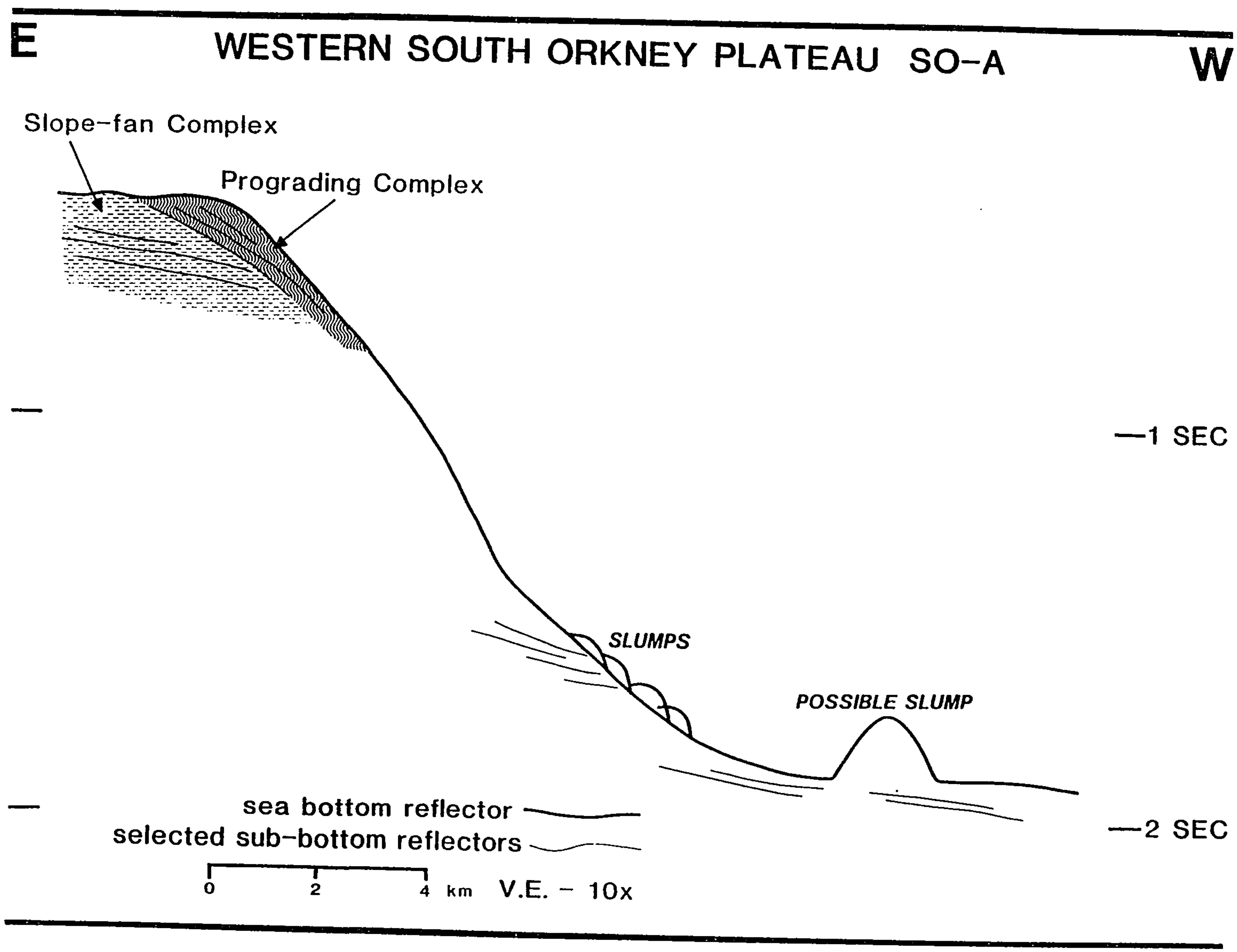
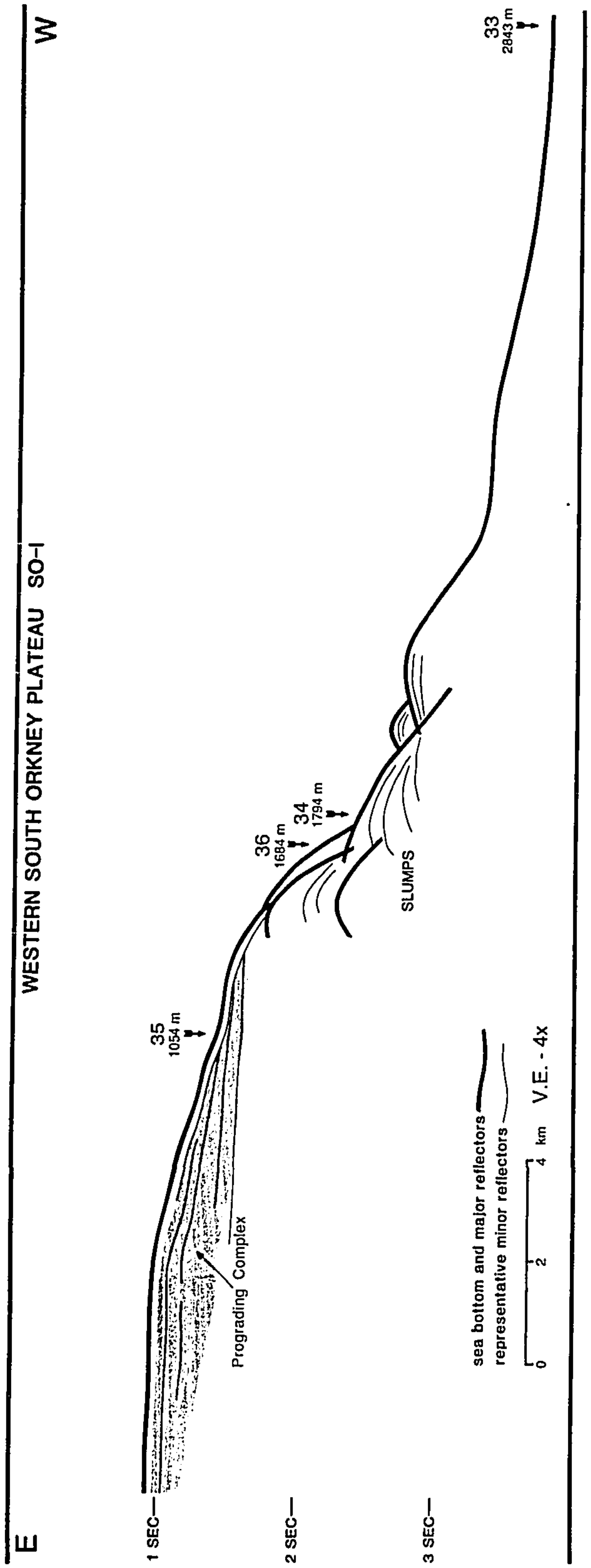

E
WESTERN SOUTH ORKNEY PLATEAU SO-A
W
Slope-fan Complex
Prograding Complex
—1 SEC
SLUMPS
POSSIBLE SLUMP
sea bottom reflector
selected sub-bottom reflectors
—2 SEC
0
2
4 km
V.E. - 10x

Figure 17. Seismic Line SO-I, 4.6 kJ single-channel sparker profile - South Orkney Plateau/Powell Basin margin. Location on figure 12.


WESTERN SOUTH ORKNEY PLATEAU SO-I
E
W
1 SEC
2 SEC
3 SEC
35
1054 m
36
1684 m
34
1794 m
33
2843 m
SLUMPS
Prograding Complex
sea bottom and major reflectors
representative minor reflectors
0
2
4
km
V.E. - 4x

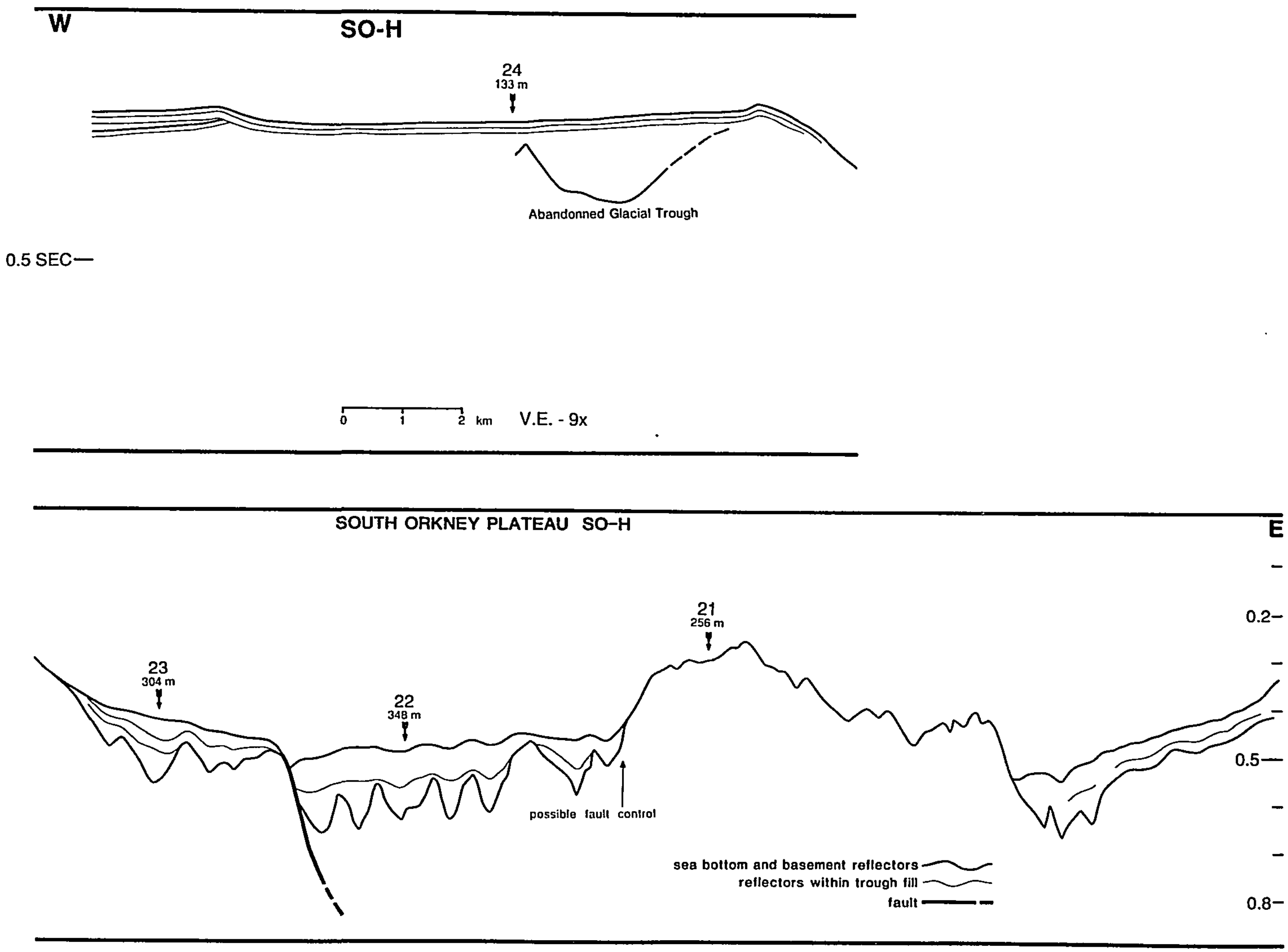
(figure 18) shows recent normal faulting in the center of the plateau near the islands; this area corresponds to the area of crustal thinning indicated by gravity modeling. The very young age of the faulting suggests that rifting (and hence thinning) may still be active. Alternatively, the faulting may be due to the increased subsidence rate brought on by the onset of drifting.

Comparison with other young passive margins

Gulf of California

The origin of the Gulf of California is interpreted as sea-floor spreading based on evidence from a variety of geophysical data. Oceanic type crust has been demonstrated to exist in the basins of the gulf using seismic velocity structure and gravity measurements. Earthquake studies show transform fault movement parallel to linear bathymetric features and characteristics of sea-floor spreading at oceanic ridges (Larson, et. al., 1972). The spreading ridge is an extension of the East Pacific Rise, which seems to disappear at the mouth of the gulf, but is actually being offset by several transform faults (the northernmost one being the San Andreas Fault) (figure 19). The ridge is apparent in the bathymetry of the mouth and the southern gulf as a distinct swell; occaisional seamounts occur on the ridge flanks. The magnetic stripe pattern at the mouth of the Gulf is fairly coherent and indicates a spreading rate of 6 cm/yr (total). Anomalies farthest from the spreading ridge are correlated with magnetic events which occurred between 4.0 to 4.5 Ma ago. However, no coherent pattern of spreading can be seen in the basins of the central or southern gulf (Larson, et. al., 1973) or the northern gulf. The proposed explanation for this is the high rate of clastic sedimentation into the gulf from surrounding continental areas. Sediments burying the ridge would change the normal process of pillow lava extrusion to an intrusive process of sill and dyke injection, thus lowering the amount of thermal remnant magnetization acquirable. In addition, slower cooling of the magma creates larger grain

Figure 18. Seismic Line SO-H, 1 kJ single-channel sparker profile - South Orkney Plateau. Location on figure 12.


W
SO-H
24
133 m
Abandonned Glacial Trough
0.5 SEC
0 1 2 km V.E. - 9x
SOUTH ORKNEY PLATEAU SO-H
E
0.2
SEC
0.5
0.8
21
256 m
23
304 m
22
348 m
possible fault control
sea bottom and basement reflectors
reflectors within trough fill
fault

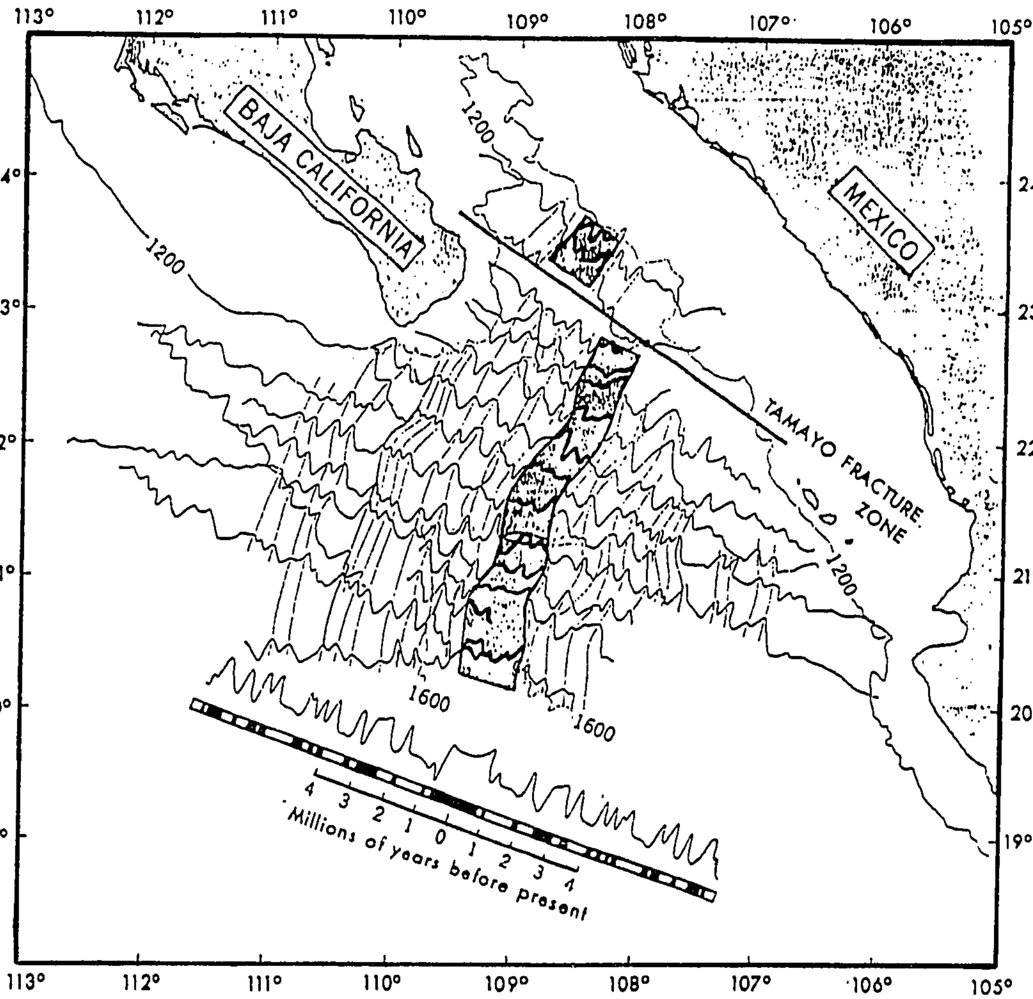


Figure 19. Magnetic anomaly patterns at the mouth of the Gulf of California showing symmetry about the spreading ridge (from Larson, et. al., 1968). A series of northwest trending transform faults in the gulf offsets the ridge.

size, decreasing the magnetic stability of the basalt (Larson, et. al., 1972). Seismic data in the northern Gulf of California indicate a crustal type intermediate between continental and oceanic (Moore, 1973). High sedimentation rates are the proposed cause of formation of transitional or intermediate crust. Menard (1967) describes several stages of transitional crust stating that intermediate type crust is not uncommon in small ocean basins, and crustal structure deduced from seismic data suggests that oceanic crust may be changed into continental type crust and vice versa. Separation in the Gulf of California is actually due to strike movement along the various transform faults trending northwesterly within the gulf (Larson, et. al., 1968), as separation in the Powell Basin is due to the movement of the large transform fault (or fault group) that makes up the South Scotia Ridge.

Seismic reflection profiles from the margins of the Gulf of California show some of the same features as those from the South Orkney Plateau/Powell Basin margin; recent normal faulting, evidence of pervasive slumping or mass flow on the slopes, and regional unconformities. In the Gulf of California the spreading ridge is only apparent near the mouth of the gulf. Elsewhere, no magnetic evidence and little bathymetric expression of the ridge exists, as in the Powell Basin. From 0.1 to 2 seconds of sediment fill the deep basins and downfaulted areas on the slope of the Gulf of California; it is unknown how much sediment fills the deep areas of the Powell Basin, but generally less than 1 second is found in grabens and lows on the slope; sedimentation rate is probably not as high in the Powell Basin as in the Gulf of California. Basement highs exist on the Gulf of California margin, but have not been attributed to intrusive or extrusive igneous activity (as on the Powell Basin margin) or diapirism.

Gulf of Aden (Red Sea)

The Gulf of Aden is estimated by Laughton (1966) to have initially opened about 20 Ma ago as Arabia and Somolia began to separate. Magnetic and seismic data from the gulf are difficult to interpret for the period 20 Ma to 10 Ma. Early stages of rifting may have been associated with complex normal and strike slip faulting and the stretching and thinning of the continental crust, thus new oceanic crust may have intruded along faults in a random pattern resulting in uncorrelatable magnetic anomaly patterns. By about 10 Ma ago, the proportion of oceanic to continental crust would have increased and the weakest zone (the center of the spreading region) would then have become the sole area of generation of new crust (Laughton, et. al., 1970). Alternatively, initial rifting stages may have been accompanied by rapid accumulation of sediments from the rifted continental margins, creating a situation similar to that of the Gulf of California (Larson, et. al., 1972). These interpretations could explain the apparent lack of oceanic magnetic anomalies in the outer (older) parts of the Powell Basin. Early rifting history may not have been magnetically recorded due to high sedimentation rate or a complex pattern of oceanic crust injection.

Geophysical data in the Gulf of Aden show strong evidence of ongoing oceanic crust generation from a spreading center. A strong negative magnetic anomaly defines a median valley within the spreading ridge, which is offset by a series of fracture zones. High heat flow is found over the gulf with highest values in the center near the ridge. Magnetic anomalies and refraction data over sediment-filled troughs flanking the ridge suggest that oceanic crust also underlies the troughs. The median valley lacks a flat sediment floor, despite photographic evidence of a high sedimentation rate (at least 10 cm/ka). Dredging in the valley produced fresh, ropy basalt and pillow lavas. Thus, the median valley is interpreted to be very young. Ocean floor generation may be episodic; reflection seismic data show the present median valley has cut down through Pleistocene sediments. The zone of tectonic activity associated with spreading extends many times wider than the median valley, suggesting uplift of a broad region about the ridge and subsequent downfaulting resulting in steep inward facing cliffs parallel to the valley. The intrusive zone today, however, is very narrow and confined to the median valley (Laughton, et. al., 1970). Although magnetic, gravity, and seismic data have not been collected over the entire Powell Basin, it is unlikely that a definite spreading ridge like that in the Gulf of Aden exists there today. Bathymetry of the basin floor shows a smooth sedimentary bottom. However, if ocean floor generation is episodic, as it appears to be in the Gulf of Aden, oceanic crust may underlie the sediments and the present may be a quiescent period for Powell Basin spreading. In both the Gulf of California and the Gulf of Aden, uplift prior to subsidence is indicated by seismic and paleontologic data. On the South Orkney Plateau/Powell Basin margin unconformities are interpreted simply as rifting and/or subsidence related and no paleontologic studies have been done, thus the amount of uplift associated with rifting is unknown.

Discussion

The South Orkney Plateau/Powell Basin margin exhibits most of the characteristic features of a passive margin except that it does not face a spreading ridge at the present time. Since only limited amounts of geophysical data and no samples are available from the deep parts of the Powell Basin, resolution of the mechanism of basin spreading is not yet possible. Assumptions can be made about the age and origin of the Powell Basin using the small amount of available data, evidence from surrounding areas, and the geometry of the regional tectonic setting. For example, Dalziel (1983) has used bathymetry and the concept of subsidence with stretching and loading to estimate the age of the Powell Basin as mid-Cenozoic. Also, a variety of geological and geophysical data supports a mid-Cenozoic age for the breakup of the Antarctic/Andean Cordillera, of which the South Orkney Plateau was a part. Although the Gulf of Calfronia and the Gulf of Aden are younger than the Powell Basin (5 Ma and 20 Ma old, respectively), both show clear evidence of a spreading ridge and emplacement of oceanic crust, whereas the Powell Basin does not. Two hypotheses which may explain this fact are, (1) the Powell Basin has evolved more slowly or differently, and has not developed a spreading center (in fact, no oceanic crust may be present at all in the basin), or (2) oceanic crust generation is episodic and no ridge or oceanic floor exists at the sea floor today because in a quiescent period sedimentation buries the spreading ridge. Burial of the oceanic crust by sediments would change the magnetic expression of underlying oceanic crust to more intermediate (lower magnitude) values. More data are needed in order to make any further interpretations about the origin or character of the Powell Basin.

CHAPTER 2. METHODS

Core Description

Piston cores collected during Deep Freeze 1985 were catalogued and split at the Antarctic core storage facility at the Florida State University. One half of each core was sent to Rice for use in this study. Each split core was analysed using x-radiography for sedimentary structures and detection of coarse material including ice-rafted debris (IRD), macrofossils, etc. Each core was then described in terms of sediment color, geotechnical properties, approximate biogenic and mineralogic content, and visible textural features. Sediment color was determined using the GSA color chart, penetrometer values and cohesive shear strength were measured at various intervals within each core (depending on sedimentologic units) using a penetrometer and torvane, respectively. Biogenic content and mineralogy were estimated by examination of smear slides. Point counting was performed on the coarse sand fractions of selected samples. Descriptive logs for each core are contained in appendix B.

Sampling Cores and Bottom Grabs

Two samples, one of approximately 5-10 grams and one of approximately 0.2-0.5 grams were taken from all surface samples (bottom grabs and/or tops of piston cores) and from selected cores at appropriate intervals for textural analysis. Each large sample was weighed dry, then wet sieved at 4.75 phi, dried and weighed again and dry sieved at -1 phi to determine weight percentages of gravel (<-1 phi), sand and coarse silt (-1 to 4.75 phi), and medium silt to clay-sized fractions (>4.75 phi). Each small sample was dispersed in a vial of calgon solution for at least 48 hours. A 0.5 to 1.0 gram split of the -1 to 4.75 phi sample was analysed using the large (1.5 meter) settling tube of the Rice University Automated Sediment Analyser (RUASA) system (Anderson and Kurtz, 1979). A small amount of the dispersed sample was analysed for medium silt to clay sized material using a hydrophotometer.

Constant volume (9 cc) samples were taken at 10 cm intervals from 2 cores, 85-12 and 85-33, to determine various sedimentologic changes downcore; hydrophotometer samples were taken at the same intervals and dispersed in calgon solution. Each 9 cc sample was weighed dry, wet seived at 4.75 phi, dried and weighed again, and dry sieved at -1 phi to determine weight percentages of gravel (<-1 phi), sand and coarse silt (-1 to 4.75 phi), and medium silt to clay-sized fractions (>4.75 phi). Weight percent of material coarser than 4.0 phi (8.125 chi) was calculated for each sample from values determined by the RUASA program, STAT 3. The STAT 3 printout gives weight percents in 1/8 chi intervals for material in the 2.0 to 16.0 chi range. From these percents, weight percents of larger than 4.0 phi material for the entire range of sediment sizes were calculated. Then, from visual examination and point counting of coarser than 1 phi material, weight percents of ice-rafted debris (IRD) were determined for each sample. Textural data is presented in appendix C.

Point Counting

-1 to 4.75 phi samples were dry sieved at 1 phi and the -1 to 1 phi fraction was split (if neccessary) using a mechanical sample splitter. At least 300 grains (or as many as existed) were counted under a binocular microscope in a cuttings tray using the ribbon method (Galehouse, 1971). The -1 to 1 phi size range is shown by Hallberg (1978) in an Iowa Geologic Survey Report to be most diagnostic of the total range of lithologies present in a sample. Lithologic types distinguished were (1) quartz and feldspar, (2) schist (mainly quartz-albite-mica-schist), (3) mica, (4) basalt and other volcanics, (5) rock fragments - plutonic, sedimentary, and metasedimentary, and (6) other (consisting mainly of mineral grains other than quartz, feldspar, or mica). These were recorded as number percents; mean and standard deviation were calculated for samples within distinct units.

The primary purpose of point counting was to determine the presence or absence of a monolithologic composition, and to determine downcore lithologic homogeneity. Most, if not all of the quartz, feldspar, and mica grains were probably derived from the schists on the South Orkney Islands. Thus, these lithologic types are grouped into a single catagory. Mineralogic data for coarse sands is presented in appendix D.

Carbon-14 Dating

Using the x-radiograph of core 85-23, two intervals containing abundant, sub-horizontallly lying pelecypod shells were selected and removed. The intervals of core were wet seived at 4.0 phi to separate the coarser shell material from the mud matrix, then sent to Krueger Enterprises, Inc. where they were prepared and analysed for Carbon-14 ages. The carbon-14 dates and their uses are described in appendix A.

Pebble Data

A total of 337 pebbles larger than 1 cm along one or more axes were located visually or by using the x-radiographs, removed and analysed for lithology and shape. A lithologic type was assigned to each pebble using hand sample identification and a binocular microscope. The pebbles were classified lithologically according to the scheme in table 2. Foliated metamorphic rocks (mainly quartzo-feldspathic schists) make up about 25% of all pebbles examined, meta-sedimentary rocks (including quartzites and meta-sandstones) make up another 24%. Volcanic and plutonic igneous rocks, the majority of which are exotic, comprise approximately 39% of the pebbles, sedimentary rocks and miscellaneous types (e.g. vein quartz) make up the remainder, about 12%. Estimated percentages of the major rock types found on the South Orkney Islands were calculated (table 1) based on island areas charted by Marr (1935) and on the general outcrop map of the islands published by Dalziel, et. al. (1981) (figure 6). Comparison of these estimates with the

Table 2. Pebble Lithology Classification

Foliated Metamorphic Rocks
- Schist
- Phyllite
- Slate

Non-foliated Metamorphic Rocks
- Quartzite
- Meta-arkose
- Meta-sub-arkose
- Meta-lith-arenite
- Meta-sub-lith-arenite

Volcanic Rocks
- Basalt
- Andesite
- Pumice
- Volcanic conglomerate and Tuff

Plutonic Igneous Rocks
- Anorthosite
- Gabbro and Dolerite
- Diorite
- Granodiorite
- Granite
- Syenite and Tonalite

Sedimentary Rocks
- Sandstones
- Muddy sandstone
- Siltstone

Other
- Ferro-manganese nodule
- Sedimentary clast
- Vein quartz

percentages of rock types found in all cores and surface samples collected from the plateau and slope reveals that approximately 70% of all pebbles are coming from the islands and about 30% are exotic (probably from the Antarctic peninsula and adjacent islands). Within the set of locally derived pebbles, approximately the same percentage of metamorphic rocks are found in the marine samples as exist on the islands, which suggests the South Orkney Islands are the primary source of the metamorphic rocks. Visual examination of the schists supports this suggestion.

Exotic clasts, because they are rafted from all over the Weddell Sea region, should be deposited fairly uniformly over the South Orkney Plateau and slope, whereas deposition of ice-rafted clasts from the South Orkney Islands should be concentrated in a smaller area. In plateau cores, 65% of pebbles are foliated metamorphic rocks, and only 11% are exotic (volcanic and plutonic rocks), whereas in slope cores only 17% are foliated metamorphic rocks and 45% are exotic. So, most ice-rafted clasts from the islands are melted out and deposited before reaching the edge of the plateau. Cumulative percent of foliated metamorphic rocks generally decreases away from the islands, from 100% in core 21 to 65% over the entire plateau (table 3).

After cleaning, all pebbles were measured for sphericity using Boulton's (1978) method of measuring long, intermediate, and short axes; roundness values were assigned to each by the comparison method of Krumbein (1941). Plots of sphericity versus roundness, a method devised by Boulton (1978), were used to help determine transport level of pebbles within the ice. This determination can be useful in differentiating glacial from glacial marine deposits. One potential problem with using this method in this particular area is that a large number (about 25%) of the pebbles are foliated metamorphic rocks which generally do not become as highly rounded or spherical as most other rock types. The low roundness values and slightly lower sphericities are most noticable in plateau samples, where 65% of the pebbles are foliated metamorphic rocks (figure 20).

Table 3. Foliated Metamorphic Rocks - Plateau Cores

Core no.*	Depth	Total no. pebbles	No. fol. meta. rx	Cumulative no. fol. meta. rx	Cumulative % fol. meta.rx
21	256	15	15	15	100
22	348	---	---	15	100
23	304	---	---	15	100
24	133	1	0	15	94
25	155	---	---	15	94
26	220	9	4	19	76
27	249	---	---	19	76
28	295	3	2	21	75
29	357	2	0	21	70
5	411	2	0	21	66
30	311	11	8	29	72
31	416	3	1	30	65
32	448	---	---	30	65

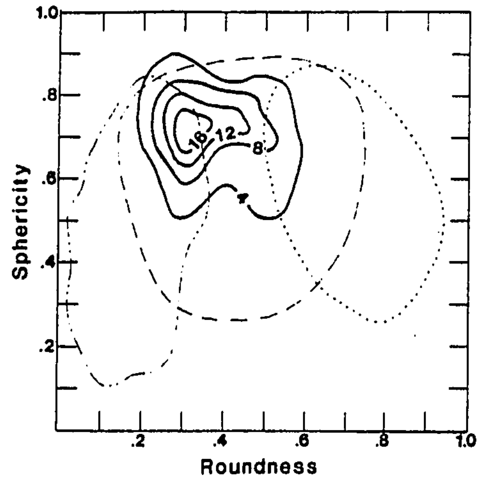
*in order of increasing distance from source

Figure 20. Sphericity vs. roundness plots of pebbles from plateau cores and grab samples; contoured in number percents. Most pebbles plot within Boulton's (1978) basal transport field. Foliated metamorphic rocks have slightly lower roundness and sphericity values.

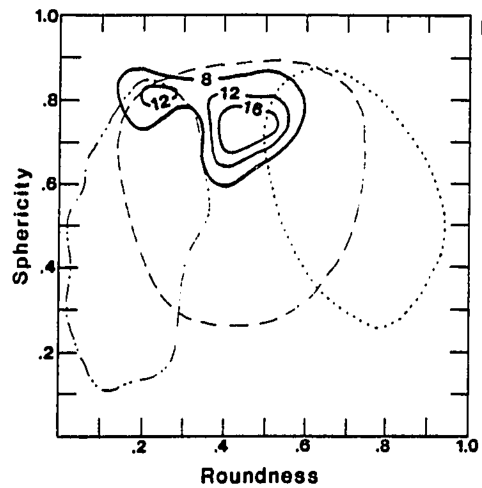
a. foliated metamorphic rocks only.

b. all pebbles except foliated metamorphic rocks.

c. all pebbles.



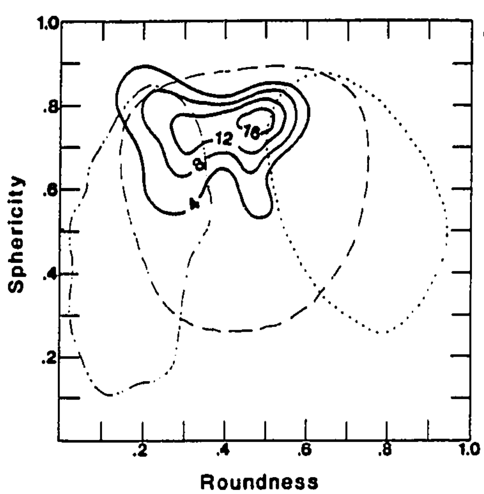
a. foliated metamorphic rocks only



b. all pebbles except foliated metamorphic rocks

BOULTON'S FIELDS
lodgement till
basal transport
high level transport

C. I. 4%



c. all pebbles

However, 90% of the plateau pebbles plot within the basal transport field, indicating that at least part of their transportation occurred in the traction zone of a glacier. In slope cores where only 17% of pebbles are foliated metamorphic rocks, 92% plot within the basal transport field, just slightly more than in the plateau samples. Thus, plots of sphericity versus roundness appear to be accurate, despite the abundance of foliated rocks.

A greater problem with the foliated metamorphic rocks is that faceting is obscured by their schistocity or cleavage, and they do not show glacial striations. Thus, two criteria that are commonly used in the identification of compound glacial marine, transitional glacial marine and basal till deposits are essentially useless in this area. Of the pebbles collected from the plateau and slope that do show abundant striation and/or well-developed faceting (mostly fine-grained sedimentary, meta-sedimentary, or igneous rocks), 31 out of 33 or 94% plot within Boulton's basal transport field, and over half also plot in the lodgement till field. Of all pebbles plotted, the field containing this group has the highest roundness and sphericity values. The pebble shape and lithologic data are presented in appendix E.

Seismic Data

Seismic lines collected during Deep Freeze 1985 are single-channel sparker data. The source used was an E. G. & G. 3-element sparker with a frequency range of 200 Hz - 5 kHz for output of 1 kJ and 100 Hz - 3 kHz for output of 4.6 kJ. Typical penetration at 1 kJ is approximately 200 meters, and at 4.6 kJ is approximately 500 meters. Data were filtered prior to recording using a high pass filter varied between 3 and 5 kHz to eliminate water turbulence noise, and a low pass filter of about 60 - 80 Hz to eliminate ship noise. Data were recorded in analog form on dry-paper recorders.

CHAPTER 3. SURFACE SAMPLE TEXTURAL DATA

Textural data from plateau surface samples 85-24 through 85-32 (figure 12) show a trend of fining with depth (and generally offshore) in the very fine sand to coarse silt range. The nine surface samples, taken along a depth transect from 133 meters to 448 meters, are all bottom grab samples, except sample 85-31 which was taken from the top of a piston core. The fining-with-depth trend is present in the dominant mode of the 3.0 - 4.5 phi fraction as well as in the mean grain size of the samples (figure 21). The most sensitive parameter for the study of very fine sand and coarse silt dispersal is modal grain size (Curray, 1960; Kulm, et. al., 1975). Progressive changes in mean grain size alone may only reflect changes in percent clay or other fraction of the sample, whereas modal changes more accurately indicate changes in the dispersal mechanism and are able to trace discrete sediment masses on the shelf (Curray, 1960).

The textural signatures of most pelagic or hemipelagic sediments from the Antarctic are complicated by the presence of ice-rafted debris (IRD), which is polymodal and completely unsorted (figure 22). In comparison, the textures of fine sands and coarse silts in samples 85-24 through 85-32 are relatively well-sorted and unimodal. These modes are interpreted as sediments which were derived via settling from suspension out of wind-driven shelf currents. The velocity of these currents on the plateau wanes with depth, depositing coarser sediments in shallower depths nearshore, and progressively finer sediments in an offshore direction (as depth increases). Oceanic circulation patterns for the South Orkney Plateau area are inferred from data compiled for the Weddell Sea (Anderson, 1975) and from wind patterns. Prevailing winds in this area are westerly; however, northwesterly summer winds are very strong, and may dominate (Lamb, 1964; Marr, 1935) driving currents in a generally N-NW to S-SE direction. These wind driven currents are redistributing sediments on the plateau in a predictable, fining-with-depth pattern. This

Figure 21. Frequency weight percent vs. phi size curves for plateau surface samples 85-24 through 85-32 (locations on figure 12). Curves include -1 to 4.75 phi size sediment only; however, total-grain-size analysis also shows fining-with-depth and a general increase in percent clay with depth. Stippled pattern indicates relatively well-sorted, marine current derived fine sand and coarse silt modes. Approximate relative percents of IRD and current-derived sediments are shown next to the curves. Note that progressive fining of the dominant mode corresponds well with depth of the sample location.

SOUTH ORKNEY PLATEAU

SURFACE SEDIMENTS - TEXTURAL ANALYSES

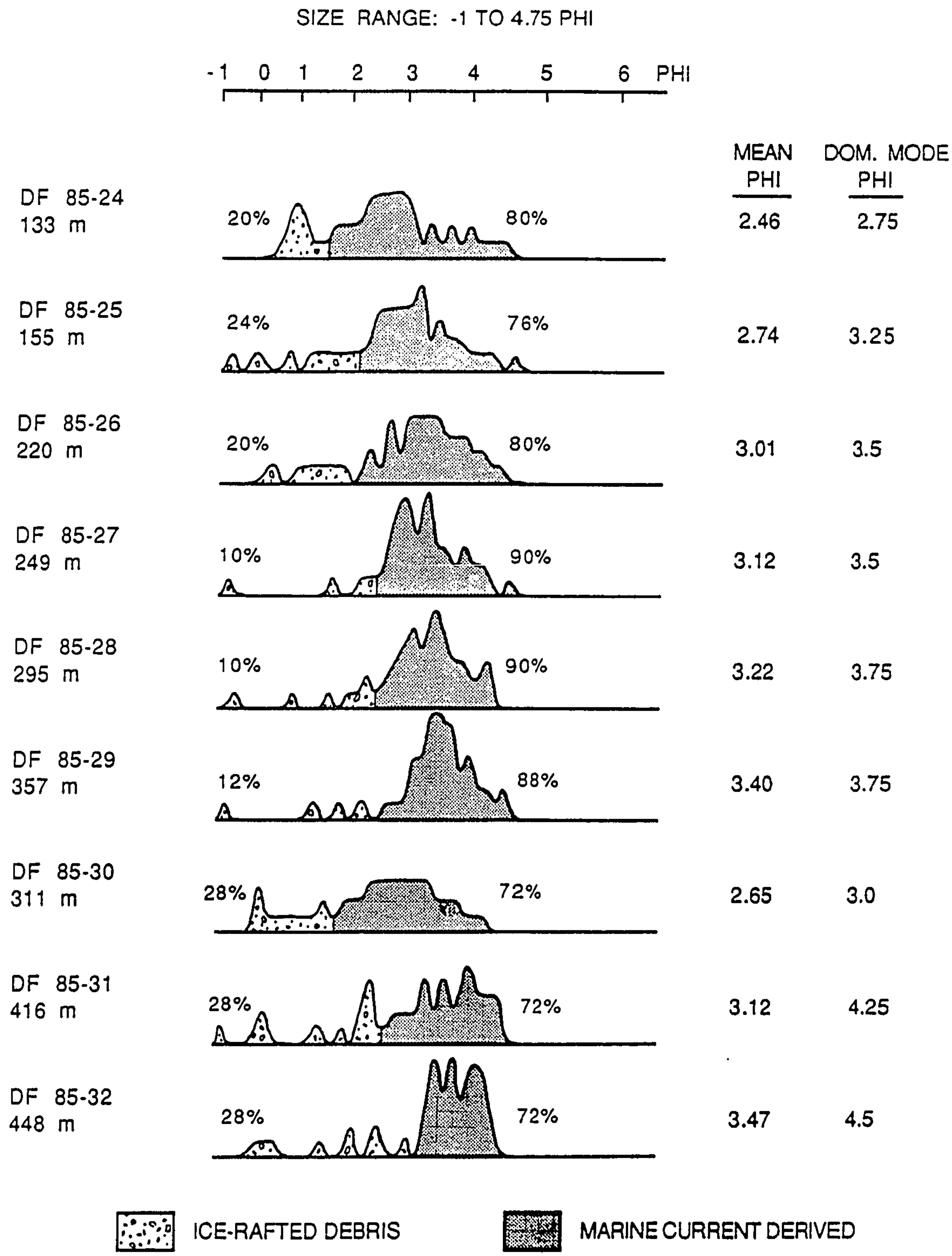
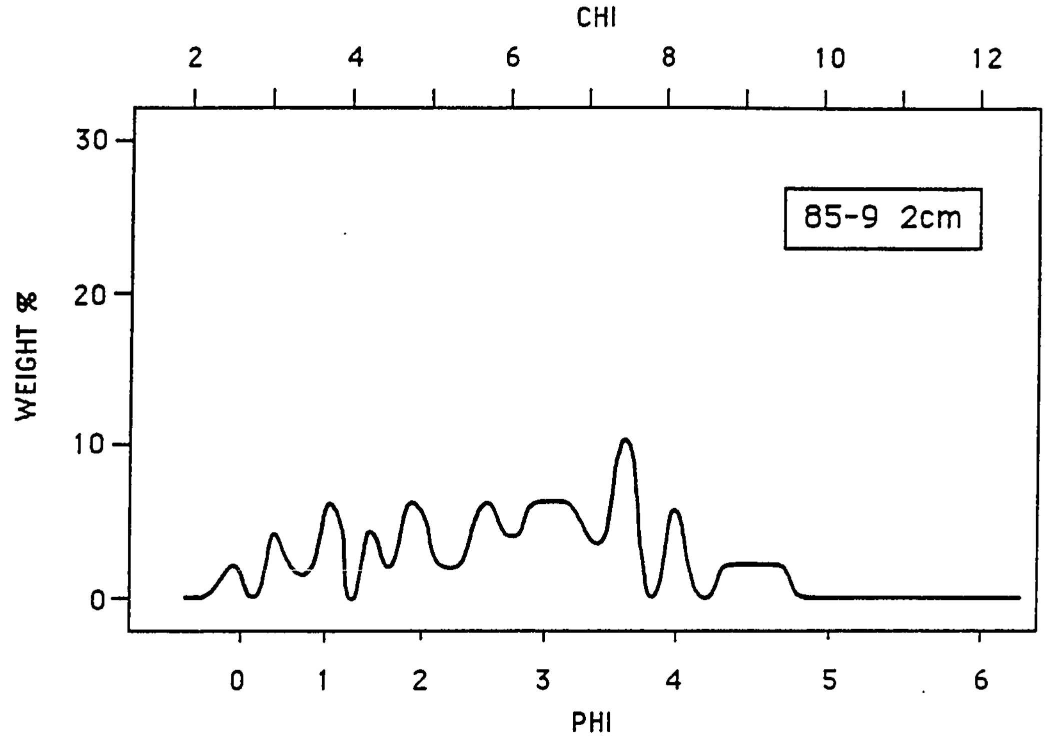
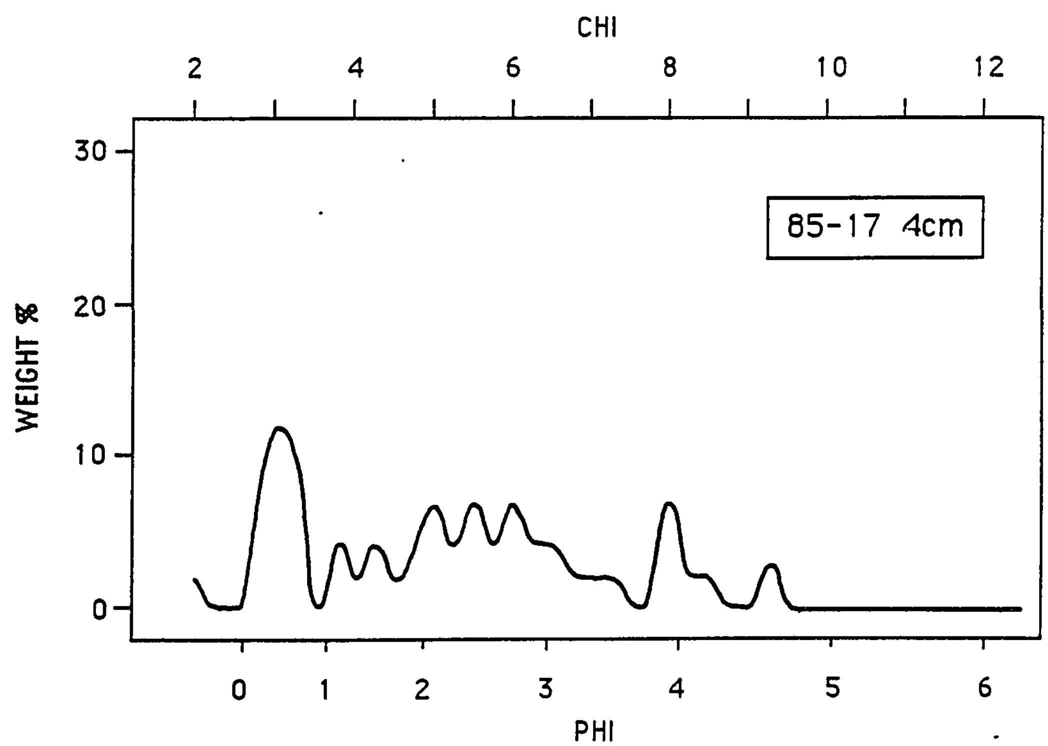


Figure 22. Examples of frequency weight percent vs. phi size curves for typical compound glacial marine sediments (size range: -1 to 4.75 phi). Note polymodal texture and poor sorting.



Compound Glacial Marine Sediment   −1 to 4.75 phi range



pattern has been theorized as textural equilibrium for a continental shelf setting, and was predicted in the literature as early as Johnson (1919). However, sediments recovered from many shelves, including most areas of the Antarctic continental shelf, are a complex mosaic of textures and compositions. On other shelves this is partly due to the presence of relict Pleistocene sediments that were originally deposited in a variety of shallower water and subaerial environments and subsequently drowned during the Holocene transgression (Emery, 1968). The Antarctic shelf is unique because of its depth, typically shoreward slope, and highly irregular bathymetry, mainly due to glacial erosion (Anderson, et. al., 1984). Several hundred meters of the continental slope were glacially eroded during the Pleistocene, exposing older sediments and rocks over large areas of the shelf. Antarctic shelf sediments, therefore, are both relict and modern, and probably reflect ancient and ongoing oceanic and glacial processes and sediment gravity flow reworking. A few shelves (such as the Oregon, Moroccan, and Niger shelves) have sedimentation patterns that are approaching equilibrium conditions, and the Southeast Bering Shelf (Bristol Bay) has been shown to be in an advanced state of textural equilibrium (Sharma, et. al., 1972; Sharma, 1975). However, most shelves are dominated by sediments apparently in disequilibrium.

Sampling from the South Orkney Plateau is not extensive, but existing data support the interpretation of an advanced state of textural equilibrium on the plateau. It is much deeper, however, than the area studied in Bristol Bay, so the processes of sediment dispersal are different. Textural sorting in Bristol Bay is apparently due to decreasing wave energy with depth (Sharma, et. al., 1972; Sharma, 1975); frequent, large storm waves affect the bottom as deep as 100 meters. On the South Orkney Plateau sediments are texturally sorted by wind-driven currents to a depth of at least 400 meters. Storm wave energy may influence sedimentation patterns close to shore, but it is not the primary mechanism for sediment dispersal on the plateau. All South Orkney Plateau surface samples would be classified as poorly sorted in the -1 phi to 4.75 phi range using Folk's (1968) classification, since standard deviations range from 1.47 to 1.92. However, this is mainly due to the presence of a small amount of IRD which is ubiquitous on the Antarctic shelf and thus does not indicate textural disequilibrium. Degree of sorting does not decrease or increase with depth in the -1 to 4.75 phi range or in total grain size analysis. Clay content does increase irregularly with depth; weight percent clay increases from about 1% at 133 meters to almost 14% at 448 meters. This is probably also a result of waning current energy.

The relatively well sorted nature of the current derived sands distinguishes them from the polymodal, poorly sorted character of IRD sands. Using this difference in textural character, each sample is divided into approximate relative percents of IRD versus current derived sands on the frequency weight percent curve (figure 21). In every case, current derived sands are much more abundant than IRD. Although the division made is an oversimplification, since undoubtedly some IRD adds to the modal size fraction defined as current derived sand, the size of IRD grains should be distributed randomly and thus could not consistently augment a single mode in the 3.0 - 4.75 phi range. Presence of IRD within the size range of the current derived modes causes the modes to be less well sorted than they would be without IRD, making the division more difficult but not significantly affecting the relative percentages. These depths (133 - 448 meters) are common on the Antarctic continental shelf, so similarly well-sorted sands may be found in other areas on the shelf. Interpretations of grain size data from Antarctic shelves should take into account the large contribution that current derived, or current reworked, sediments can make to the total sand and coarse silt fractions. Previously used definitions of IRD as all non-biogenic and non-volcanic sediments larger than 4.0 phi may be invalid in areas where marine currents are, or could have been active.

The source of these current derived or reworked sands may be from the South

Orkney Islands or from sediments already deposited on the plateau by other means. The amount of sediment being eroded from the South Orkney Islands is unknown. Summer meltwater erosion may provide significant depositional input onto the plateau; the South Orkney Plateau lies further north than the South Shetland Islands and Bransfield Strait area where meltwater deposition accounts for at least 50% of the total sedimentation in the fjords and bays (Griffith, pers. comm., 1987; Singer, 1987). However, the climatic regime of the South Orkneys differs from that of the South Shetlands, and may more closely approximate conditions on the Antarctic Peninsula, 3° to 4° south of the South Orkneys. Contours of mean annual surface air temperatures and wind regimes show colder conditions at the South Orkneys than at the South Shetlands (figure 23; Schwerdtfeger, 1984) and more frequent gale force winds (Lamb, 1964). Prevailing winds and ocean currents cause pack ice and icebergs from the Weddell Sea to drift northward to northeastward along a path between 35° and 40° West. A tongue of ice has been observed to regularly follow this course (Schwerdtfeger, 1984). The effects of the northward driftng ice as it breaks up and melts are the cooling of surface water masses over a wide area, and cooling of the air above the waters. Mean annual surface air temperatures from stations along the ice path (Orcadas and Signy - South Orkney Islands; Grytviken - South Georgia) are consistently lower than annual means from stations outside the path, even though some are at a higher latitude than stations within the ice path. Figure 23 (from Schwerdtfeger, 1984) illustrates this situation along parallels 50° and 60° South. However, the geographic position of the South Orkneys also seems to result in large variations in climate (Marr, 1935; Lamb, 1964; Schwerdtfeger, 1984); greatest variations of temperature occurring in the Antarctic from one year to another, and greatest anomalies of monthly mean barometric pressure recorded in the Antarctic (to 1964) were at the South Orkney Islands (Lamb, 1964). So, climatic conditions vary widely, and meltwater sediment input probably varies as well. Another source of fine-grained sands and silts

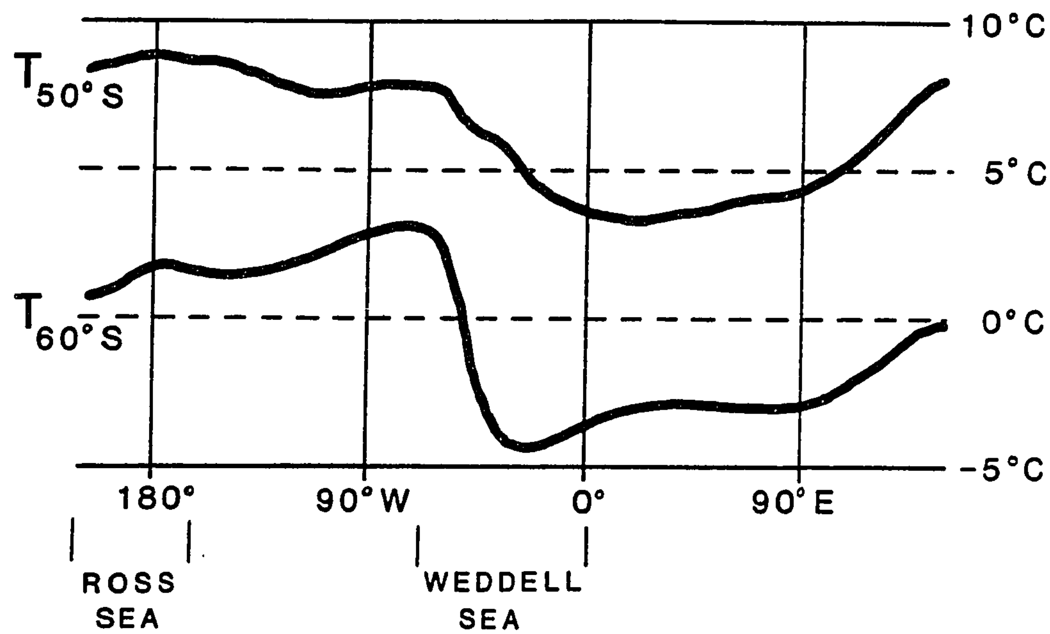


Figure 23. Zonal profile of mean annual air temperature near sea level along parallels 50°S and 60°S (from Schwerdtfeger, 1984). The South Orkney Plateau lies at approximately 60°S and 40° - 45°W.

being redistributed on the plateau may be collapse of the walls of glacially carved troughs or submarine canyons such as the one near Deep Freeze 85 seismic line SO-A (figure 12) (Vail, pers. comm. 1986).

CHAPTER 4. GLACIAL REGIME AND HISTORY

Introduction

The South Orkney Plateau is an ideal setting for examining late Cenozoic glacial/climatic events because of its geographic and oceanographic location. The glacial regime of the South Orkney Islands, consisting mainly of piedmont glaciers, a few valley glaciers, and a thin highland ice cap (Marr, 1935), is more likely to be affected by small climatic changes than the relatively stable Antarctic continental ice sheet or its associated ice shelves. Therefore, the South Orkney Plateau should have a more complete and detailed sedimentological record of high frequency, low amplitude climatic events than an area proximal to the continental ice sheet system. The South Orkney Plateau is also an ideal location to look for evidence of certain large scale events such as the massive ice-shelf expansions proposed by Johnson and Andrews (1986). Their model, based on oxygen isotope records, suggests that a floating ice shelf surrounded the continent and extended to a latitude north of the South Orkney Islands around 125 ka B.P., and for some period of time around 20-15 ka B.P. Since the South Orkney Plateau lies near the proposed outer limits of the ice shelf expansion, and is far enough away from the peninsula to be out of range of the effects of minor expansions, it is possibly the best location to test this hypothesis.

Glacial Setting

The glacial setting of the South Orkney Islands today is much like that of the northern Antarctic Peninsula. Except for Signy Island, all of the larger islands in the group are extensively ice covered (Pirie, 1913; Marr, 1935). Ice-free areas are scarce on the northern and western coasts of the islands where maximum precipitation occurs; they are more common on the sheltered southern and southeastern coasts and on Signy Island. Glaciation on the South Orkneys includes many different ice features, and does not fit a simple morphological classification (Matthews and Maling, 1967). Many of the glaciers are short and terminate in low, wide cliffs at the coastline. These were characterized by Marr (1935) as "ice-foot" or piedmont glaciers and are similar to those in northern Graham Land (Thomson, 1974). Cirque glaciers are present in the mountainous areas of the islands (Matthews and Maling, 1967). Only one example of a true valley glacier on Coronation Island is desribed by Marr, although another was described by Pirie (1913) on the north coast. On the western side of the island, Marr describes more highland ice development, with the highland ice reaching the coast unbroken and smooth in some areas. According to John (1934) all of the glaciers on Coronation Island are too heavily crevassed to maintain a "floating snout" as they are pushed out to sea, thus all are grounded at or near sea level and terminate at their grounding lines. The South Orkney Plateau is generally covered by 7/10 to 10/10 pack ice from mid-May to early November, and 0/10 to 5/10 through December, although the heavy pack ice edge remains close to the South Orkneys until early January. From January to early May, the area is essentially pack-ice-free; the ice edge is commonly 200-300 km south of the South Orkney Islands in mid-summer (US Navy Antarctic Ice Charts, 1973-1978 and 1983-1984).

The South Orkney glaciers do not appear to have the capacity to produce large icebergs; the glaciers are observed to move very slowly, some may even be dormant, according to Marr (1935), because the islands lack a large source of inland ice to feed and push the glaciers downwards and outwards to the sea. Ice on the highest points of the islands is so thin that the underlying irregularities of the rock are easily seen. Pirie's (1913) study of Laurie Island states that the forward motion of the glaciers there is also very slight, and they calve infrequently, producing "pieces of trifling size", nothing larger than an "ordinary tramcar". However, the small glaciers do seem to have caused or be causing significant amounts of erosion. On the eastern side of Coronation Island, adjacent glaciers tend to coalesce at their seaward ends, implying that the dividing ridges have undergone, or are undergoing, erosion by the ice (Marr, 1935).

Pebble lithology data from Deep Freeze 85 cores also show evidence for glacial erosion of the islands. Exotic clasts, because they are rafted from all over the Peninsula and Weddell Sea region, should be deposited fairly uniformly over the South Orkney Plateau and slope, whereas ice-rafted clasts from the South Orkney Islands should be concentrated in a smaller area. Sixty-five percent of the pebbles from plateau surface samples and cores are foliated metamorphic rocks found on Coronation and/or Signy Island, mainly quartz-albite-mica-schists and a few phyllites and slates (described by Thomson, 1968, 1974). Twenty-four percent are other lithologies that could be locally derived; only 11% of pebbles are exotic. In slope cores only 17% are foliated metamorphic rocks and 45% are exotic. So, on the plateau, deposition of ice-rafted clasts from the islands exceeds that from other areas. Relative percentage of clasts from the islands is greatest closest to land and decreases seaward from the islands across the plateau (table 3).

Previous Work

The Late Wisconsin glacial regime and history of the South Orkney Islands and plateau have not been investigated. Sugden and Clapperton's (1977) study of South Georgia, the South Shetlands, and the South Orkneys determined that the maximum glaciation on these island groups occurred before the Late Wisconsin. The Late Wisconsin glacial period was a time of major advances of the ice sheets of Antarctica and the Northern hemisphere, and also a large eustatic sea-level fall. Evidence for more extensive ice cover during this period exists on other sub-Antarctic Islands, such as Marion Island (Hall, 1983) and Kerguelen Island (Hall, 1984). Thus, a coincidental ice expansion would also be expected on the South Orkney Islands and Plateau.

Evidence of at least one formerly more extensive glaciation on the South Orkney

Islands has been observed by several authors including Pirie (1913), Holtedahl (1929), Marr (1935), and Matthews and Maling (1967). Pirie, Holtedahl, and Marr all cite land-based evidence for expanded ice such as numerous *roches moutonées* and islands of rounded outline all around the coast (Pirie, 1913) and marked transverse ridges separated by wide trough valleys (Holtedahl, 1929). Numerous drift deposits, perched glacial erratics, erosional features, and exposed terminal morraines on Signy Island indicate at least one previous glacial expansion there as well (Thomson, 1968; Matthews and Maling, 1967). Important models suggested for the glacial history of this area are Sugden and Clapperton's (1977) model of locally-derived grounded ice on the shallow part of the plateau, and the massive continental ice shelf expansion model of Johnson and Andrews (1986). Sugden and Clapperton's (1977) model suggests glacial maxima on the South Orkney Plateau in which ice was grounded no further than the present -200 meter bathymetric contour (figure 24 a). Using Harrington's (1968) bathymetric data, they cite radial troughs extending from the islands and platform, and the highly irregular sea floor between the troughs down to approximately 200 meters depth as evidence of submarine glacial erosion (figure 24 b). This erosion could only have occurred during a much more extensive glaciation than exists today. Also, the intermediate position of the South Orkney Islands between the South Shetlands and South Georgia, which have abundant land-based and marine evidence of previous glacial maxima, infers formerly more extensive ice cover also on the South Orkneys. The maximum glacial advance is suggested by Sugden and Clapperton to have occurred before the most recent (18 ka B.P.) glacial advance, perhaps during a pre-Sangamon glaciation (i.e. more than 200 ka B.P.).

Johnson and Andrews (1986) have postulated two expansions of Antarctic ice in the form of massive floating ice shelves, which extended to 58° South latitude in the Antarctic Peninsula region (figure 25). Evidence supporting this theory includes oxygen isotope records which show two termination events, or melting events, one during the

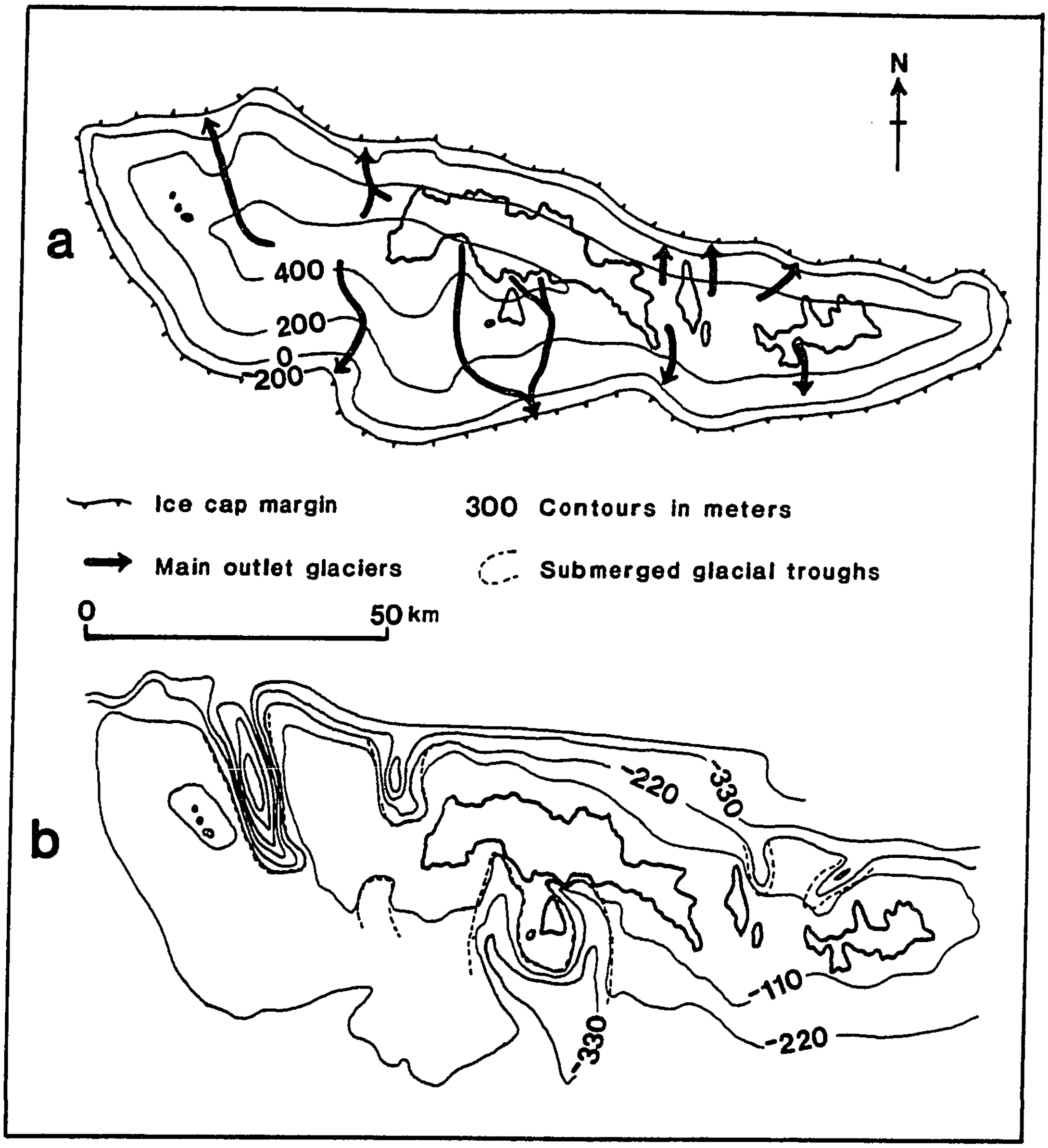


Figure 24.

a. Reconstruction of the South Orkney ice cap at its maximum extent, showing general flow patterns of the main outlet glaciers. Maximum thickness of the ice cap was about 600 meters.

b. Bathymetry of the South Orkney shelf [after Harrington, 1968] showing glacially carved troughs radiating from the islands and plateau (from Sugden and Clapperton, 1977). Troughs are U-shaped and overdeepened. Troughs on the northern plateau margin may have been subsequently deepened by turbidity currents.

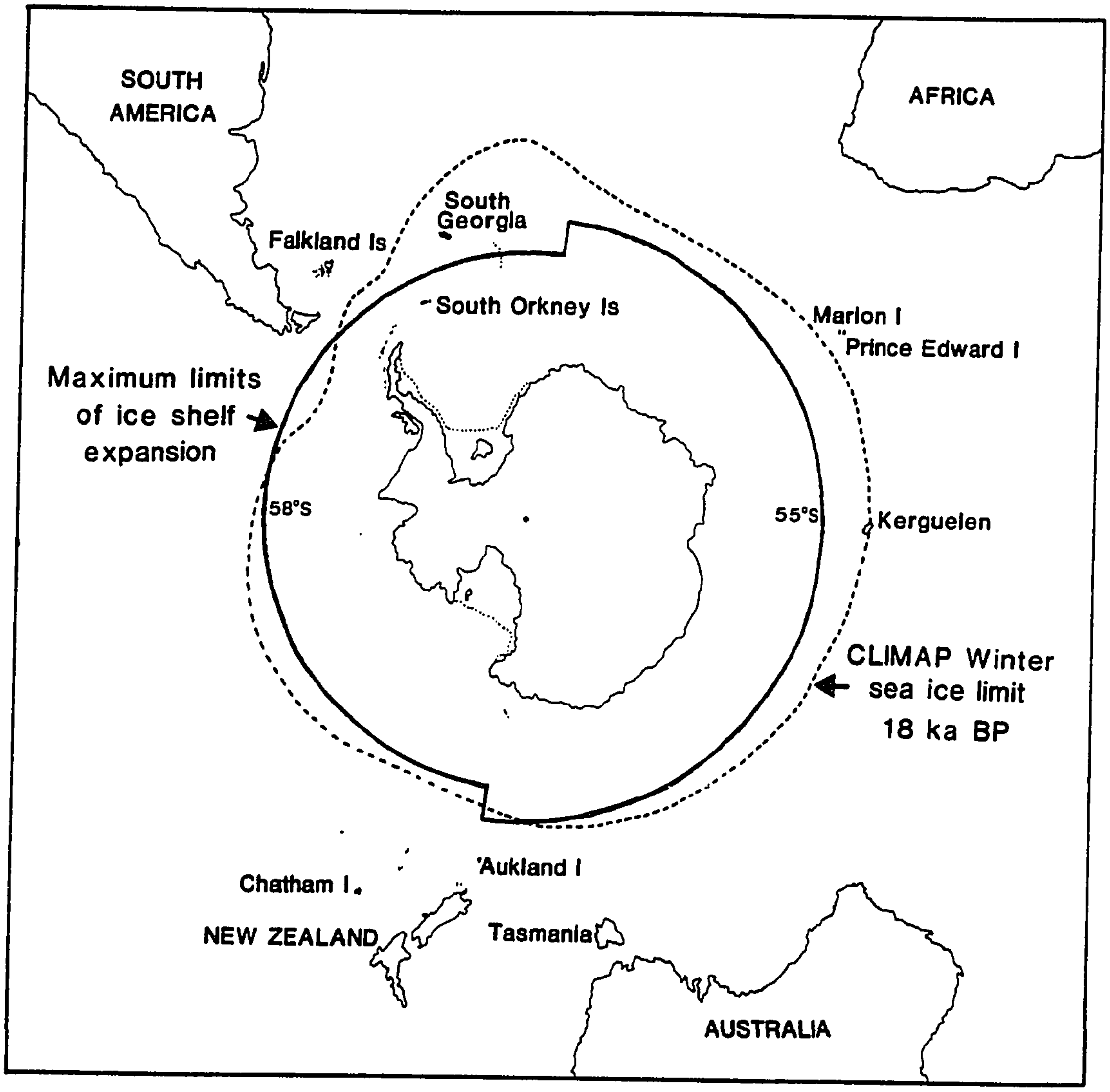


Figure 25. Possible maximum extent of late Wisconsin floating ice shelf, modeled using 18 k.a.winter ice limits suggested by CLIMAP [Hayes, et. al., 1976] (from Johnson and Andrews, 1986). East model limit is 55°S, west model limit is 58°S.

period 15-12 ka B.P., and one at about 125 ka B.P. Isotope signals for both events show changes equivalent to a 50-60 meter eustatic sea-level rise. These must be explained by the melting of floating ice since no evidence for sea-level rises of that magnitude exist at the times of the events. Field evidence shows that the younger event cannot be attributed to disappearance of Northern hemisphere glacial ice (Johnson and Andrews, 1986), and so must indicate Antarctic ice. If an ice shelf did extend from the Antarctic continent to 60° South latitude, it would have completely covered the South Orkney Plateau and grounded on the shallow areas of the plateau and islands. These conditions would have markedly changed sedimentation patterns on the plateau.

Results and Discussion

There are three possible scenarios of glacial expansion on the South Orkney Plateau during Late Wisconsin time.

(1) An ice sheet was grounded over the entire plateau.

(2) A smaller ice sheet was grounded near the islands, with or without floating ice (an ice shelf or permanent pack ice) covering the remainder of the plateau, and possibly the entire Southern Ocean.

(3) Expanded ice cover was limited to the islands, and ice conditions over the plateau were similar to those of today.

Evidence for grounded ice on the plateau and floating ice (shelf or pack) over the plateau during late Wisconsin time is found in cores collected from different locations on the plateau and slope. Evidence for the presence of a massive floating ice shelf is inconclusive.

Evidence for Grounded Ice on the Plateau

Evidence for grounded ice is confined to cores from less than 250 meters depth, which is compatible with the glacial expansion model proposed by Sugden and Clapperton (1977). Core sample 85-21 (depth 246 m), closest to the islands and located on the bathymetric high separating the two branches of Signy Island Trough (figure 26), is an overcompacted diamicton. A system of criteria for describing glacial and glacial marine deposits has been developed by Anderson, et. al. (1980) (table 4). Criteria used in interpretation of core sample 85-21 are:

(1) homogeneous and restricted lithologic composition (quartz-albite-mica schist);

(2) small depth of core penetration suggesting overcompaction;

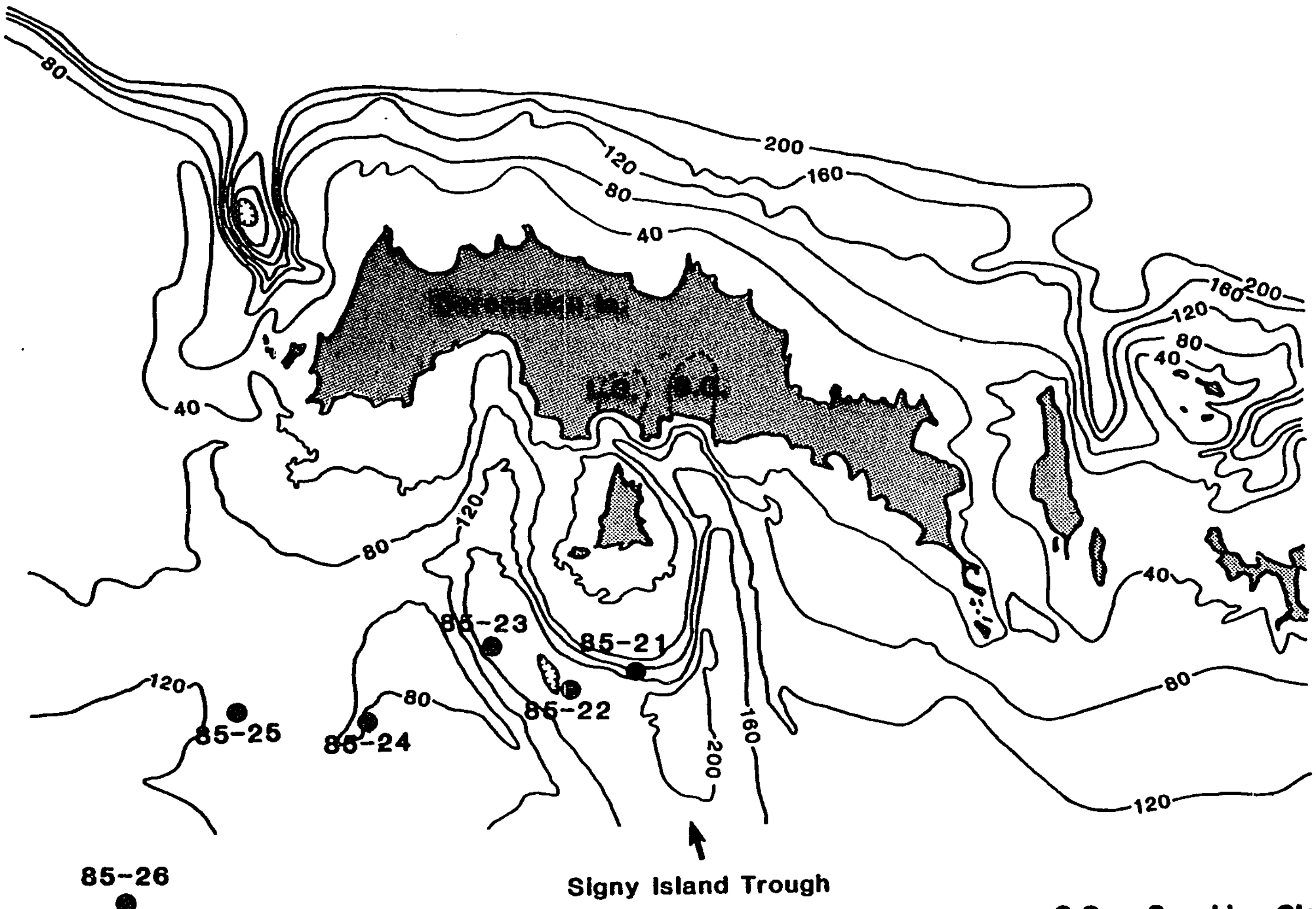
(3) complete lack of marine fossils; and

(4) texture - very poorly sorted, polymodal, and slightly negatively skewed.

All 15 pebbles removed from the three core samples (cutter nose, core catcher, and bagged core) and the bottom grab sample at location 85-21 are of petrologically identical schist. In the gravel fraction (-1 phi to pebble size) 99.6% or 234/235 grains counted are composed of the same identical schist. Point counting of the three core samples reveals uniformly 97-98% of the coarse sand fraction (-1 to 1 phi) is either the schist or its separate mineral components (quartz, feldspar, or mica). The other 2% consists of accessory minerals such as garnet, and quartzites, which may actually be a component of the schists. Thus, virtually all of the grains could be sourced from a single location. The obvious source for the schist type present in sample 85-21 was described by Thomson (1974) and is directly upstream along what would have been the flow line of the expanded Sunshine and Laws Glaciers, which partly formed the Signy Island Trough (figure 26). By comparison, coarse sand and gravel within compound glacial marine samples from the plateau (85-29 and 85-30) contain from 1% to around 15% exotic material, such as volcanics (scoria and pumice) and felsic plutonic rock fragments. Compound glacial marine units from slope cores contain up to 20% or more exotic lithologies.

Sample 85-21 is interpreted as either a basal till or a transitional glacial marine

Figure 26. Detail of South Orkney Plateau bathymetry near the islands showing location of Signy Island Trough and two of the active glaciers on the southern coast of Coronation Island. Locations of cores 21 through 26 are also shown. Bathymetry is in meters.



S.G. – Sunshine Glacier
L.G. – Laws Glacier
● Core and/or Grab Location
C. I. 40 fathoms

TABLE 4. CRITERIA FOR DISTINGUISHING BASAL TILLS, GLACIAL MARINE DEPOSITS, AND SEDIMENT GRAVITY FLOWS (After Anderson, et. al., 1980)

	BASAL TILL	TRANSITIONAL GLACIAL MARINE	COMPOUND GLACIAL MARINE	SEDIMENT GRAVITY FLOW DEPOSIT
STRATIFICATION	None (massive)	Subtle, if present	Crudely to well strati-fied	Massive, graded, or laminated
CONTACTS	Sharp upper and lower	Gradational upper, sharp or gradational lower	Gradational upper and lower	Sharp upper and lower
TEXTURE	Polymodal, neg. skewed matrix. Homo-geneous within units	Polymodal, homogeneous within units	Broadly bimodal with silt mode and unsorted ice-rafted mode	Polymodal, poorly to well sorted
PHYSICAL PROPERTIES	Overcompacted	Loosely compacted	Water saturated	Loosely to moderately compacted
PEBBLE SHAPE	Medial round-ness and sphericity; 80% facted 12% abundantly striated	Medial round-ness and sphericity; 80% facted 12% abundantly striated	Low to medial roundness and sphericity; 80% facted 6% abundantly striated	Unaffected by transport, source con-trolled
MINERALOGY	Homogeneous	Homogeneous	Heterogeneous	Heterogeneous, source con-trolled
MARINE FOSSILS	None, or reworked	Rare to abundant,low diversity	Variable abundance and diversity	None, or reworked
DISTRIBUTION	Continental shelf	Continental shelf	Continental shelf to abyssal floor	Continental shelf to abyssal floor

deposit. The fundamental difference between these two kinds of deposits is their mode of deposition, since both are composed of basal debris. A basal till is deposited from grounded ice by the process of lodgement, whereas a transitional glacial marine deposit is melted out from the base of a floating ice shelf near its grounding line (Anderson, et. al., 1984). The distinction is significant in trying to establish a previous grounding line for an ice sheet or glacier; basal tills and transitional glacial marine sediments could be deposited adjacent to each other from the same ice body, one on either side of the grounding line.

In a surface sediment sample, the only criteria which distinguish basal tills from transitional glacial marine deposits are (1) the possible presence of diagnostic marine fossils, which would be found only in the transitional deposit, and (2) degree of overcompaction. Since sample 85-21 contained no marine fossils, this criterion is inconclusive. A basal till deposit should have cohesive strength greater than 0.25 kg/cm^2 (Anderson, et. al., 1980). Core sample 85-21 was very hard but too small (a few centimeters long) to obtain reliable cohesive strength measurements. However, regardless of whether this sample is interpreted as basal till or transitional glacial marine, it indicates that grounded ice has extended further out onto the plateau than at present.

Samples taken at shallower depths, but futher seaward from the islands (cores 85-24, -25, and -26) also contain evidence of expanded ice during the time represented by the cores. The cores are short (the longest is 40 cm), partly because marine currents are very active at these depths and create lags, or residual glacial marine deposits, with large clasts which prevent core penetration. Shallow penetration may also indicate a glacially overcompacted deposit (i.e. lodgement till) at or very close to the surface. Unless the overcompacted deposit is successfully sampled, it is impossible to clearly differentiate between the two causes of shallow penetration. At sample location 85-24 (depth - 133 m), lack of penetration caused recovery of only a bottom grab and an extremely small amount of core (appendix B). Texturally, the samples are poorly sorted, although due to current winnowing, clay is nearly absent (<1%), and less than 10% is finer than 5.5 phi. The composition of the coarse sand and gravel fractions is 21% quartzo-feldspathic schist or its components and about 75% dolerite. The remaining 4% consists of some quartzites and a few accessory mineral grains. As in sample 85-21, all of the sample material could be derived from essentially one point source. Dolerite dikes and sills intrude the metamorphic rocks at Return Point on the westernmost end of Coronation Island and on Monroe and the Larsen Islands (Thomson, 1974). The two samples contain very little biogenic material, mostly broken sponge spicules and a few broken (probably reworked) diatoms. Therefore, these samples are interpreted as either a transitional glacial marine deposit or basal till; as for 85-21, the small sample size precludes making a definitive interpretation.

The bottom grab sample recovered at location 85-25 (depth - 155 m) is an unsorted glacial marine deposit (appendix B); 91% of coarse sand is schist or its components, 5% is quartzite or meta-sediments, 2% is igneous and 1% consists of forams and other fossil fragments. The matrix is a siliceous mud; diatoms are common and sponge spicules are abundant. The core at location 85-25 could be a diamicton, but it was washed during recovery, so that textural analysis downcore is not possible. Petrographic examination of the coarse sand (-1 to 1 phi) and gravel (larger than -1 phi) fractions reveals a nearly mono-lithologic composition throughout core 85-25, similar to sample 85-21, consisting of 94% to 95% schist, 3% quartzite or meta-sediments, and 2% dolerite. This sample could also be derived entirely from Coronation Island. Because the core was washed, all clay- and silt-sized material was lost, including any diatoms or sponge spicules which may have been present. Washing also indicates that the sample was loosely compacted, and thus is probably not a basal till. However, the mineralogic analysis suggests that the core is more likely to be a transitional glacial marine than a compound or residual glacial marine deposit.

The lower 20 cm of core 85-26 (depth - 220 m) is an overcompacted diamicton (appendix B). The cohesive strength value at shearing was 0.8 kg/ cm^2. All of the material larger than -1 phi (gravel and pebbles) consists of schist and a few pieces of dolerite. Although all coarse sand could possibly be sourced from the islands, it shows a wider range of lithologies than in samples 21, 24, or 25. Point counting determined 76% - 86% of the -1 to 1 phi fraction is composed of schist, quartz, feldspar, or mica, from 5 - 15% is quartzite (or meta-sedimentary rock fragments), and 8 - 12% consists of dolerite. All of these lithologies crop out on the southern coast of Coronation Island, and thus could have been deposited as lodgement till from the same basal debris zone. However, there are slight variations in the percentages of metamorphic, meta-sedimentary, and igneous lithologies within the unit, and the relatively broad range of lithologies within a basal debris zone would be fortuitous. A lodgement till deposit should be more homogeneous, and should probably also have a more restricted composition.

Texturally, the diamict unit is unsorted, containing clay-sized through pebble-sized (> 1 cm) material. The upper contact is sharp and is marked by a thin lag deposit. Following retreat of grounded ice, or under floating ice, marine currents could create a lag deposit at this depth (<200 meters at that time) by eroding the fine-grained material out of the top few centimeters of the diamict, or by winnowing the fine-grained sediment in the water column from what is deposited above the diamict. There are no diatoms in the diamict unit, but sponge spicules are present.

The overlying unit has a similar matrix composition but is more loosely compacted (cohesive strength = 0.27 kg/cm^2), and diatoms, as well as sponge spicules, are common. This upper unit is interpreted as a compound glacial marine deposit, and probably represents depositional conditions much like those that exist today.

Tentative interpretation of the diamict unit is that of a transitional glacial marine deposit. The lack of diatoms suggests deposition under thicker and more persistent ice than exists today on the plateau. However, it seems unlikely that the range of lithologies present would have come from a single, point source on the island, as do samples from location 85-21 and 85-24. The mineralogic similarity of the overlying compound glacial marine unit suggests that ice conditions were not neccessarily radically different from those existing today when the diamict was deposited. Also, a lag would not be easily formed from the top of a till, due to its high cohesive strength, but could be formed from a transitional or compound glacial marine deposit. The overcompaction of the diamicton is most easily explained by lodgement till deposition, but could be due to other possible causes: one, ice was grounded over this area at the time corresponding to the top of the diamict unit, but deposited no basal till; or two, a large iceberg grounded on the plateau at this location, overcompacting the diamict unit. It is also possible that the overcompacted diamicton represents lodgement till and the lag represents a transitional deposit which occurred as the ice sheet decoupled from the plateau and retreated landwards.

Plateau cores and surface samples from deeper than 250 m (85-27 through 85-32) contain no evidence of deposition by grounded ice. Core 85-27 is mainly diatomaceous mud, with minor interbedded layers of carbonate sand and sandy mud, and a possible sub-pack ice deposit. Core 85-28 is a pebbly diatom mud, containing more ice-rafted debris (IRD) than the other glacial marine sediments of the plateau. Cores 85-29 and 85-31 are typical diatomaceous glacial marine deposits. Grab sample 85-32 is a diatomaceous mud with very little IRD.

Core 85-30 is very short (21 cm) and bottomed out in a hard, unsorted diamicton (appendix B); cohesive strength measured was 0.55 kg/cm^2. All of the gravel and pebbles are lithologic types that are found on the South Orkney Islands. Most of the larger clasts (>1 cm) are composed of schist or quartz. Eighty percent of gravel (-1 phi to pebble size) is also composed of schist or quartz. However, diatoms and sponge spicules are present thoughout the core, and the sand-sized component has a more heterogeneous composition (including a small percentage of exotic material) than the coarser fraction. Thus, this sample does not fit some of the important criteria used to define a basal till deposit. For a till to have been deposited at core location 85-30, grounded ice would have had to expand at least 110 km out from its source on Coronation Island, which is only about 13 km at its widest by 48 km long, with a surface area of roughly 340 km^2 (Marr, 1935). Also, there is no evidence of basal till deposition in cores 27, 28, 29, 31 or grab sample 32 (except that core recovery at location 85-32 was small, indicating a hard sea floor). The evidence given supports the interpretation that ice was never grounded on the South Orkney Plateau deeper than the present -250 meter bathymetric contour. The origin of the overcompaction in core 30 may have been loading of a compound glacial marine deposit, perhaps by an iceberg grounding on the plateau. Although rare, the presence of any exotic lithologies within the IRD precludes the interpretation of lodgement till or sub-ice shelf transitional glacial marine deposition.

From field studies (Sugden and Clapperton, 1977), it is apparent that even at its maximum extent, the South Orkney ice cap left much of the higher elevations of Coronation Island ice free. Sugden and Clapperton (1977) estimate that ice altitude was probably very similar to today; their reconstructed maximum ice cap is no thicker than 600 meters at its thickest part, covers an area of 6000 km^2 and a volume of 3000 km^3. Even with a 130 meter sea-level drop during a glacial advance, a much larger source area and much thicker ice cap would probably be required to ground an ice sheet further seaward than the present -250 meter contour.

The age of the maximum glaciation in which the troughs and rugged bathymetry were created was estimated by Sugden and Clapperton (1977) to have been at least 200 ka B.P. This date was based on evidence from South Georgia and the South Shetlands, and inferred to be approximately synchronous for the South Orkney Plateau. Deep Freeze 1985 geophysical data and the sedimentation rate estimated from ^{14}C dating of core 85-23 suggest a younger age estimate for trough formation. There is about 70 milliseconds of sediment fill at core location 85-23 in Signy Island Trough, shown on seismic line SO-H (figure 27). This would be about 60 meters of sediment deposited since the trough was carved. At the approximate sedimentation rate determined by radiocarbon dating of core 85-23 ($\approx$50cm ka^{-1}), this fill represents approximately 120 ka of sediment. Thus, if sedimentation rate has remained constant, the trough was carved or re-carved approximately 120 ka ago. This evidence is not conclusive; sedimentation rates may have been different in the past, and small hiatuses, undetectable on the seismic data, could be present. However, this age correlates fairly well with the date of an early Wisconsin climatic cold peak at approximately 105 ka, determined by work on radiolarian fauna by Hays, et. al. (1976).

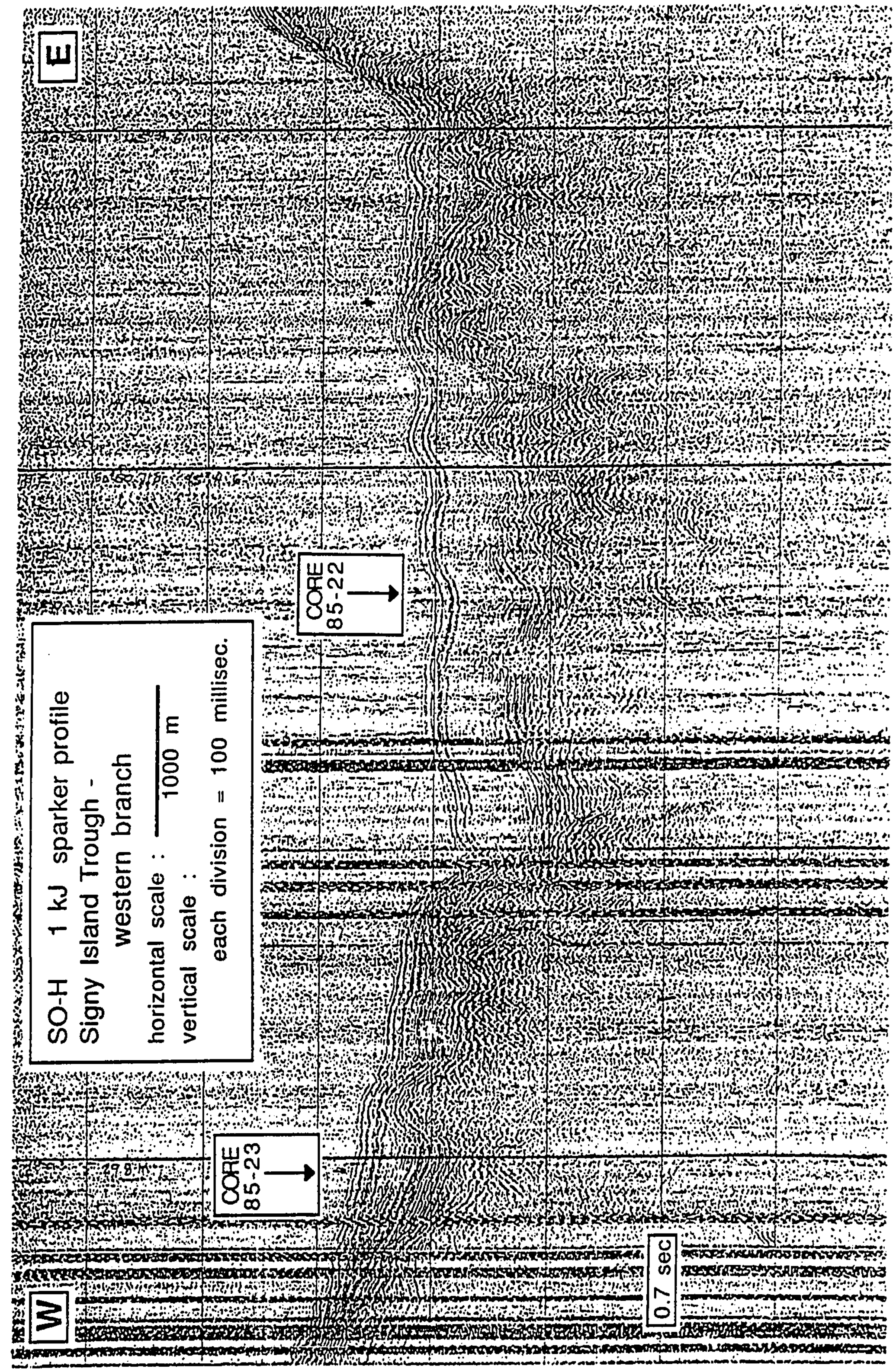
Evidence for Ice-Shelf Cover over the Plateau

Sediments deposited under a floating ice shelf are by definition transitional glacial marine deposits, characterised especially by homogeneous texture and mineralogy, low diversity and abundance of marine fossils, and pebble shapes indicative of basal transport, including faceting and striations (table 4) (Anderson, et. al., 1980).

Sedimentary units deposited on the South Orkney Plateau underneath a massive, stable, continent-surrounding ice shelf, would be transitional glacial marine deposits, and thus would be expected to have certain distinguishing characteristics. One, the biogenic component (primarily diatoms) would be rare or absent; two, there would be a paucity of IRD, and thus a fine-grained texture, and three, any IRD within a sub-ice shelf unit should have a restricted mineralogy. These characteristics and their causes will be discussed below.

Biogenic sedimentation in the Antarctic is mainly due to diatom productivity. Diatom abundances and distribution depend on availability and quality of light (DeFelice

Figure 27. Seismic data from profile SO-H, showing the western branch of Signy Island Trough. At least two complete seismic sequences are present within the trough fill. The sedimentary fill at location 85-23 is approximately 70 milliseconds, or 60 meters thick. Using the sedimentation rates determined from ^{14}C dating for the Signy Island Trough, this corresponds to about 120 ka of deposition. The hummocky surface reflects the highly irregular basement within the trough. The fault cutting the trough is very recent, probably no more than a few thousand years old.


W
E
SO-H 1 kJ sparker profile
Signy Island Trough -
western branch
horizontal scale : 1000 m
vertical scale :
each division = 100 millisec.
CORE 85-23
CORE 85-22
0.7 sec

and Wise, 1981), which would be extremely limited under an ice shelf. A sub-ice shelf assemblage of benthic forams has been described (Anderson, 1975), however, diversity and abundance would be small. Near an ice shelf edge, fluctuating current velocities could transport in and deposit some biogenic material. Biogenic material frozen into the base of the Ross Ice Shelf may have been transported in by currents (Zotikov and Jacobs, 1985).

Due to the basal thermal regime, and processes of tidal pumping and ocean current circulation, the base of a large ice shelf is melted landward of the calving line (Robin, 1979; Thomas, 1979; Hughes, 1981). This theory is supported by observations of net melting at the base of the Ross Ice Shelf (Jacobs, et. al., 1979), the lack of basal debris found in drilling through the Ross Ice Shelf (Drewry and Cooper, 1981), and also by indirect observations of bottom melting in the frontal 50 km of the Ronne Ice Shelf, estimated to be 3.2 meters/year at 20 km landward of the ice front (Kohnen, 1982). Net freezing onto the base of the Amery Ice Shelf was found for 210 km seaward of the grounding line (Morgan, 1972), but the remaining 70 km to the ice shelf showed little positive or negative mass flux, and as in the Ross Ice Shelf no glacially eroded basal debris was found in a hole drilled through the ice shelf (Budd, et. al., 1982). Also, a paucity of IRD was found in surface samples collected along the front of the Ross Ice Shelf (Anderson, et. al., 1984).

Icebergs calved from large ice shelves therefore should have little or no basal debris and will not raft much sediment out to sea. Unlike an ice shelf produced by surging from the continental ice sheet (Wilson, 1964, 1969), a massive ice shelf developed due to Northern hemisphere glaciation and maintained primarily by surface accumulation (Johnson and Andrews, 1986) would not cause an increase in the amount of IRD carried out to the Southern Ocean. In fact, a decrease in IRD would occur except in a zone probably no more than 8 km in width adjacent to the ice shelf grounding line. The exception is englacial or supraglacial debris, however englacial entrainment of debris is uncommon in an ice shelf because temperatures over the land based ice sheets which feed the ice shelves are always well below freezing, thus most ablation is by calving and flow lines within the ice will be horizontal or downward (Hughes, 1981). Therefore, virtually no debris from the continent should be rafted out within an ice shelf as far as the South Orkney Plateau.

Flow lines within a massive, continent-surrounding ice shelf have not been discussed, but it seems likely that any IRD deposited on the plateau during a massive ice shelf expansion would have come from the more proximal South Orkney Islands. Thus, any IRD within a sub-ice shelf unit should have a restricted mineralogy. An upward change from an IRD mineralogy restricted to lithologies found on the South Orkney Islands to a more heterogeneous mineralogy including exotic material would indicate the retreat or collapse of the ice shelf. Today, IRD is sourced not only from the South Orkneys, but from all over the peninsula and possibly from other areas of the continent as well. However, petrographic data from compound glacial marine samples collected on the plateau shows very little exotic material (from less than 1% up to a maximum of about 10%), so that for plateau cores, an ice-shelf retreat may not show up in petrographic data alone.

Biogenic (i.e. diatomaceous) sediments and ice-rafted debris make up an important percentage (often more than 50%) of the total amount of sediments on the South Orkney Plateau and slope today. Thus, sedimentary units deposited during a period of massive ice-shelf expansion would also be thin, since accumulation of IRD and biogenic sediment would be slow or non-existent under a large, coherent ice shelf. Any rapid sedimentation would be mainly a function of sub-ice shelf marine currents redistributing sands and silts over the plateau. Given the right conditions, a period of such an ice shelf expansion could even be represented by a hiatus. If the ice shelf is thick enough to prevent biogenic production, little or no IRD is transported out onto the South Orkney Plateau, and marine currents are maintained at a velocity just fast enough to keep any fine pelagic material present in suspension, no deposition should occur at all. Unfortunately, such hiatuses are not easily recognized, measured, or correlated between cores. Although current erosion, slumping, and sediment gravity flow are altering the deposits on the slope, similar, perhaps residual, transitional glacial marine units should also be present in some slope cores, if an ice shelf expanded from the continent to 58° South.

Plateau cores

Most cores collected from the plateau area (<500 m depth) are short (20 - 80 cm) and, depending on sedimentation rates, may not have penetrated sediments as old as 16 - 13 ka B.P. Core 85-27, however, recovered 200 cm of mainly pelagic sediments (appendix B). The sedmentation rate at this core location is unknown, but considering the current regime on the plateau (discussed in Chapter 3 - Surface sample textural data), a sedimentation rate greater than a few centimeters per 1000 years seems unlikely. This core should, thus, contain the sedimentary record of any glacial events during the last 30 - 40 ka B.P. One section (depth - 140-180 cm) in the core does contain very few diatoms. It is moderately compacted with a sharp lower contact and a gradational upper contact, and has a slightly different mineralogy than the rest of the core (i.e. more mafic material). Cohesive strength increases from an average of 0.19 kg/cm^2 above the unit to 0.37 kg/cm^2 within the unit. However, it is coarser grained than sections above or below, which suggests more IRD, or removal of diatoms by winnowing. Immediately above and below the compacted unit are thin, very fine-grained sections of different color than the rest of the core, much higher diatom abundance (nearly diatom ooze), and relatively low cohesive strength values. The diatom-poor unit could represent a period of heavier pack ice cover, but because of the increase in IRD, deposition from beneath a coherent ice shelf is unlikely. No other sections in the core indicate expanded ice cover. Other plateau cores that contain sections with few diatoms are 85-26 (disscussed above under "Previous Glacial Expansion") and 85-31. Core 85-26 (appendix B) contains a unit that could represent deposition under a massive, coherent ice shelf, but at a much higher level in the core than 85-27. Most of the diatom-poor section of 85-31 is flow-in, so that interpretation is unreliable.

Slope Cores

Most cores collected from the slope (depths >500 m) contain at least one section with very few or no diatoms, although few are correlatable. In several cores (85-1, -3, -8, -12, -15, -33, -35, and -36) the diatom-poor section is overlain by a diatomaceous compound glacial marine deposit to the top of the core. In cores 85-1, -8, -12, -15, -33, and -36, IRD abundance also decreases within the diatom-poor section.

Two cores from different depths on the slope (85-12 and 85-33) were sampled more closely (every 10 cm) for a detailed, downcore sedimentological study. Data show evidence for a past glacial advance in the form of expanded floating ice cover.

Core 85-12 can be divided into 4 genetic units on the basis of visual core description, textural analysis, IRD content, mineralogy, and biogenic (diatom) content (appendix B). The upper 155 cm of core comprise a diatomaceous mud unit with burrowing in some intervals and a fairly wide diversity of diatom species. The unit is texturally homogeneous except for a slight coarsening at the top, which could be due to minor washing of the core top during recovery. IRD is present but amounts to less than 15% of the total sediment weight, except in the top 20 cm of core. The second interval is a thin (about 8 cm) laminated diatom ooze (155-163 cm). Although it contains slightly less sand and coarse silt than sediments above or below it, the dominant mode of the unit is slightly coarser (9.75-12.0 chi), perhaps reflecting the dominant size distribution of diatoms within the unit. The third interval (163-198 cm) has a sharp basal contact, a general fining-upwards trend in both the mean and dominant mode, and one soft sedimentary clast near the middle of the unit. The upper contact is not sharp, however, and diatoms and sponge spicules are common throughout the unit. It is tentatively classified as a debris flow.

The last unit (underlying the possible debris flow) grades upwards from mainly compound glacial marine sediment at the base of the core, to a "sub-ice" deposit at 198 - 220 cm. The "sub-ice" deposit is finer grained than the rest of the unit (contains less IRD), is texturally and mineralogically homogeneous, and diatoms are rare. However, it contains some exotic material (mostly scoria and pumice) within the coarse sands. The next section (220 - 255 cm) is also texturally and mineralogically homogeneous, diatoms are rare, and pebbles plot within Boulton's (1978) field of basal transport. It also contains a few percent exotic igneous rock fragments; and from 6 - 14% volcanic rock fragments in the coarse sand fraction. Possible sources for the scoria and pumice are volcanoes in the northern Antarctic Peninsula and South Shetland Islands. Below 255 cm, the mineralogy and texture are similar to those of the overlying units, but it contains two very angular pebbles and three pebbles exotic to the South Orkney Plateau (two granites and a basalt). It is also more cohesive and diatomaceous.

A possible interpretation of the depositional history of this core is as follows. From the base (277 cm) up to about 255 cm is a compound glacial marine unit grading upwards into a sub-pack ice unit, deposited under increasingly greater ice cover. The "sub-ice" unit (255 - 200 cm) was presumably deposited when the pack ice expansion was most extensive and stable, allowing deposition of less exotic debris (material not sourced from the South Orkney Plateau), and less IRD in general. The contact at the top of the unit (at 198 cm) is sharp, which implies a rapid change in the extent of ice cover. In the overlying unit (198 - 163 cm) IRD content drops dramatically and biogenic content increases. Mean grain size is significantly finer, but the dominant mode remains roughly the same across the contact and then fines upwards through the unit. The reason the mean fines across the contact but not the mode is because the coarse fraction (< 4 phi) drops from 40% to about 18% of the sediment, and percent gravel and pebbles (<-1 phi) drops to zero, i.e. IRD content is very low. This is consistent with the interpretation of deposition by debris flow, however, the fining-upwards mode could also indicate waning current flow over time. Above the debris flow the diatom content increases greatly and coarse material decreases, probably representing pelagic, open-marine deposition during a period of relatively warm climate and less sea ice cover. During deposition of the uppermost section (155 cm to the top), conditions were probably similar to those of today - primarily biogenic and pelagic deposition with a small amount of IRD (about 10-15%). Texture is remarkably homogeneous, as is diatom and sponge spicule content, evidence that little, if any, oceanographic change has occurred during the time represented by the upper section of core (155 cm). Mineralogy is consistent up core and is similar to most other diatom muds on the South Orkney Plateau and slope - quartz and feldspar grains dominate with minor amounts of lithic fragments and heavy minerals, particularly epidote and amphiboles.

Core 85-33 is divided into three basic genetic units (appendix B). The top 20 cm of core consists of a sandy diatom mud with a fairly well-sorted sand mode at about 6.0 chi (2.75 phi). The consistency of the modal size and its degree of sorting indicates that it is probably current derived. The same mode shows up in samples at 1, 4, 11, and 18 cm. The second unit (approx. 20 - 60 cm) has a restricted mineralogy, 80% of the coarse sand fraction is quartz, feldspar, mica, or schist fragments, another 15% is locally-derived meta-sediments or dolerite, and exotic grains make up only 5% of the sample. The unit also lacks marine fossils and contains a relatively small amount of IRD. Texturally, the unit is homogeneously fine-grained, polymodal, and very poorly sorted.

From 60 cm to 80 cm there is a gradual downcore increase in mean grain size and percent IRD, and mineralogy is slightly less restricted. More exotic grains, i.e. plutonic and volcanic rock fragments, are present than in the overlying unit; marine fossils are still absent.

The basal unit (80 - 118 cm) is texturally homogeneous, with a larger percentage of IRD than the unit from 20 to 60 cm. The unit is also fairly mineralogically homogeneous; however, more exotic material is present (12 - 20% in the coarse sand fraction) than would be expected in a sub-ice shelf deposit. Sponge spicules are present, though not abundant; diatoms are absent. This unit could be interpreted as compound glacial marine. The absence of diatoms could be attributed to some increased ice cover, or possibly to current winnowing of fine material, since this section is coarser grained than the rest of the core. The exotic clasts (basalt and granite) and exotic grains in the coarse sands suggest that this unit was deposited under less pack ice cover than the overlying unit, and that peninsula-derived icebergs drifted freely through the area.

An interpretation of the depositional history of this core is as follows, starting from the base: first, during an early stage of a glacial expansion, deposition occurred under relatively thin and perhaps seasonal pack ice (118 - 80 cm). A gradual build up of the pack ice led to deposition of a transition unit (80 - 60 cm), and finally, a unit deposited beneath thick, perennial pack ice (60 - 20 cm). A moderately sharp contact at the top of the unit indicates, as in core 85-12, a fairly rapid disintegration of the ice. Then, under conditions similar or identical to those of today, a sandy compound glacial marine unit was deposited (20 cm to top of core). The current-derived component throughout this unit could be attributed to geostrophic flow of deep and bottom water from the Weddell Sea around the Powell Basin.

Although cores 85-12 and 85-33 both consist of compound glacial marine deposits overlying "sub-ice" deposits, the scale of the individual units is very different and some characteristics of the "sub-ice" deposits are not correlatable. Cores collected from depths similar to that of core 85-33 are more correlatable with core 33. Cores 85-1 and 85-15 both consist of apparently "sub-ice" deposits overlain by diatomaceous compound glacial marine sediments. However, the same cannot be said about shallower cores (from depths similar to core 12). Sediment gravity flow and slumping have affected more than 2/3 of the slope cores, particularly those from steep, mid-depth areas of the slope. Thus, a consistent, correlatable sedimentary record of the Pleistocene/Holocene glacial history of this area may only be found in very deep basinal or abyssal deposits.

Evidence against Major Late Wisconsin Sea-ice Expansion on the South Orkney Plateau

Two cores, 85-22 and 85-23, were collected from Signy Island Trough, which was probably carved during an early Wisconsin or late Illinoisian glacial expansion (Sugden and Clapperton, 1977). Core 85-23 (appendix B), dated using shell material (see appendix A - Carbon-14 Dating), is probably no more than 6-7 ka old at its base (approximately 3 meters), thus it would not contain pre-ice shelf break-up deposits, or sediments corresponding to a Late Wisconsin grounded ice event. Core 85-22, located in a deeper part of the trough, recovered over 550 cm of pelagic sediment with no obvious textural or compositional changes (appendix B). Although core 85-22 is much longer, its sedimentation rate may have been significantly higher than that measured in core 85-23, so that it may not represent a much longer time than core 23. Fine-grained sediments winnowed from the plateau would tend to collect in the deepest parts of the trough. Seismic data from core location 85-23 show no evidence of a major sedimentologic change in the upper 40 milliseconds, or about 30-35 meters of sediment (figure 27). At the sedimentation rate calculated for core 85-23, 30-35 meters of sediment represents 60-70 ka of deposition. Although the evidence is not conclusive, since a hiatus might not produce a seismic reflector, the data suggest relatively consistent depositional conditions and ice cover during the last 60 ka at this location.

Conclusions

South Orkney Plateau core and seismic data indicate that there has never been an ice sheet grounded over the entire plateau. The furthest seaward sedimentological evidence for grounded ice on the plateau was found at core location 85-26, currently at 220 meters depth. Also, field data show that the Coronation Island ice cap has never covered the highest points in the island (Sugden and Clapperton, 1977) and thus was probably never a large enough source to ground an ice sheet further than the -250 meter contour. Cores collected from the South Orkney Plateau and slope do contain sections which were apparently deposited under thicker and more persistent floating ice than exists there today. One characteristic common to these "sub-ice" deposits is the lack of, or very limited amount of biogenic material (especially diatoms). Although no specific correlations can be made between cores, nearly every slope core contains a section with very few or no diatoms. Some of these are sediment gravity flow deposits or products of current winnowing of silt-sized (diatom-sized) material, however many must represent deposition under sea surface conditions unsuitable for inhabitance by phytoplankton, normally abundant in the Antarctic Ocean. Terrigenous dilution is unlikely since the only proximal source of terrigenous sediment is the South Orkney Island group, which is too small to contribute a large percentage of sediment to the outer plateau and slope. Complete dissolution of siliceous tests at this latitude is also improbable since near-surface dissolution of biogenic silica in Antarctic Ocean waters is slow (Nelson and Gordon, 1982). In the Antarctic, the most likely condition under which non-deposition of diatoms would occur is beneath some kind of permanent (perennial) ice cover. Because some species of diatoms are known to thrive within and under sea ice (1-2 meters thick)

(Meguro, 1962; Horner, 1976, 1977; Hoshiai, 1977), a complete lack of diatoms probably indicates deposition under thick, permanent pack ice or a coherent ice shelf. A few cores from the plateau were probably deposited under a true ice shelf (i.e. those which may be either basal tills or transitional glacial marine sediments). However, there is no definitive evidence for the presence of a massive, coherent ice shelf over the entire South Orkney Plateau or slope.

The most likely ice condition represented by the "sub-ice" units within the cores is that of thick, permanent pack-ice cover. This condition could prevent much, or all, of the primary biogenic production, but would allow some large icebergs from the Antarctic Peninsula to pass through the area and deposit small amounts of exotic debris. Pack ice, unlike shelf ice, moves constantly, driven by winds and surface currents. Large, deep-draft icebergs within the pack ice, may be frozen in and move with it, or may move independently, driven by sub-surface currents. Today, Weddell Sea pack ice moves in a generally clockwise pattern around the basin, as shown by the drift tracks of the Endurance and the Deutchland. During late Wisconsin time the drift pattern of the pack ice was probably different and more sluggish because of expanded permanent pack ice to at least 60° South, and possibly expanded ice shelves as well. Therefore, fewer peninsula icebergs would pass over the South Orkney Plateau during a given time, and generally less IRD and exotic material would be deposited.

Sedimentological data from cores 85-22 and 85-23 (in the Signy Island Trough) suggest no changes in the extent of floating ice cover during at least the last 6-7 ka. The textural homogeneity and lack of diatom-poor sections in the cores indicates stable glacial and oceanographic conditions at that location.

Although the seismic data imply that an ice shelf never covered the Signy Island Trough, the evidence is not conclusive. It is possible that a hiatus caused by an ice shelf over the area would not produce a seimic reflection. Conclusive evidence for an ice shelf was not found in slope cores either. However, a large percentage of the cores are affected by sediment gravity flow, and cannot be used to interpret glacial history. Therefore, in spite of the lack of supporting evidence, the ice-shelf expansion hypothesis of Johnson and Andrews (1986) cannot be ruled out.

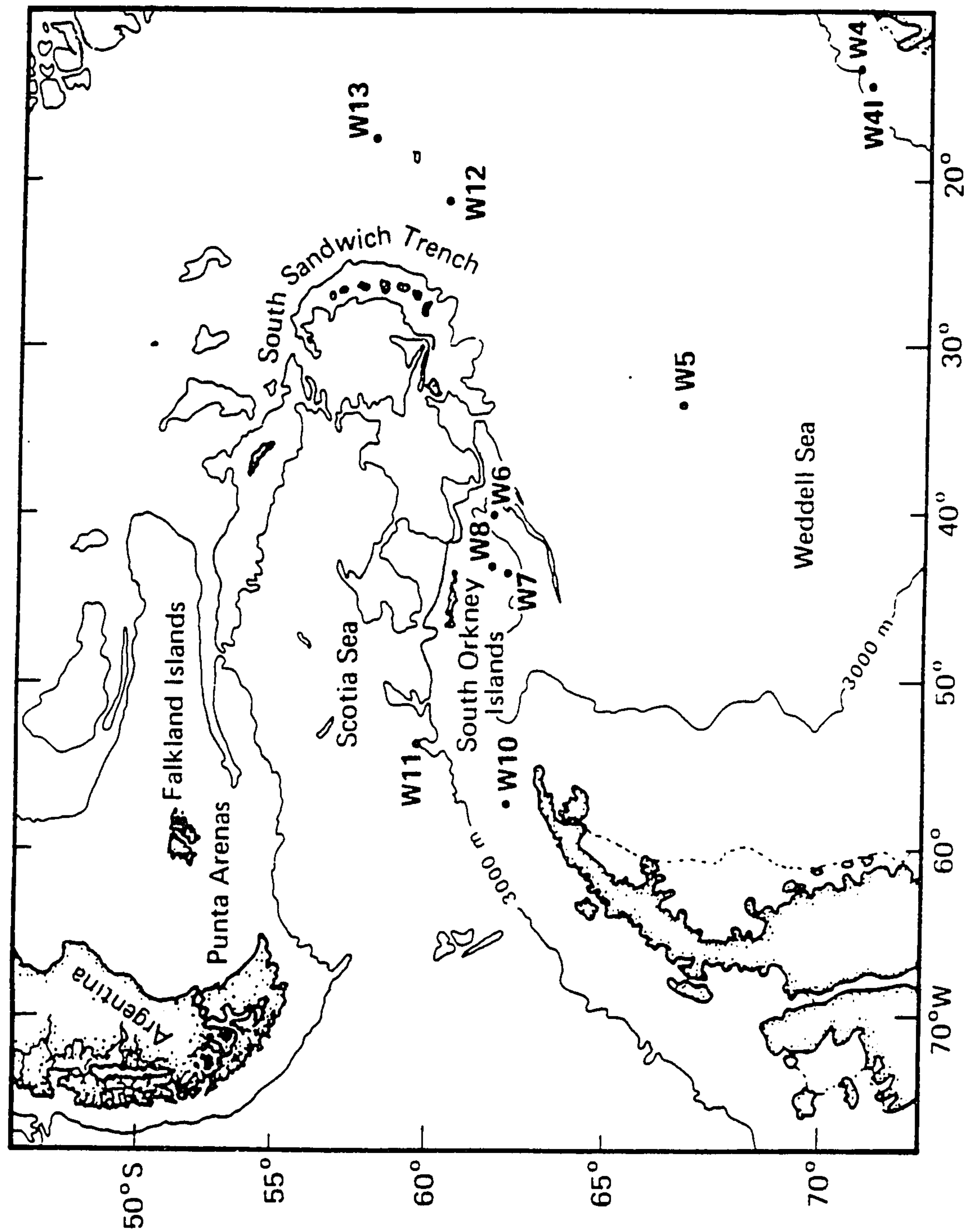
CHAPTER 5. PALEOCEANOGRAPHY

Introduction

Various workers have inferred that a causal relationship exists between Antarctic water mass production and circulation, and glacial expansion and retreat of the Antarctic Ice Sheets (Kennett and Brunner, 1973; Kennett, 1977; Ciesielski, et. al., 1982; Osborn, et. al., 1983). The study of Antarctic glacial history, using this inferrence, is a major objective of the 1987 O.D.P. Leg 113 coring operations. Continous core was recovered from three sites on the South Orkney Plateau during this leg (figure 28: W6, W7, and W8) in order to study vertical water mass distribution and paleoclimate, and interpret Cenozoic Antarctic glacial history (Kennett and Barker, et. al., 1986). The study of water mass distributions will utilize measurements of oxygen and carbon isotopes on calcareous tests expected to be found in the cores. Paleoclimate and ice volume history of the Antarctic will be studied using oxygen isotope measurments, ice-rafted debris (IRD) accumulation, and possible records of continental vegetation. The Deep Freeze 85 investigation also has measured apparent IRD accumulation, as well as several other parameters, to study the feasibility of paleoceanographic interpretation in this area. Certain results of this investigation reveal possible problems in achieving the major objectives. Therefore, this paper is potentially important to any investigations using the cores from sites W6, W7, or W8.

There is evidence that during late Wisconsin time ice sheets were grounded on the Weddell Sea continental shelf (Anderson, et. al., 1980; Elverhøi, 1981), and that some kind of floating ice expansion also occurred during that time (Johnson and Andrews, in press). Evidence for late Wisconsin (?) glacial expansion on the South Orkney Islands and Plateau is presented in Chapter 4 (Glacial History and Regime). The late Wisconsin climatic change and resulting glacial expansion would certainly have been severe enough to cause the increases in water mass production and circulation expected from the models of

Figure 28. ODP leg 113 site locations in the Weddell Sea and southern Scotia Ridge areas. Sites W6, W7, and W8 were drilled on the eastern South Orkney Plateau.


Argentina
Punta Arenas
Falkland Islands
Scotia Sea
South Sandwich Trench
South Orkney Islands
Weddell Sea
3000 m
3000 m
W4
W4I
W5
W6
W7
W8
W10
W11
W12
W13
50° S
55°
60°
65°
70°
70°W
60°
50°
40°
30°
20°

Kennett and Brunner (1973) and Osborn, et. al. (1983). Therefore, if a causal relationship does exist between water mass production and glacial expansions, sediments of Pleistocene and younger age should show paleoceanographic evidence of at least one glacial expansion and subsequent retreat. Because of the oceanographic and geographic location of the South Orkney Plateau, sediment cores collected there are an ideal data set with which to test the feasibility of paleoceanographic interpretation, and the relationship between oceanographic change and glacial history.

Methods and materials

Two cores (85-12 and 85-33) were chosen for detailed, down-core textural and compositional analyses because they appeared least likely to be the products of slumping or affected by sediment gravity flow, long enough to provide a record of sedimentation through the most recent glacial maximum, and possibly deposited at depths influenced by two different water masses. Core 85-12 (water depth 962 meters) was deposited within the zone of intermediate depth water masses (specifically Warm Deep Water), whereas core 85-33 (water depth 2843 meters) may have been deposited within a zone affected by a bottom-water mass composed of a mixture of Weddell Sea Bottom Water and Warm Deep Water. The depth of core location 85-33 is approximately the present lower boundary of Warm Deep Water in the Weddell Sea area, and bottom potential temperatures at the location of core 85-33 suggest a mix of roughly half Weddell Sea Bottom Water and half Warm Deep Water (figure 29; Foster and Carmack, 1976). Each core was sampled at 10-cm intervals; parameters studied include total grain size, apparent IRD content, mineralogy of coarse sands, gravel, and pebbles, and biogenic content (approximate abundance of diatoms and other microfossils). IRD content and qualitative biogenic content were also measured in all other slope cores, except those consisting primarily of sediment gravity flow deposits. Other selected cores were also analyzed for total grain size

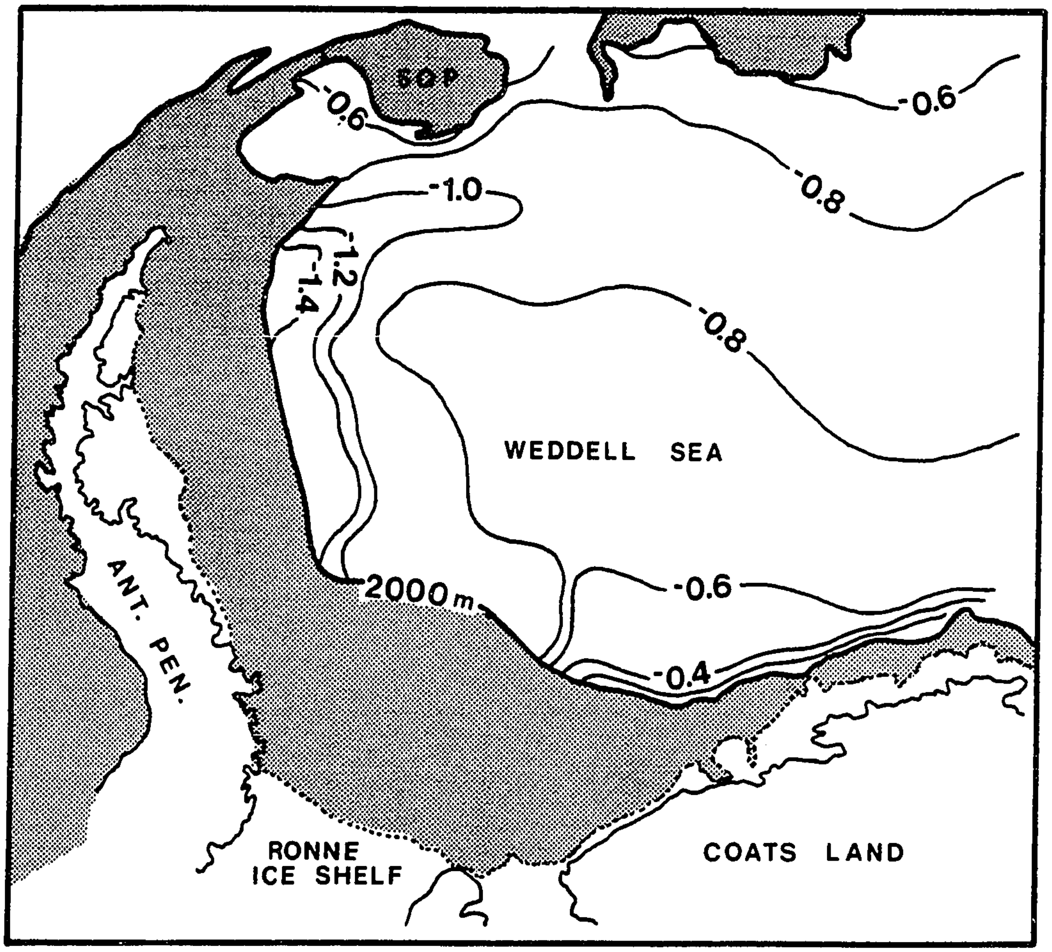


Figure 29. Bottom potential temperatures for depths greater than 2000 meters (from Foster and Carmack, 1976). The temperature along the eastern Powell Basin suggests a mixture of about half Weddell Sea Bottom Water and half Warm Deep Water.

and mineralogy.

Results

Debris flows, turbidites, and slumps are ubiquitous on the western slope of the South Orkney Plateau, precluding (with very few exceptions) any correlations between even closely spaced cores. Eleven of the 23 cores collected from the slope contain one or more sedimentary clasts in at least one core section. Most of core 85-2 consists of distinctly graded turbidites; 12 cores are interpreted as part or all debris flow (figure 30). Only nine of the 23 cores (85-1, -3, -8, -10, -14, -15, -16, -33, and -36?) appear to be free of any influence by sediment gravity flow. Of these, one (85-16) is outcrop (or possibly a slump) and one (85-14) is a lag. Core 85-36 was collected from a slope which appears to be heavily affected by slumping. Thus, only six of the slope cores, or slightly more than one-fourth of those collected, can be relied upon to contain a possible undisturbed record of glacial history or paleoceanographic changes. In addition, every slope seismic profile contains evidence of slumping on a large scale, especially on slopes of greater than 5°, e.g. lines SO-A, SO-D, SO-G, and SO-I (figures 16, 14, 15, 17), but also on more gentle slopes. Although the eastern margin of the plateau has a more gentle gradient (<1° where sites W6, W7, and W8 are located), local gradients of 3 - 5° are common and are enough to initiate and sustain sediment gravity flow. The eastern slope also has a tectonic history similar to that of the western slope (pull-apart or transtensional margin) and could have had steeper gradients during an earlier phase of development. Slumps are observed on slopes of 2 - 5° in the Antarctic (Anderson, pers. comm. 1986), and at least one slump has occurred on a slope of 2.5° on the western margin of the South Orkney plateau (figure 31).

Core 85-12 is divided into 4 genetic units (figure 32), which appear to correspond to different glacial conditions (see Chapter 4 - Glacial History). Any paleoceanographic record within the lowest unit of the core ("sub-ice" deposit) is obscured by glacial-marine

Figure 30. Bathymetric and core location map of South Orkney Plateau. Symbols indicate cores which recovered glacial or glacial-marine sediments, sediment gravity flow deposits, outcrop, and lag deposits. In general, glacial and glacial-marine sediments from shallower than 250 meters are basal tills and transitional glacial marine sediments; those from deeper than 250 meters are compound and residual glacial marine sediments.

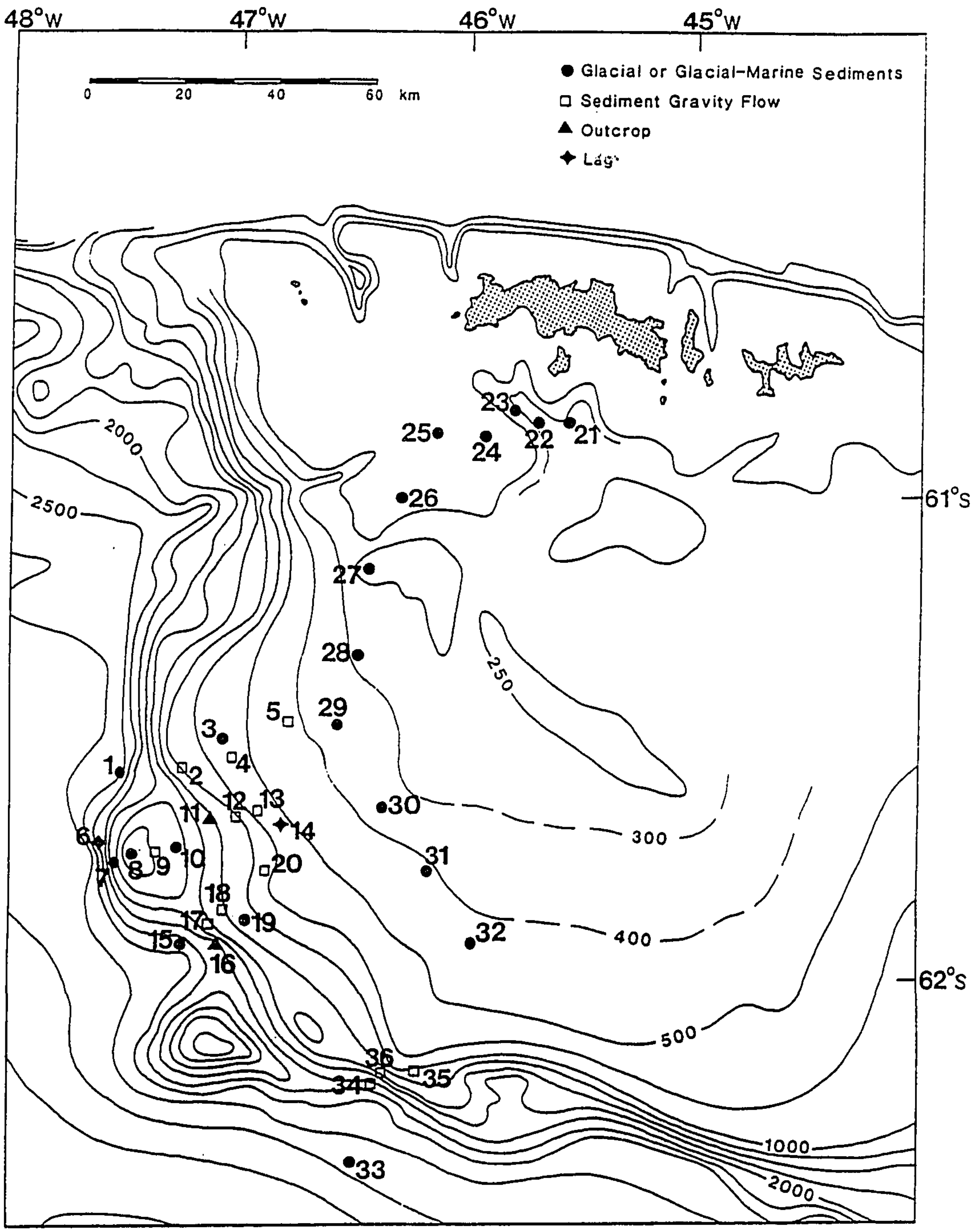

48°W
47°W
46°W
45°W
0 20 40 60 km
Glacial or Glacial-Marine Sediments
Sediment Gravity Flow
Outcrop
Lag
61°S
62°S
2000
2500
250
300
400
500
1000
2000
1
2
3
4
5
6
7
8
9
10
11
12
13
14
15
16
17
18
19
20
21
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Figure 31. Seismic data from profile SO-B, showing large-scale slump feature on a slope of about 2.5°.

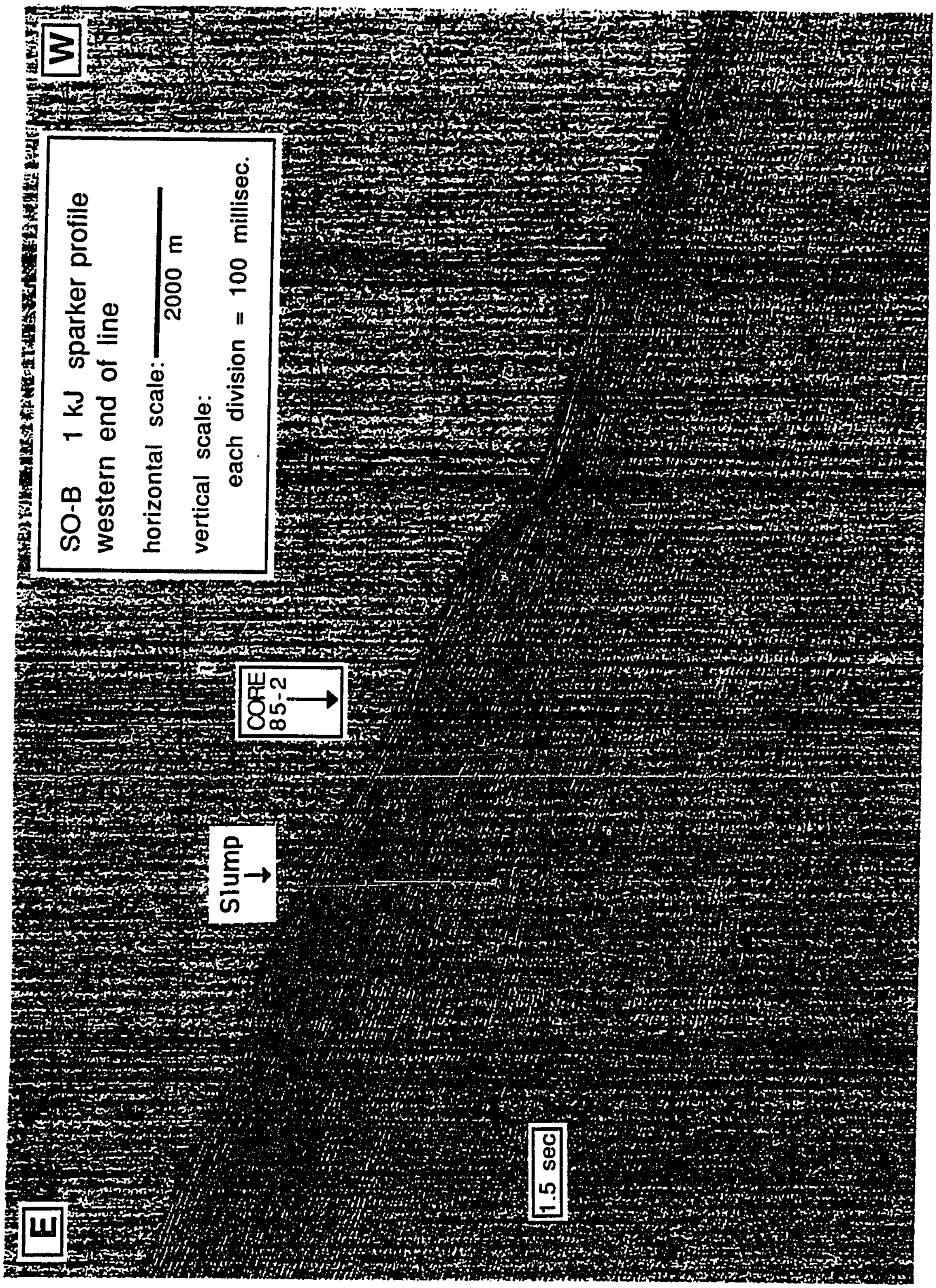
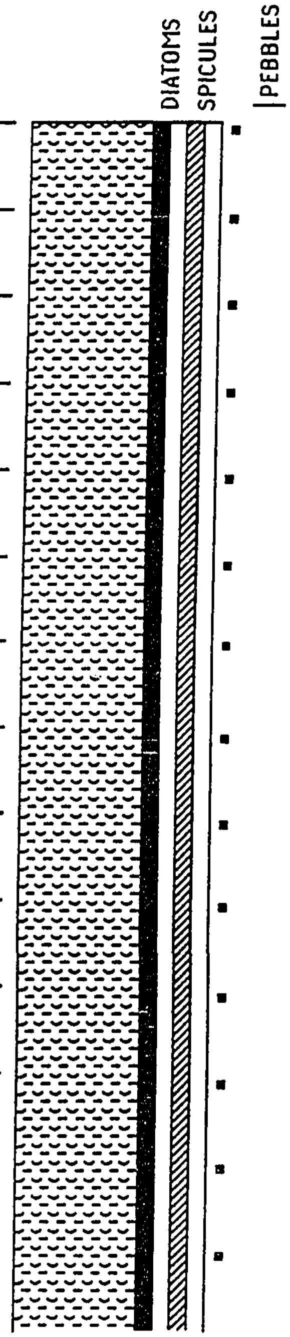

W
SO-B 1 kJ sparker profile
western end of line
horizontal scale: 2000 m
vertical scale:
each division = 100 millisec.
CORE
85-2
Slump
1.5 sec
E

Figure 32. Descriptive log of core 85-12. Explanation of symbols is in Appendix B. IRD is defined as material larger than 4.0 phi. Colors are from the GSA Color Chart. Diatoms and sponge spicules are shown as qualitative abundances.

962 m

CORE 85-12



DEPTH CM	MEAN CHI	MODE CHI	% IRD
0			29
10	10.3	7.12	16
20	10.7	10.0	19
30	11.1	9.75	12
40	12.5	12.0	
50	12.5	12.0	
60	12.4	12.5	
70	12.2	12.0	<10
80	12.4	12.0	
90	12.0	9.75	
100	12.9	10.5	
110	12.3	9.75	
120	12.6	9.75	
130	13.1	12.5	
140			

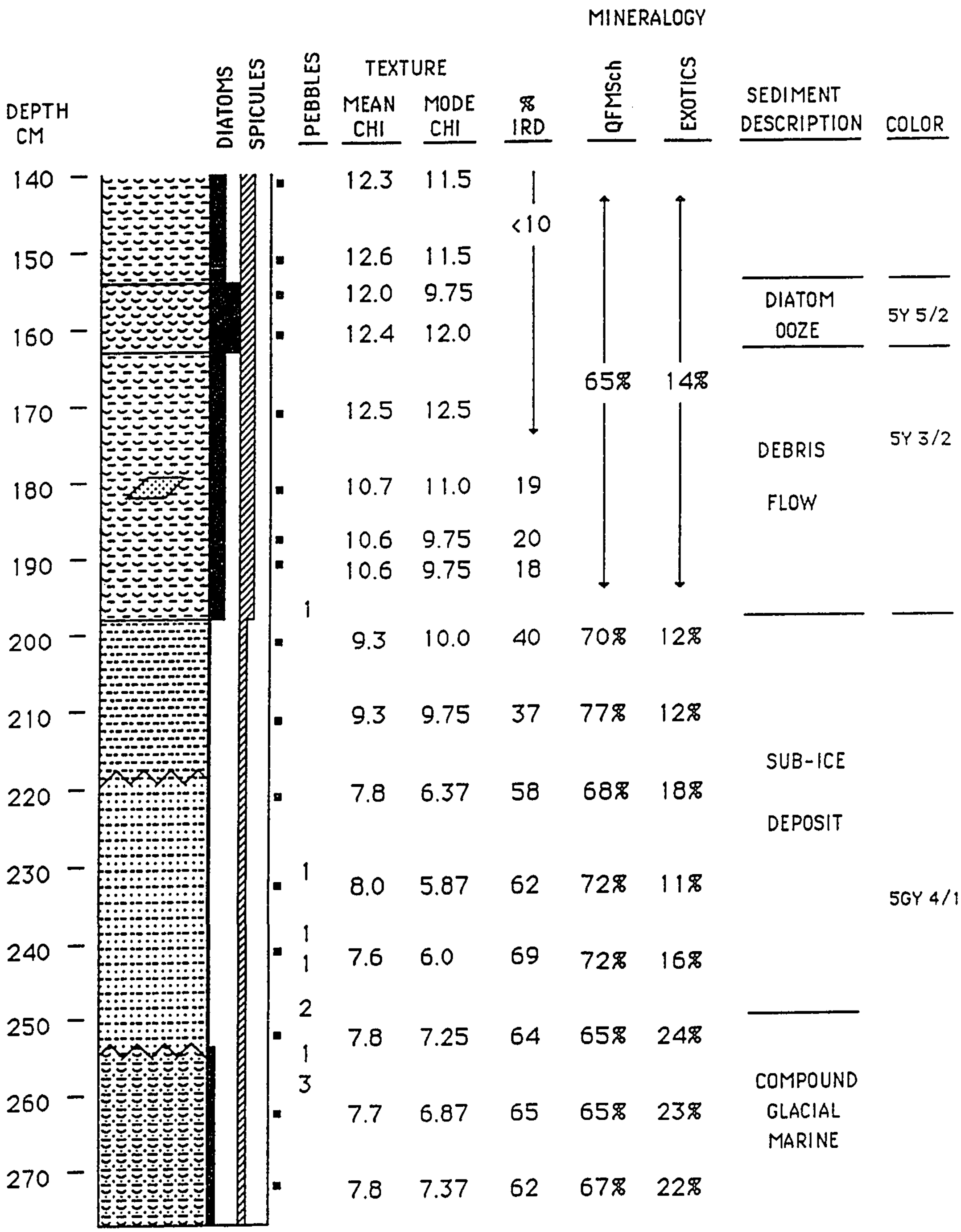
MINERALOGY

Interval	QFMSch	EXOTICS
~5–75 cm	58%	23%
~88–135 cm	90%	5%

SEDIMENT DESCRIPTION: COMPOUND GLACIAL MARINE

(Very little IRD)

COLOR: 10Y 4/2


MINERALOGY
DEPTH CM
DIATOMS
SPICULES
PEBBLES
TEXTURE
MEAN CHI
MODE CHI
% IRD
QFMSch
EXOTICS
SEDIMENT DESCRIPTION
COLOR
140
150
160
170
180
190
200
210
220
230
240
250
260
270
12.3 11.5
<10
12.6 11.5
12.0 9.75
12.4 12.0
12.5 12.5
65% 14%
10.7 11.0 19
10.6 9.75 20
10.6 9.75 18
1
9.3 10.0 40 70% 12%
9.3 9.75 37 77% 12%
7.8 6.37 58 68% 18%
1
8.0 5.87 62 72% 11%
1
1
7.6 6.0 69 72% 16%
2
7.8 7.25 64 65% 24%
1
3
7.7 6.87 65 65% 23%
7.8 7.37 62 67% 22%
DIATOM OOZE
5Y 5/2
DEBRIS FLOW
5Y 3/2
SUB-ICE DEPOSIT
5GY 4/1
COMPOUND GLACIAL MARINE

deposition. The overlying unit contains a fining-upwards mode, which could possibly indicate waning current velocity. However, the sharp upper and lower contacts and the soft sand clast within the unit suggest debris flow as the depositional mechanism. Above the debris flow unit, there is a very thin section of diatom ooze (<10 cm). This could indicate a different oceanographic regime, however there is almost no textural changes between it and underlying or overlying units. Texture and marine fossil content are homogeneous from the top of the ooze to the top of the core (155 cm). Thus, temperature, salinity, and current velocity are inferred to have been constant throughout deposition of the top 155 cm of core. Percent IRD increases slightly in the top few centimeters of core, which is probably an effect of washing during recovery.

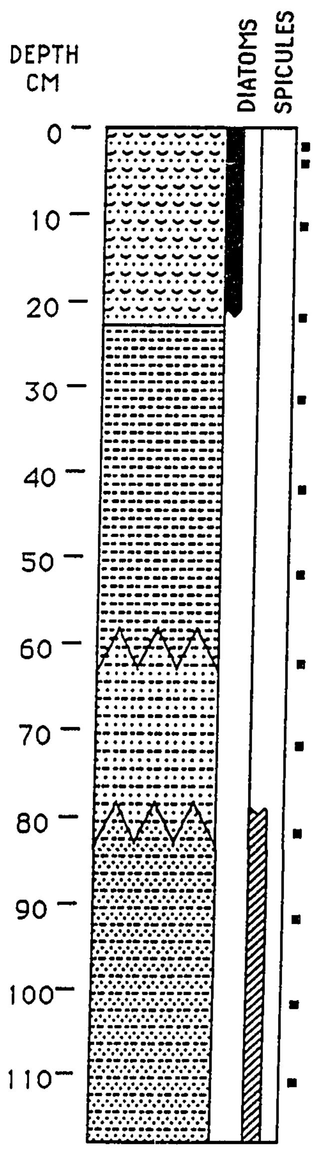
Core 85-33 is divided into three genetic units (figure 33). From the base of the core to 80 cm, texture, mineralogy, biogenic content, and percent IRD are homogeneous. Like core 85-12, the "sub-ice" section of core (23-80 cm) is dominated by glacial-marine sedimentation, which overprints any possible record of paleoceanographic changes. The top 20 cm of core shows a fairly well-sorted sand mode at about 6.0 chi (2.75 phi). The same mode occurs in samples at 1, 4, 11, and 18 cm. The consistency of the modal size and its degree of sorting indicates that it is probably current derived. The location of core 85-33 is likely to be influenced by deep and bottom water contour currents flowing out of the Weddell Sea (figure 34). There are no changes in the size of the current-derived mode within the unit (approximately 20 cm), thus no changes in current velocity are indicated; diatom content is homogeneous throughout.

Cores 85-12 and 85-33 are correlatable only at the most basic level, i.e. compound glacial marine sediments overlying "sub-ice" deposits. Their differences may be explained in part by the differences in depth and location of the two cores on the slope. Today, core 85-12 is probably under the influence of a different set of oceanographic parameters (i.e. a different water mass) than core 85-33, thus rates of deposition, mean grain size and

Figure 33. Descriptive log of core 85-33. Explanation of symbols is in Appendix B. IRD is defined as material larger than 4.0 phi. Colors are from the GSA Color Chart. Diatoms and sponge spicules are shown as qualitative abundances.

CORE 85-33

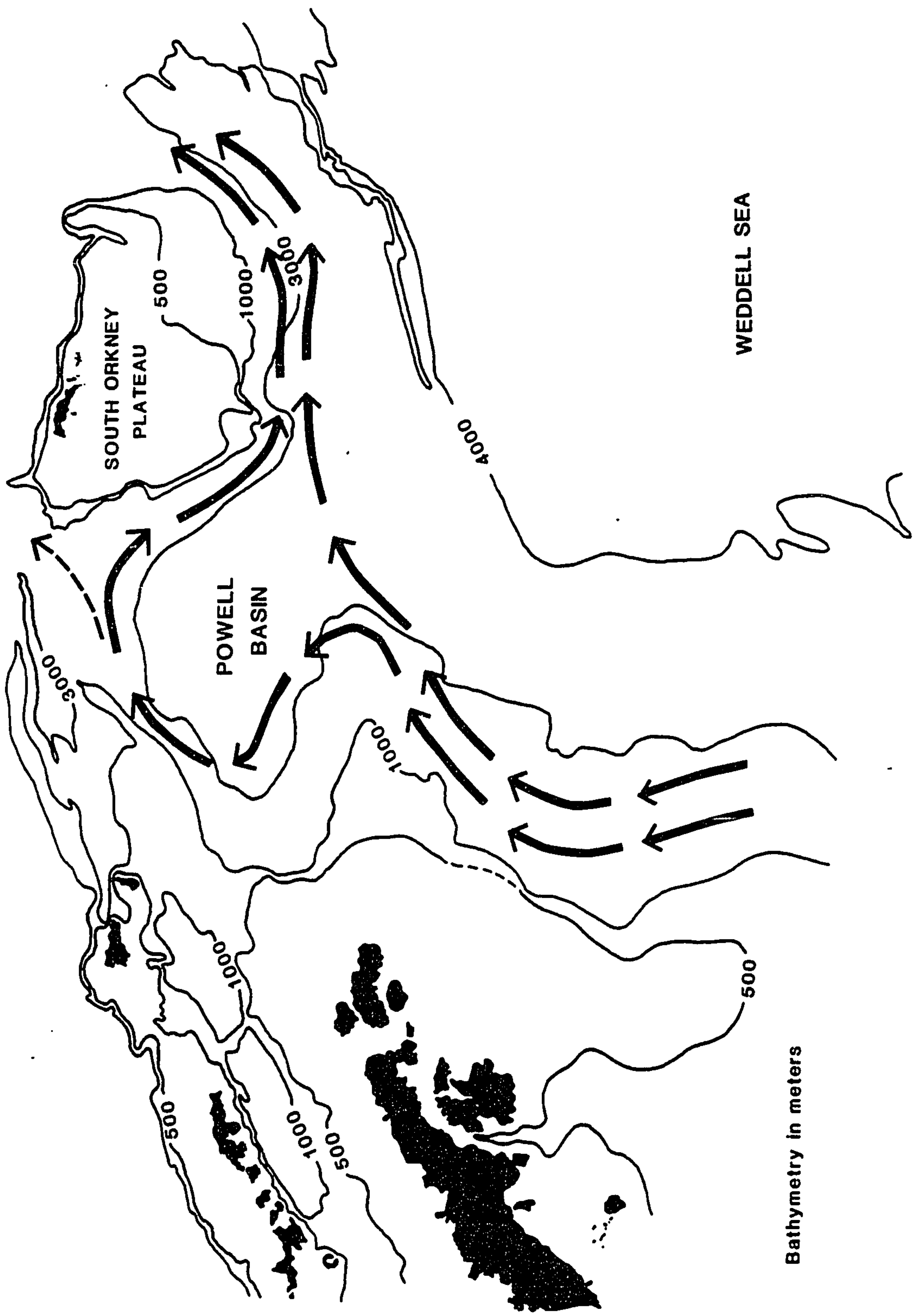
2843 m



PEBBLES	% IRD	TEXTURE: MEAN CHI	TEXTURE: MODE CHI	MINERALOGY: QFMSch	MINERALOGY: EXOTICS
	73	7.0	5.75	72%	15%
	69	7.0	6.25		
3	76	7.2	6.0	63%	24%
	32	10.0	5.87	74%	16%
	15	10.9	9.75	↑	↑
1	17	10.8	9.75	80%	5%
	24	10.4	11.0	↓	↓
	34	9.3	10.5	71%	16%
3	57	8.2	6.12	71%	16%
	58	7.8	3.37	67%	20%
4	58	8.2	5.0	74%	12%
2	59	8.1	6.0	71%	15%
3	54	8.1	6.0	69%	18%

SEDIMENT DESCRIPITON	COLOR
COMPOUND GLACIAL MARINE	5Y 4/1
"SUB-ICE" DEPOSIT; SLIGHLTY BURROWED; ?	5Y 5/2
COMPOUND GLACIAL MARINE ?	5Y 4/1

Figure 34. General circulation pattern of deep and bottom water in the Powell Basin -- inferred from Weddell Sea circulation patterns, coriolis deflection, and bathymetry.


SOUTH ORKNEY PLATEAU
POWELL BASIN
WEDDELL SEA
500
1000
3000
4000
Bathymetry in meters

dominant mode of units deposited, and biogenic content are different. This may also have been true in the past, thus the lack of correlatable units. Two cores collected from depths similar to that of core 85-33 are correlatable with core 33; cores 85-1 and 85-15 both consist of apparently "sub-ice" deposits overlain by diatomaceous compound glacial marine sediments. However, the thicknesses and texture of the units within the cores are slightly different, possibly due to the distances separating the three cores. No current-derived sand mode is apparent in the tops of cores 85-1 or 85-15.

No cores were found which correlate with core 85-12, which is mainly because sediment gravity flow and slumping have affected nearly 3/4 of the slope cores, particularly those from steep, mid-depth areas of the slope. Due to the high latitude and depths, neither core contains carbonate marine fossils, thus oxygen isotope measurements are not possible.

Discussion

Experimental work and observations indicate that pure debris flow, if it is thick enough, and possesses a fluid matrix strong and dense enough to support all grains, and has no dispersive pressure, will move on any slope, no matter how gentle (Middleton and Hampton, 1976). Although submarine debris flows would be under dispersive pressure from the overlying water column, 2 - 3° slopes would probably be sufficient to initiate and maintain flow. Slopes on the western South Orkney Plateau margin range from less than 1° to more than 25°.

Debris flows may be difficult to recognize in cores, especially if they do not transport large clasts. Submarine debris flows can be sustained with very little clay within their matrices (2 - 20%), so that some sandy debris flows may be texturally indistinguishable from sands deposited by other means (Middleton and Hampton, 1976). Debris flow deposits are difficult to differentiate from basal tills and transitional glacial marine deposits. The only possible critieria for distinguishing them in core samples are (1) heterogeneous mineralogy (but this is controlled by source), (2) lack of pebble striations on harder clasts (but this is also source controlled since in the Antarctic the source may be a glacial deposit), and (3) lower degree of compaction than basal tills (but the range of compaction of the two sample types probably overlaps). Other distinguishing criteria require observations laterally within the unit, or investigations of lateral facies relationships, not possible using cores (Anderson, et. al., 1980).

Turbidites are mentioned in the sediment type descriptions of ODP sites W6 and W8 (Kennett and Barker, et. al., 1986) which suggests that these sites are, or were in the past, affected by sediment gravity flow. Calcareous faunal assemblages will undoubtedly be found in some or all of the sites as expected. Fairly high abundances of calcareous forams (planktonic and benthic) were found in Deep Freeze 85 cores collected in 988 meters (85-2) and 1794 meters (85-34) on the western slope. However, these occurrences are within debris flow and turbidite units, as determined by sedimentology. Therefore, interpretations of down-core changes in sedimentological characteristics or paleontological assemblages and abundances should be made with caution, avoiding any possible sediment gravity flow units.

Results of studies on Deep Freeze 85 cores show evidence for at least one past glacial advance. Evidence for some form of expanded ice cover is present in sections of nearly all slope cores, but the sections are generally not correlatable, and may indicate more than one glacial event. Although some physical and chemical oceanographic changes undoubtedly occurred as a result of the glacial event(s), the sedimentary record of these changes is obscured and altered by glacial sedimentation and by processes such as slumping and sediment gravity flow. Water mass development or change is commonly interpreted from paleotemperature and/or salinity determinations. Detailed paleo-environmental work on diatom assemblages and oxygen isotope studies on calcareous tests (such as will be done on cores from the O.D.P. sites), as well as cores containing continuous, undisturbed records of sedimentation not affected by sediment gravity flow would be neccessary to determine temperature or salinity variations through time.

Quaternary to Pliocene (?) glacial history of the Antarctic Peninsula is another of the primary objectives of drilling sites W6 - W8. One parameter that has been widely used to infer glacial advances and retreats is IRD accumulation. Measurements of IRD concentrations made from cores may not positively correlate with actual IRD accumulation rates. Typical IRD measurements are affected not only by the likely presence of sediment gravity flow units but also by the presence of current-derived sand modes (see Chapter 3 - Surface Sample Textural Data). Current-derived sand is present throughout the upper 20 centimeters of core 85-33. Furthermore, there are uncertainties about the meaning of changes in IRD concentrations (Watkins, et. al., 1974). It is not known whether an increase in IRD accumulation indicates a period of glacial expansion or retreat. Each case must be evaluated separately in terms of the mechanism of ice rafting. Early IRD studies usually assumed that an increase in apparent IRD accumulation was synonomous with a period of glacial expansion and therefore cooling. However, a glacial expansion may be in the form of expanded ice shelves which do not create an increase in IRD, except perhaps near their grounding lines, and may actually cause a decrease. Also, an increase in IRD accumulation could be due to a period of warming, when increased melting and calving rates may cause greater amounts of bedrock erosion and transportation of IRD to the sea floor (Denton, et. al., 1971; Anderson, 1972; Fillon, 1972; Watkins, et. al., 1974).

Flux of IRD to the sea floor depends mostly on three factors: (1) the glacial maritime setting, (2) surface water temperature, and (3) iceberg drift tracks (Anderson and Molnia, 1986). The glacial maritime setting seems to be conducive to IRD deposition, and although surface water cooling is observed due to the flux of ice through the area

(Schwerdtfeger, 1985), sea surface temperatures are near 0° C (Priestly, et. al., 1964), allowing for melting out of basal debris.

The iceberg-drift-track factor in this particular area of the Antarctic is less straightforward. This area is known to be along a path of large numbers of icebergs. Most reports of ice in the South Orkney Islands region since the islands' discovery in the 1820's mention several hundreds to thousands of floating and grounded icebergs. Most of these, however, came from the Ronne and Filchner Ice Shelves. During Deep Freeze 1985, hundreds of icebergs were observed in the study area, many of which were large, tabular bergs which could only have come from the Ronne or Filchner Ice Shelves; other large bergs were probably from the peninsula area, as the glaciers on the South Orkney Islands are not considered capable today of producing large icebergs (Marr, 1935). So, although the number of icebergs which travel throught this area is large, many are from the Weddell Sea ice shelves, and are not considered to be an important means of debris dispersal. Thus, since present IRD accumulation is not well understood, past fluctuations in IRD content within cores may be very difficult to interpret.

Summary

Glacial conditions on the South Orkney Plateau have decreased in severity from the late Wisconsin (?) to the present. Thus, glacial controls on sedimentation have also decreased, allowing oceanographic processes to become increasingly obvious in the more recent sedimentary record.

Three fundamental problems adversely affect correlations and paleoceanographic interpretation of cores from the western slope of the South Orkney Plateau. First, sediment gravity flow deposits are ubiquitous on the slope. Only about one-fourth of the western slope cores can be relied upon to contain a possible undisturbed record of glacial history or paleoceanographic changes. The eastern margin is probably also affected by sediment gravity flow. Local gradients of 3 - 5°, tubidites noted in O.D.P. sediment descriptions, and similarities between the eastern and western margins suggest that O.D.P. sites W6 and W8 probably are, or were in the recent past, affected by sediment gravity flow. Cores containing continuous, undisturbed records of sedimentation would be neccessary to determine paleoceanographic variations through time.

Second, non-gravity-induced sedimentation appears to be dominantly controlled by the glacial regime. Nearly all sedimentologic variation obvious in the cores can be attributed to changes in the amount of ice cover. Although some physical and chemical oceanographic changes undoubtedly occurred as a result of glacial event(s), the sedimentary record of these changes is obscured by glacial-marine sedimentation, as well as by sediment gravity flow processes. Thus, interpretations of down-core changes in terms of paleoceanography should be made with caution.

Third, IRD measurements are affected not only by the presence of sediment gravity flow units but also by the existence of current-derived sand modes. Marine currents definately redistribute sand-sized sediments on the plateau to depths of at least 400 meters, and probably also have a significant influence on slope deposits. Thus, past fluctuations in sand content within cores may be very difficult to interpret.

CHAPTER 6. SEISMIC DATA

Introduction

A series of high-resolution, single-channel seismic profiles was collected on the western South Orkney Plateau and margin as part of the Deep Freeze 1985 sampling operations. The main objective was to recover a detailed record of the upper few hundred meters of section. The three primary purposes of collecting these data were, (1) to investigate the possibility of past grounded ice on the plateau, (2) to look for evidence of recent tectonic activity that could be related to continued development of the passive margin, and (3) to gain an understanding of the seismic stratigraphy of the area. Previous seismic data collected from this area include a set of refraction profiles (Harrington, et. al., 1972), and single-channel airgun data studied by King (1983). No high-resolution seismic data had been previously collected in this area. However, this is an ideal setting in which to use relatively low-energy, high-resolution systems because acoustic basement is generally shallow, and many interesting features occur within the uppermost strata; much of the most interesting glacial and oceanographic history in and around Antarctica has taken place during the middle to late Cenozoic. Also, data collection using large, multichannel receiving arrays is difficult because of the year-round presence of sea ice and large icebergs. The seismic profiles were also useful in locating specific coring sites for paleoceanographic and glacial history investigations. In many cases, core recovery can be predicted using the seismic record. Only two cores recovered pre-Pleistocene outcrop, so there is very little age control for stratigraphic interpretation. However, using the principles of sequence stratigraphy (Vail, et. al., 1977; Vail and Todd, 1981; Vail, et. al., 1984; Posamentier and Vail, unpub.), it is possible to make some stratigraphic interpretation. Systems tracts, corresponding to glacial-eustatic sea level variations, are interpreted on several of the dip-oriented lines, and are probably related to late Wisconsin glacial events and the influence of tectonic subsidence on the margin.

Data distribution

Nine profiles were shot on the South Orkney Plateau during Deep Freeze 1985 (figure 12), including five dip-oriented lines across the plateau/Powell Basin margin and one long profile across the western side of the plateau and up to the islands, crossing the Signy Island Trough. The total amount of coverage is approximately 280 kilometers.

Space limitations and poor reproducibility at a small scale prevent the publication of entire profiles in this paper. Line drawings of all the dip sections and part of line SO-H were made to summarize the data, with simplified core logs to help illustrate the different seismic facies present. Also, selected examples of the actual data are presented to illustrate specific points made in the text.

Manual Deconvolution

The sparker source creates an air bubble in the water column which tends to fluctuate before it collapses, producing a pattern of multiple acoustic pulses. This pattern is often referred to as the "bubble pulse", and is recorded in the direct arrival at the top of each seismic record (figure 35). This same pattern is also recorded in the sub-surface record (with reversed polarity) each time there is enough of an impedance contrast to produce a reflection of seismic energy. Therefore, instead of a single reflector for each impedance contrast there is a series, or package, of reflectors. When boundaries which produce impedance contrasts are closer together than the width of the reflector package, interference results, and the entire reflector package is not present for each boundary. Individual reflectors are defined by the tops of the reflector "packages", which are found by looking for the pattern traced from the direct arrival. Since data were recorded in analog form only, this method of manual deconvolution was used, where possible, to help interpret structural and stratigraphic features.

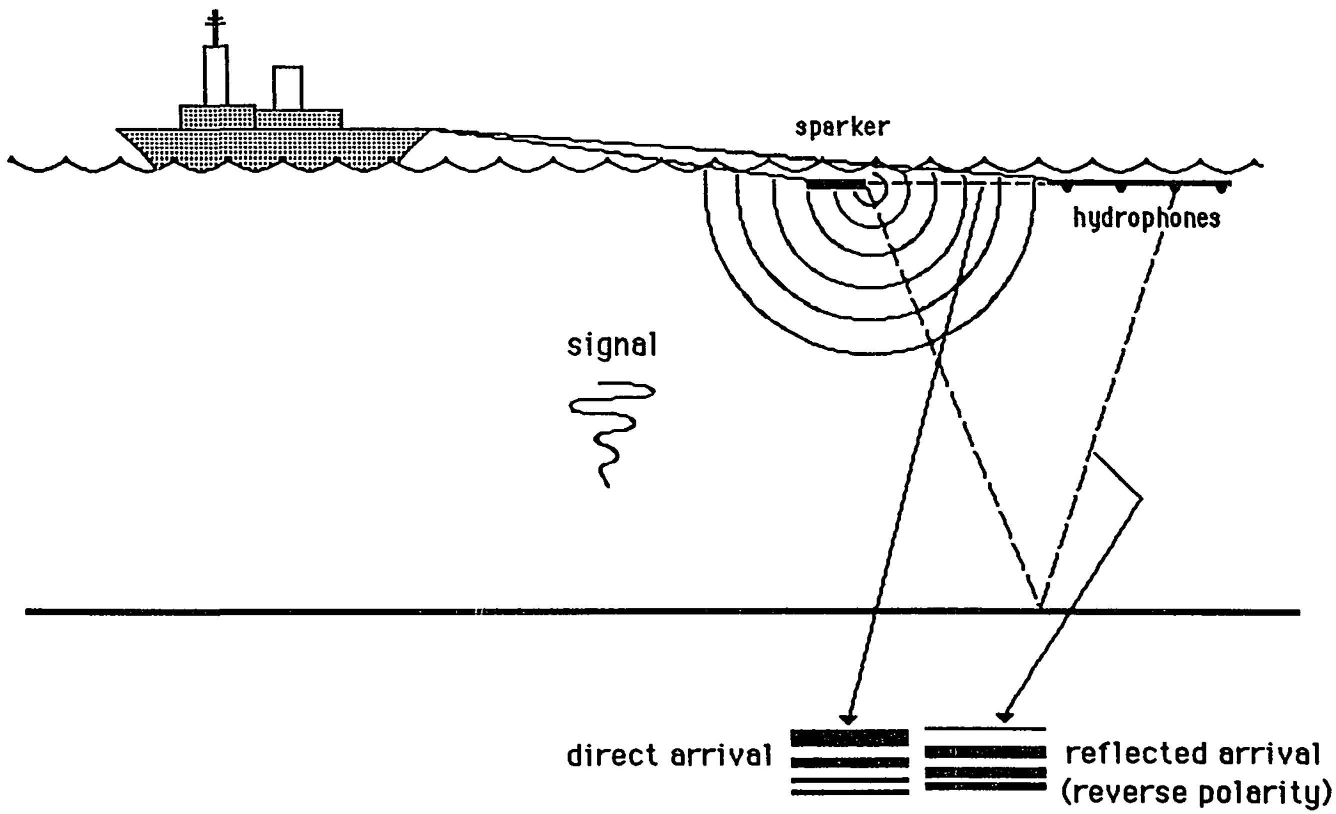


Figure 35. Schematic drawing of marine seismic operations, showing simplified source pulse shape, an example of the direct arrival pattern, and the reversed reflected arrival pattern. Individual reflectors within the data show up as repetitions of all or part of the reflected arrival pattern.

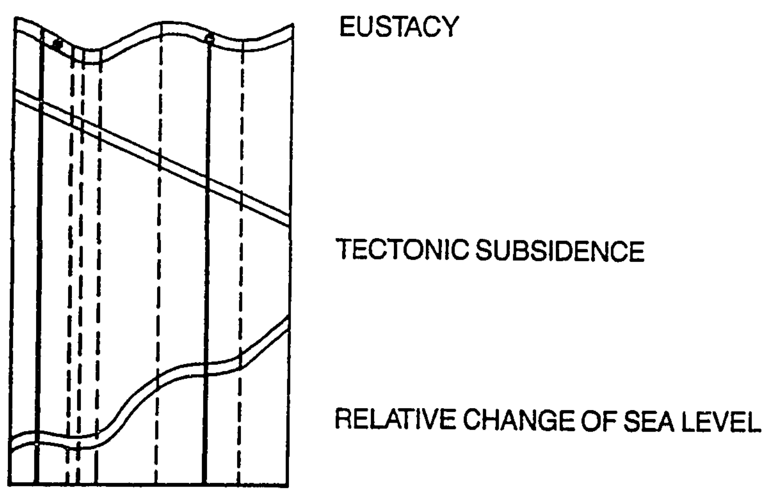
Slope Profiles - Description and Stratigraphic Interpretation

The five slope profiles, SO-A, -B, -D, -G, and -I, illustrate sedimentation on a sediment-starved, young passive margin influenced by both tectonic controls and glacial eustasy. Most sedimentation has occurred during lowstands of sea level, thus seismic facies seen are of the lowstand wedge systems tract. The lowstand wedge systems tract is represented by slope-fan complexes and prograding complexes (figure 36). The slope-fan complex consists of leveed channel and overbank deposits, formed during maximum lowstands. The prograding complex consists of a large prograding lobe or series of lobes on the slope, which formed as sea level began to rise. The melting South Orkney ice cap probably increased the sediment supply to the plateau and slope during glacial retreats. Channeling of this sediment across the plateau in one or more glacial troughs (e.g. the Signy Island Trough), may have caused the thick sediment accumulations on the slope (prograding lobes and "perched" slope-fan complexes) (figure 37). These processes were probably active during several periods of rising sea level caused by disintegration of the late Wisconsin ice sheets. At the ends of the sea level rises, the shelf was flooded and the sediment supply greatly reduced or cut off, thus highstand systems tracts are very thin and are not recognized in the data, except at the surface. Today, mainly pelagic sedimentation, complicated by sediment gravity flow and ice rafting, occurs on the slope. Sedimentation has been strongly influenced by the faulting and intrusive or extrusive igneous activity associated with passive margin formation.

Line SO-D

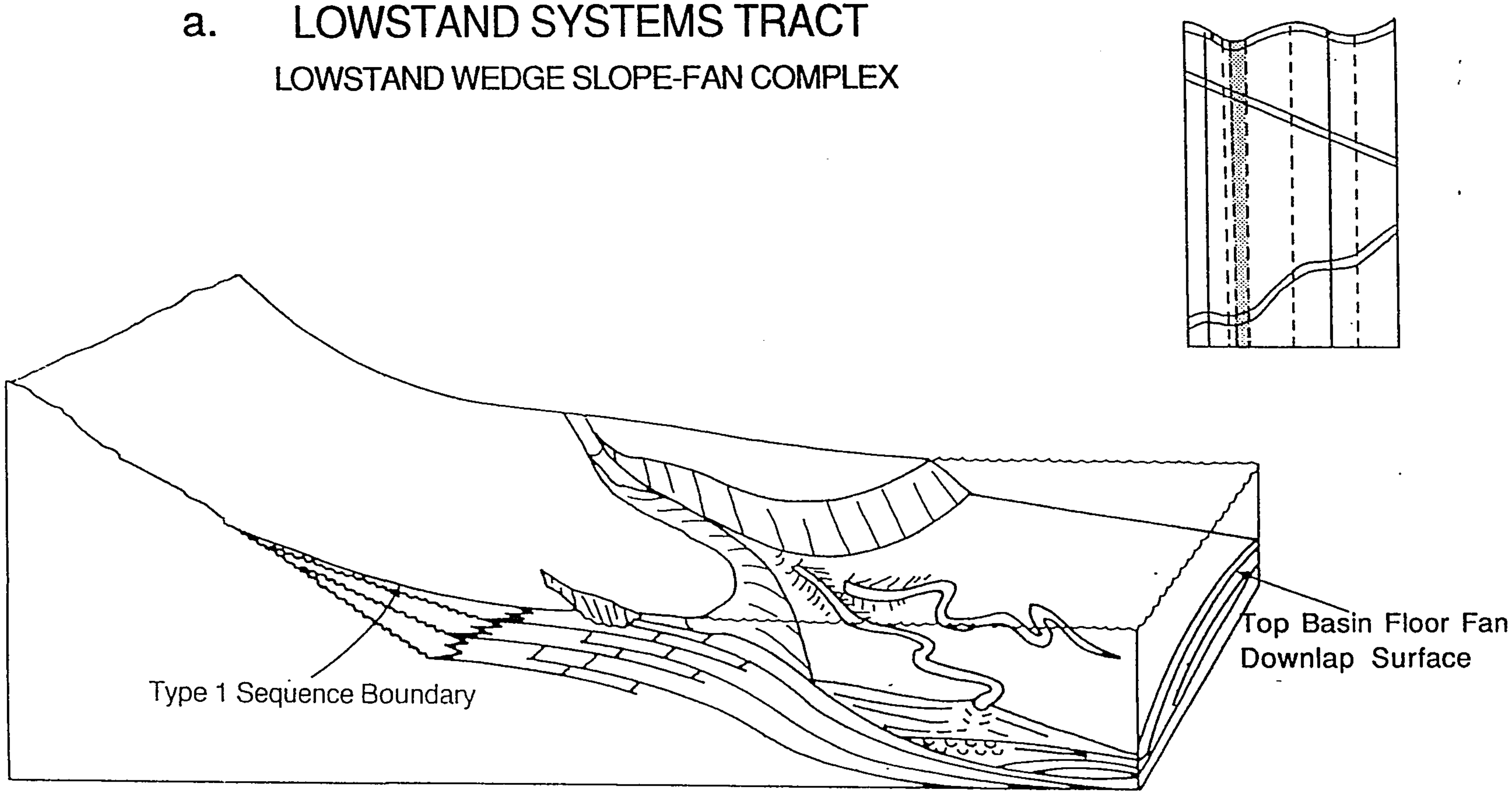
Line D was shot across one of the outer margin highs and shows the normal faulting associated with formation of the Powell Basin (figure 38). Landward of the faulting the profile consists of facies of the prograding complex of the lowstand wedge systems tract. The most basinward fault defines a large block which has rotated (or slid) downslope

Figure 36. Block diagrams of facies of the Lowstand Wedge Systems Tract.
a. Slope-fan complex - consists of leveed channel and overbank deposits. Deposited during the initial rise of sea level after the maximum lowstand.
b. Prograding complex - consists of sediments deposited seaward of the depositional shelf edge, commonly produces a prograding offlap pattern on seismic data. Deposited during a period of rising sea level when sediment supply was high.



a. LOWSTAND SYSTEMS TRACT

LOWSTAND WEDGE SLOPE-FAN COMPLEX



b. LOWSTAND SYSTEMS TRACT
LOWSTAND WEDGE-PROGRADING COMPLEX

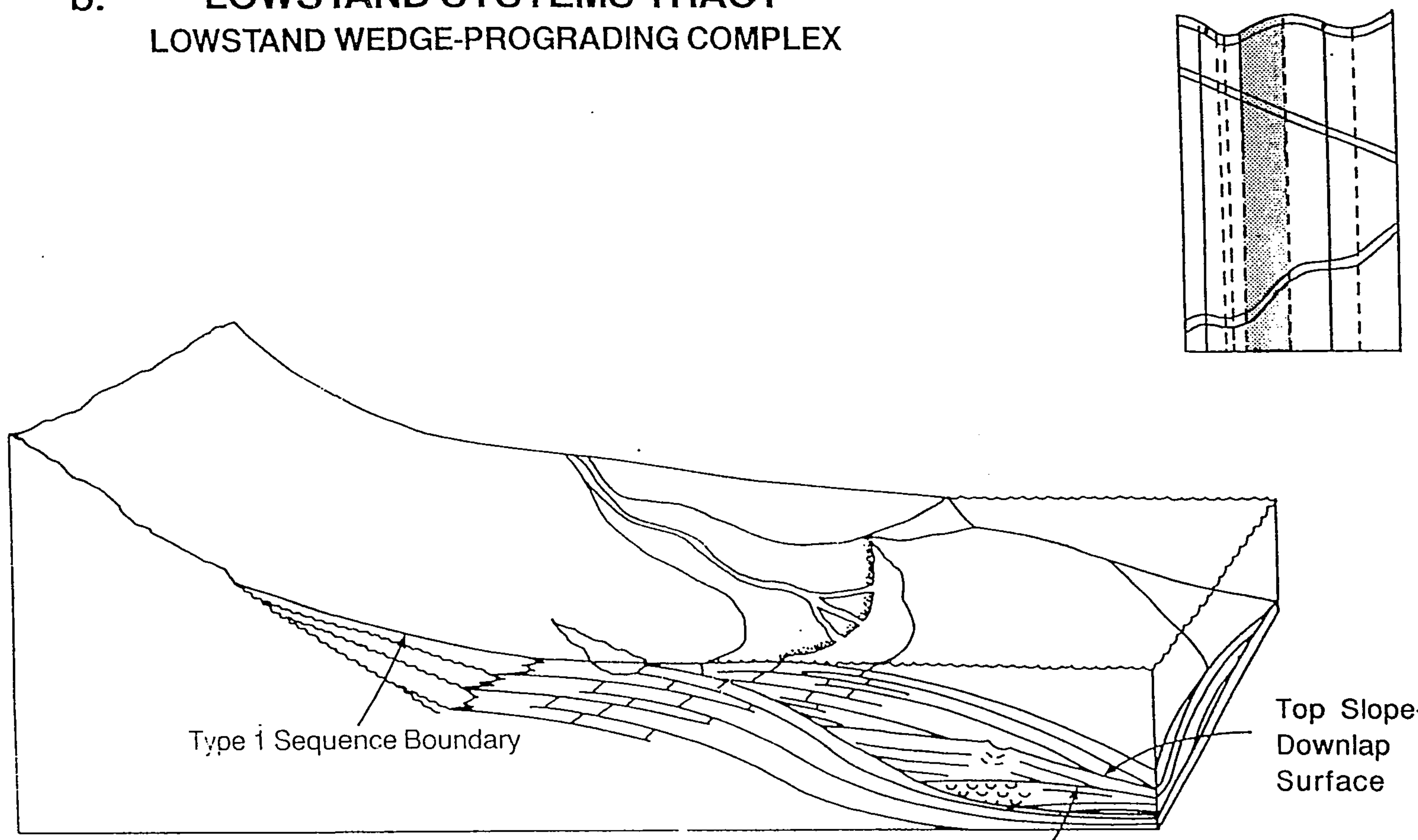


Figure 37. South Orkney Plateau bathymetry showing seismic facies inferred from slope profiles, and possible channels or paths of sediment transport across the plateau and slope. Stippled pattern indicates areas of accumulation of prograding complex sediments. Heavy arrows are inferred paths of sediment transport across the slope during the early part of Lowstand Wedge deposition (slope-fan facies). Some of the sediments are deposited behind the outer margin highs as the slope-fan complex, and some are diverted around the highs and accumulate in fans at the base of the slope.

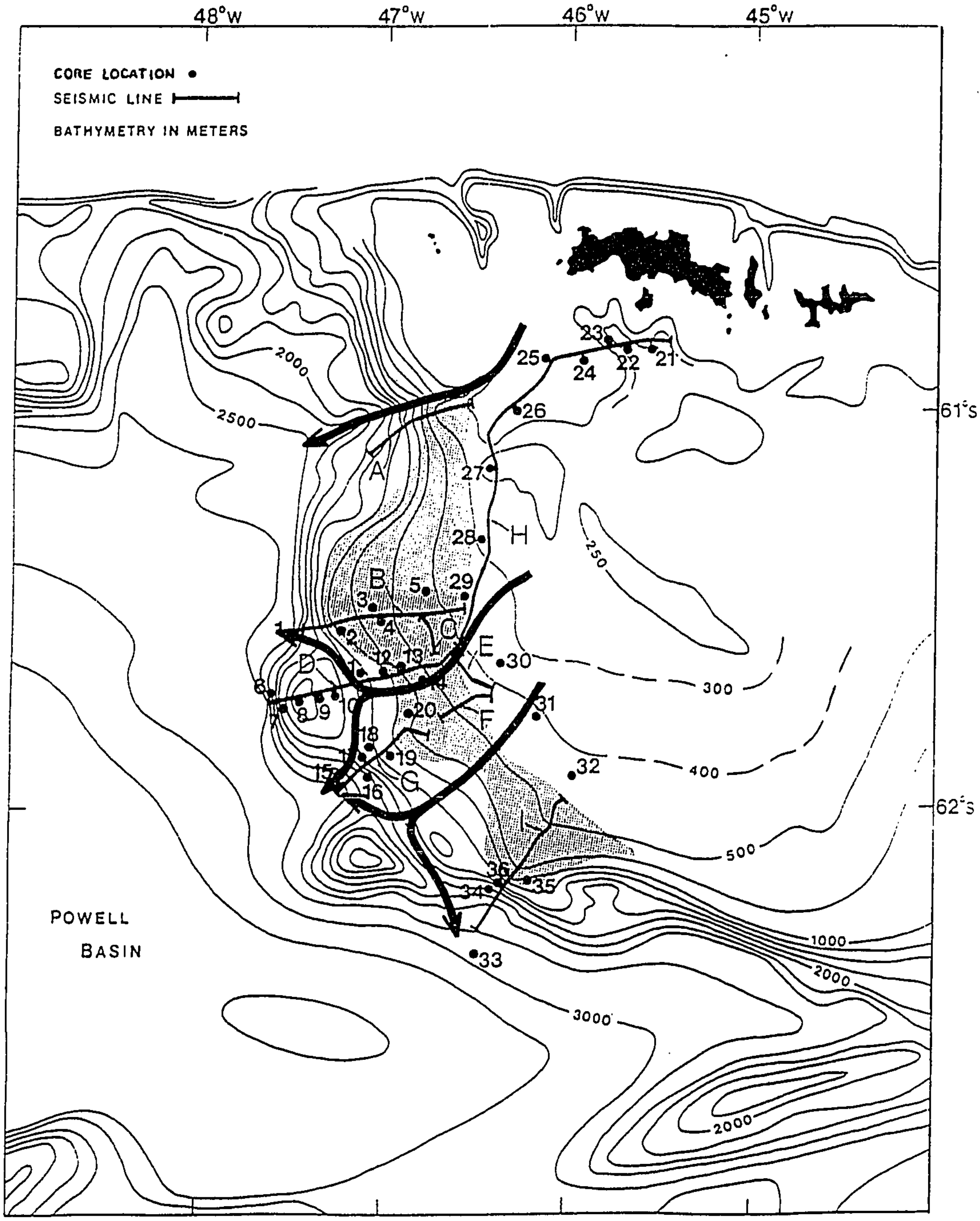
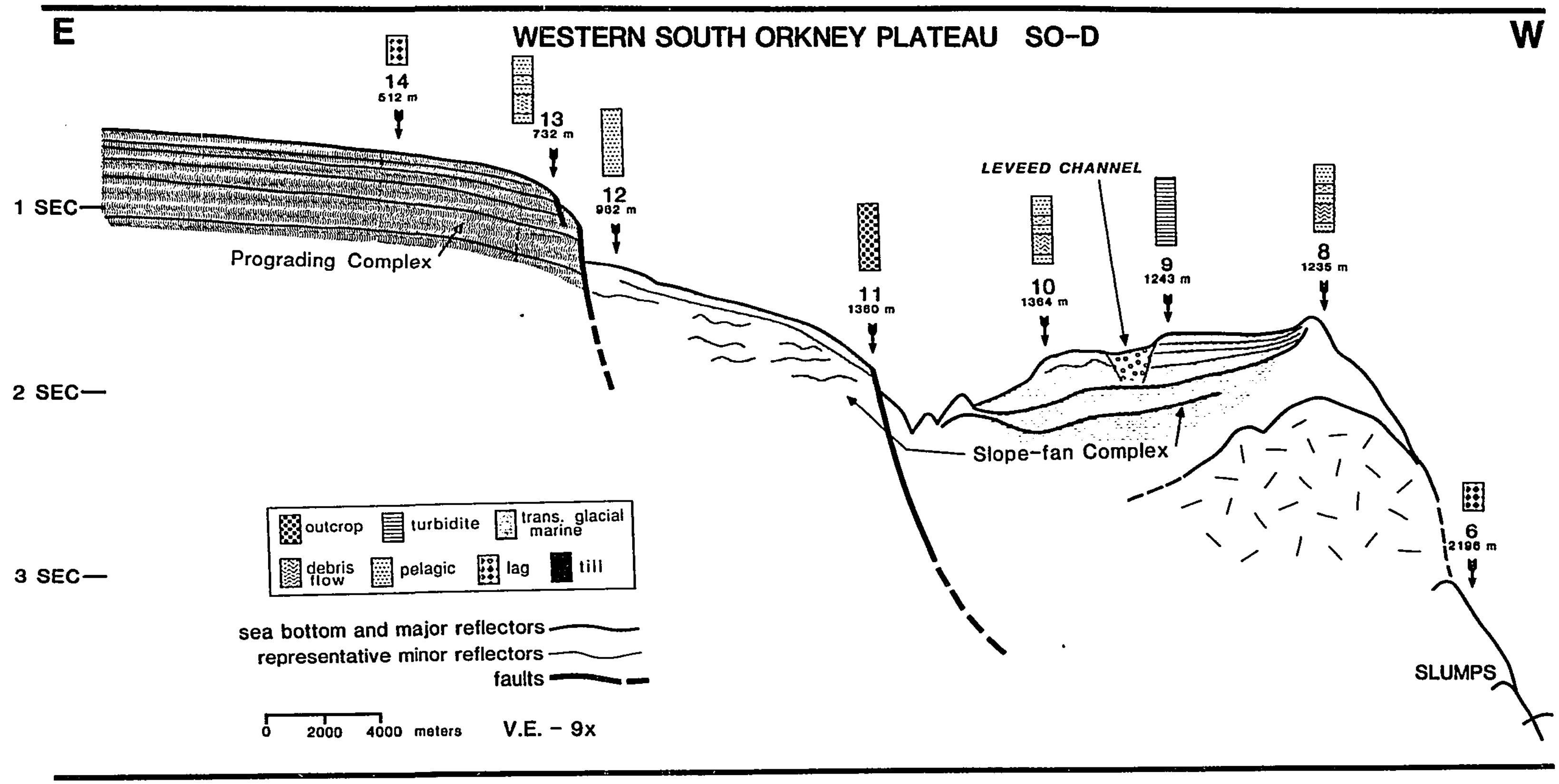

48°W
47°W
46°W
45°W
CORE LOCATION
SEISMIC LINE
BATHYMETRY IN METERS
61°S
62°S
2000
2500
250
300
400
500
1000
2000
3000
2000
A
B
C
D
E
F
G
H
POWELL
BASIN

Figure 38. Seismic Line SO-D, 4.6 kJ single-channel sparker profile - South Orkney Plateau/Powell Basin margin. Location on figure 12.


E
WESTERN SOUTH ORKNEY PLATEAU SO-D
W
14
512 m
13
732 m
12
982 m
11
1360 m
10
1364 m
9
1243 m
8
1235 m
6
2196 m
LEVEED CHANNEL
1 SEC
2 SEC
3 SEC
Prograding Complex
Slope-fan Complex
SLUMPS
outcrop
turbidite
trans. glacial marine
debris flow
pelagic
lag
till
sea bottom and major reflectors
representative minor reflectors
faults
0
2000
4000
meters
V.E. - 9x

towards the Powell Basin. Most reflectors within the block dip slightly landwards. The outer part of the block is a buried volcanic feature (figure 39), as indicated by its shape and by dredges on its outer side that recovered young (<5 Ma old) basalts (King, 1983). Because this feature creates a bathymetric high, the area behind it (shelfwards) has probably been a sedimentary depocenter for as long as the volcanic high has existed.

Within the rotated fault block, seismic penetration is good, and up to 600 milliseconds of sediments have been deposited. Features of the slope-fan complex of the lowstand wedge systems tract are apparent within these sediments. A large leveed channel feature and associated overbank deposits are seen at the top of the record (figure 40). At least three sequences of slope fan complex sediments can be discerned within the underlying sedimentary fill, mostly consisting of overbank deposits. As the block continued to rotate basinwards, the submarine currents filling in the depocenter with leveed channel and overbank deposits, became concentrated in the low just seaward of the fault. This caused increased current velocity, and erosion rather than deposition, thus creating the V-shaped cuts or channels at that location. This interpretation as a lowstand, slope-fan complex is supported by the core descriptions. Core 85-9, proximal to the leveed channel, consists of a series of fine-grained sediment gravity flow deposits which correspond to overbank deposits seen on the seismic data. Core 85-10, more distal from the channel, consists mainly of pelagic deposits (laminated, burrowed, diatom mud), with one interbedded, sandy, overbank deposit. Core 85-12, also located away from the channel, consists mainly of pelagic sediments. Miocene outcrop was recovered from the fault scarp at location 85-11. The outer slope of the block is very steep (15° to 25°). Two attempts to core the slope recovered one 10-centimeter long section of a debris flow deposit (85-6); there was no recovery at location 85-7. The basinward edge of the record shows that sediment is being ponded at the base of the slope.

Figure 39. Seismic data from profile SO-D. The outer margin bathymetric and structural high is interpreted by King (1983) as a buried volcanic feature. Multiple seismic sequences are interpreted within the data shelfward of the high and are described in the text.

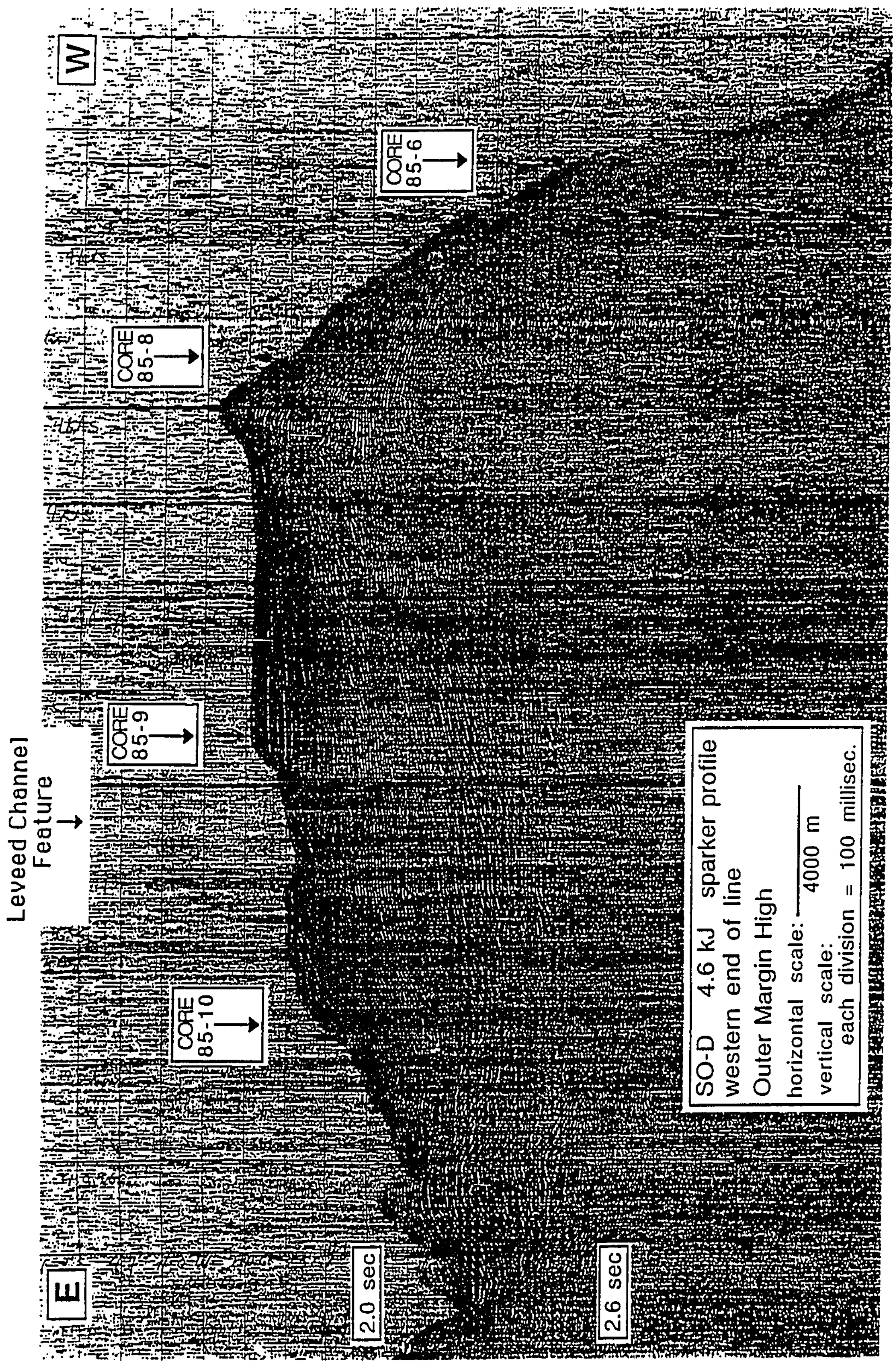
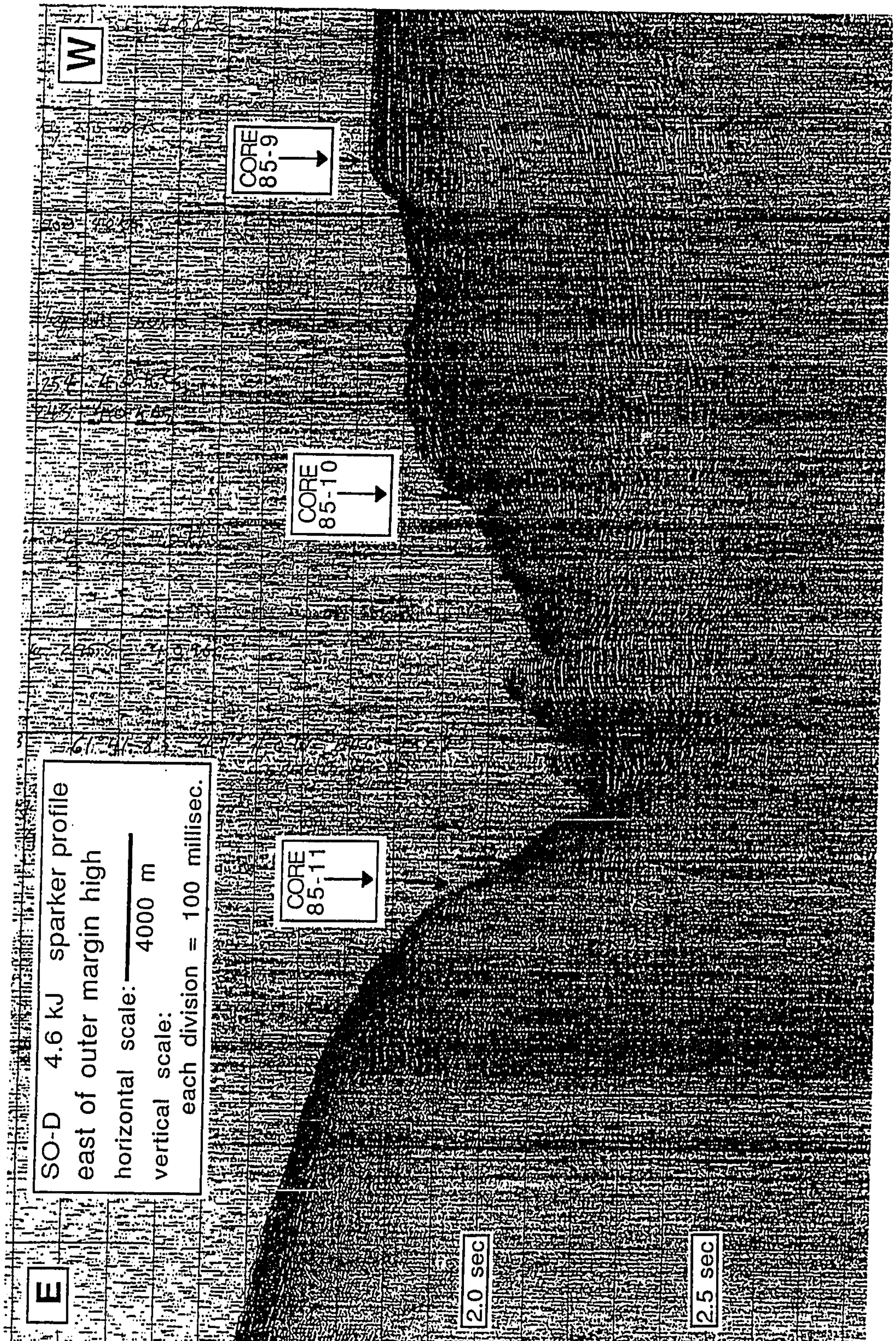

W
CORE 85-6
CORE 85-8
CORE 85-9
Leveed Channel Feature
CORE 85-10
E
2.0 sec
2.6 sec
SO-D 4.6 kJ sparker profile
western end of line
Outer Margin High
horizontal scale: 4000 m
vertical scale:
each division = 100 millisec.

Figure 40. Seismic data from profile SO-D, showing fault scarp and outcrop reflections at core location 85-11 where Miocene sediments were recovered.


E
W
SO-D 4.6 kJ sparker profile
east of outer margin high
horizontal scale: 4000 m
vertical scale:
each division = 100 millisec.
CORE 85-9
CORE 85-10
CORE 85-11
2.0 sec
2.5 sec

Line SO-G

Line G was shot between the two prominent bathymetric highs, presumably down the axis of one of the submarine channels that fed the base-of-slope fans. Thick sediment packages on the plateau end of the profile appear to be deep water deposits (i.e. turbidites) and probably represent facies of the prograding complex, although clinoforms are not well developed (figure 41). Normal, block faulting is also seen on this profile. Sediments seaward of the first fault may also be a series of overbank deposits as on line D (figure 42). Core 85-20 consists of a short section of debris flows separated by thin lags, and overlain by a very thin diatom ooze (a few cm). At core location 85-18 a 145 cm section of diatom mud (highstand, pelagic sediment) was recovered; the top 10 cm is sandy, probably representing a lag. Seaward of 85-18 downslope to location 85-15, seismic reflectors are convolute, discontinuous, and hummocky, and numerous side echoes are present. This is indicative of slumping and/or sediment gravity flow. Core 85-17 consists of a series of sediment gravity flow deposits similar to 85-9 with a thin lag at the top. This could be more overbank deposits, correlating with the subsurface reflectors to the east. Core 85-16 is a 42-cm section of mid-Miocene-age(?) outcrop (dated using diatoms by D. Harwood), which was probably recovered from a slump scar. Below the slumped section the slope flattens out, and reflectors are more continuous and flat-lying. Core 85-15, at the base of the slope, consists of apparently undisturbed, fine-grained "sub-ice" sediments overlain by compound glacial marine sediments. Basinward of core 85-15, data show two sequences of lowstand fan deposits which were probably deposited by the turbidity currents that created the upper slope leveed channel and overbank facies.

Line SO-B

Line B profiles the lobate feature to the north of line D. Data consist of a thick, prograding package of sediments (up to 500 milliseconds) which is unfaulted and lacks

Figure 41. Seismic Line SO-G, 4.6 kJ single-channel sparker profile - South Orkney Plateau/Powell Basin margin. Location on figure 12.

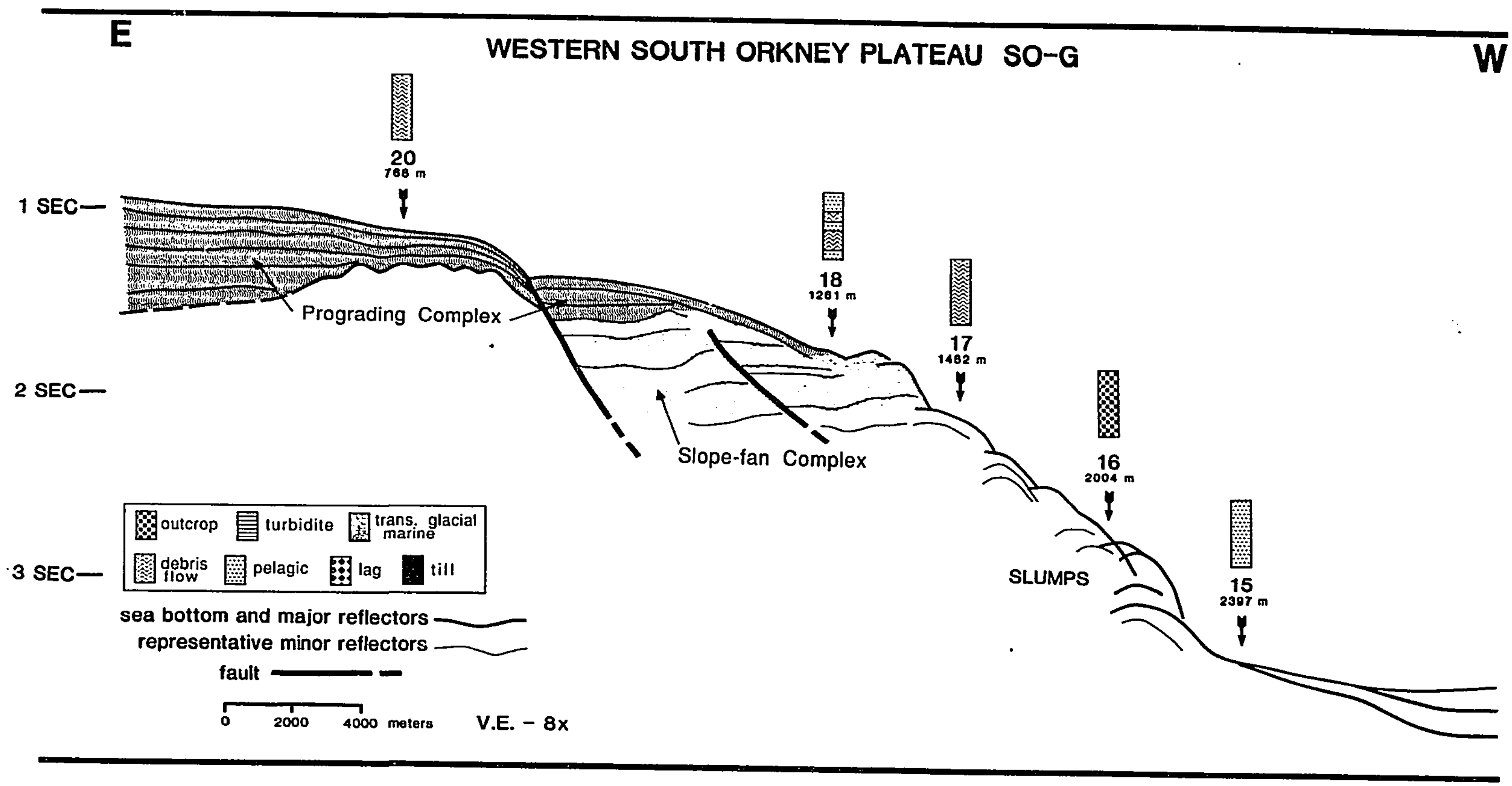
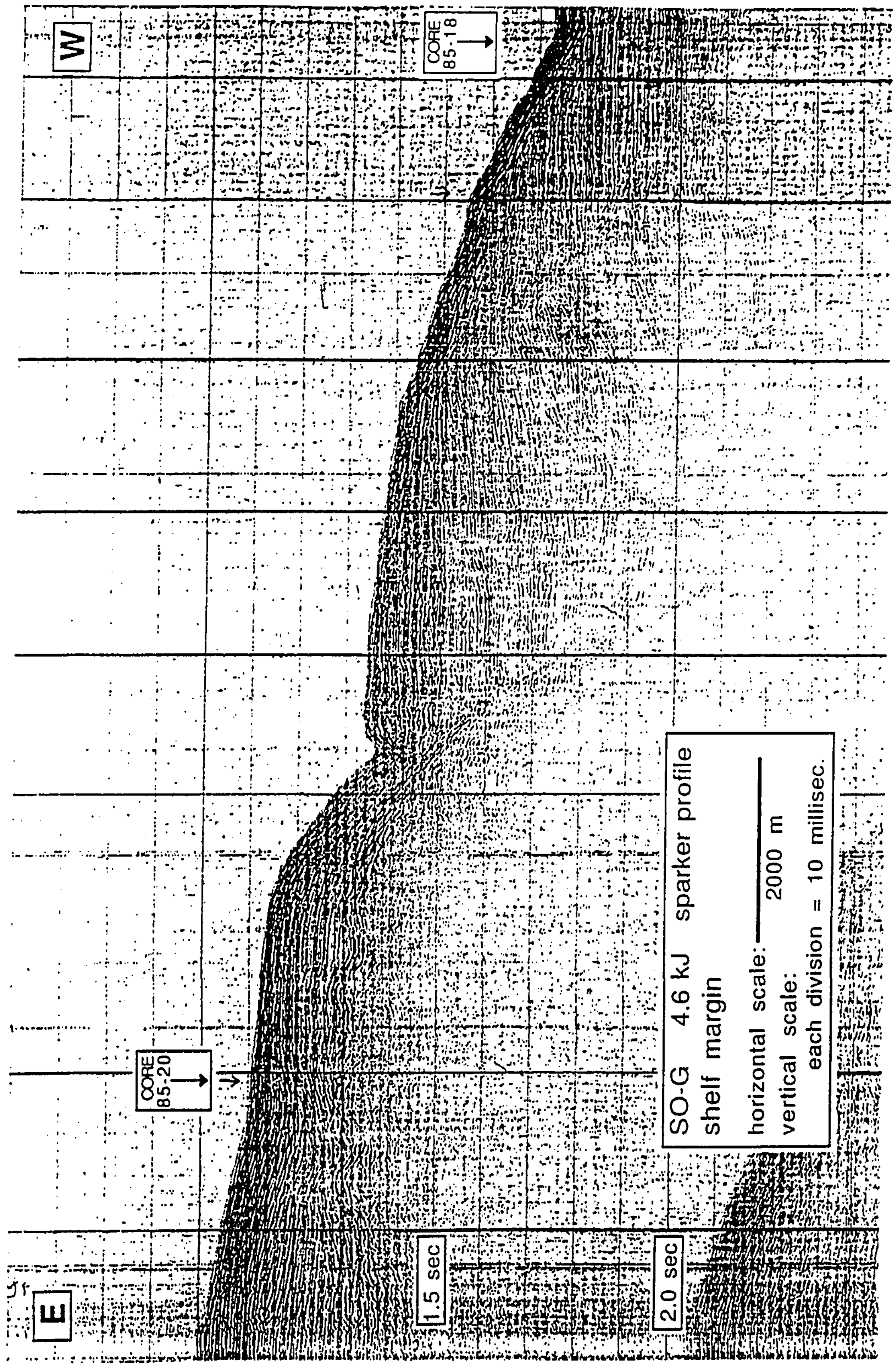

E
WESTERN SOUTH ORKNEY PLATEAU SO-G
W
20
768 m
18
1261 m
17
1482 m
16
2004 m
15
2397 m
1 SEC
2 SEC
3 SEC
Prograding Complex
Slope-fan Complex
SLUMPS
outcrop
turbidite
trans. glacial marine
debris flow
pelagic
lag
till
sea bottom and major reflectors
representative minor reflectors
fault
0
2000
4000 meters
V.E. - 8x

Figure 42. Seismic data from profile SO-G, showing faulting near the shelf break and seismic facies of the lowstand wedge systems tract. Facies of the prograding complex are seen shelfward of the faulting; reflectors seaward of the fault are mostly slope-fan complex facies (see Figure. 41).


W
CORE 85-18
E
CORE 85-20
1.5 sec
2.0 sec
SO-G 4.6 kJ sparker profile
shelf margin
horizontal scale: 2000 m
vertical scale:
each division = 10 millisec.

discontinuities except on the steepest part of the slope (figure 43). This probably represents a series of prograding complexes of the lowstand wedge systems tract as are seen on lines G and D. Both the seismic data and the areal geometry of the features support this interpretation. Tectonic subsidence of the margin allowed prograding lobes to be built out during several cycles of lowstand sedimentation. Cores 85-2, -4, and -5 consist of sandy turbidites and debris flows. Core 85-3 is mainly pelagic sediment. Data on line B also show several large slump features frozen on the slope, which has a 2 - 2.5° gradient.

Line SO-A

Line SO-A, the northernmost slope profile, shows two units of seaward-dipping reflectors at the shelf break separated by a discontinuity (figure 44). The lower unit dips more gently than the upper unit and may correlate with the slope-fan facies, whereas the upper unit probably correlates with the prograding "lobe" facies. The shelf break is sharp at about 350 meters depth; below it the slope is steep (approx. 7.5°) and shows evidence of slumping. The slope flattens out at a depth of about 1300 meters, at which point there is an isolated mound, approximately 100 meters high and 1 kilometer in length (figure 45). The reflectors are parabolic in shape, suggesting reflection from a small (or point) source. No internal structure can be seen in the mound, and it is not connected in the plane of the section to the slope deposits. The mound may be a large slump which came to rest at a relatively flat area on the slope.

Line SO-I

Line I crosses one of the steepest parts of the slope, just south of the southern outer margin high. The outer part of the plateau here has been eroded and overlain by a pelagic drape, as can be seen in the truncated reflectors near the shelf break, overlain by a thin

Figure 43. Seismic Line SO-B, 4.6 kJ single-channel sparker profile - South Orkney Plateau/Powell Basin margin. Location on figure 12.

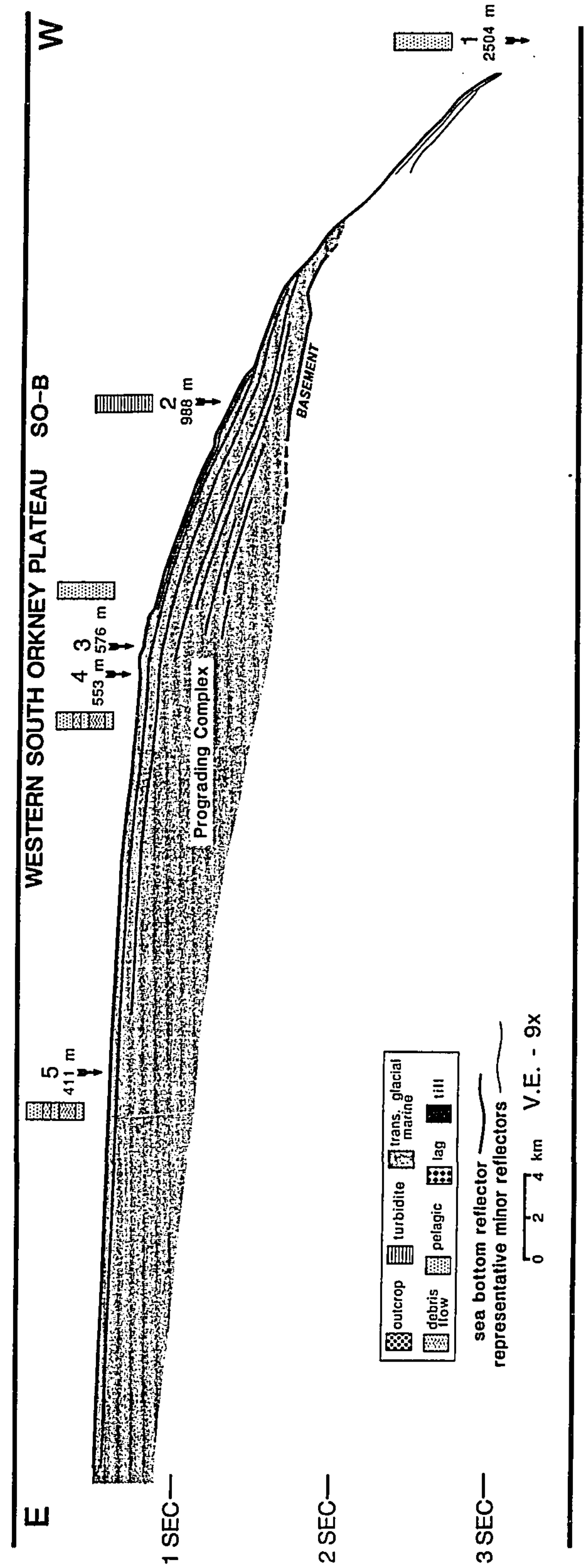

WESTERN SOUTH ORKNEY PLATEAU SO-B
E
W
1 SEC
2 SEC
3 SEC
5
411 m
4
553 m
3
576 m
2
988 m
1
2504 m
Prograding Complex
BASEMENT
outcrop
turbidite
trans. glacial marine
debris flow
pelagic
lag
till
sea bottom reflector
representative minor reflectors
0 2 4 km
V.E. - 9x

Figure 44. Seismic Line SO-A, 1 and 4.6 kJ single-channel sparker profile - South Orkney Plateau/Powell Basin margin. Location on figure 12.

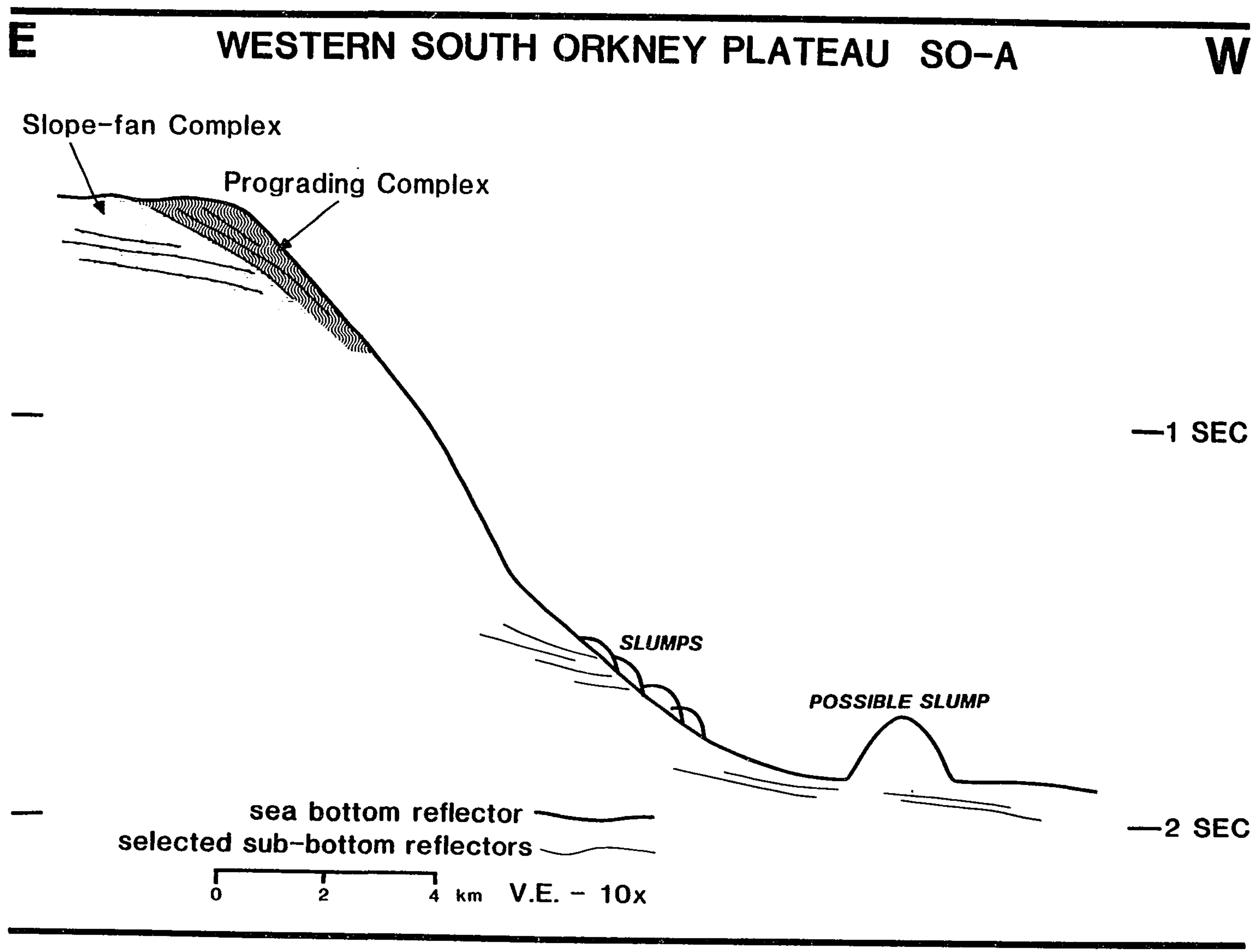
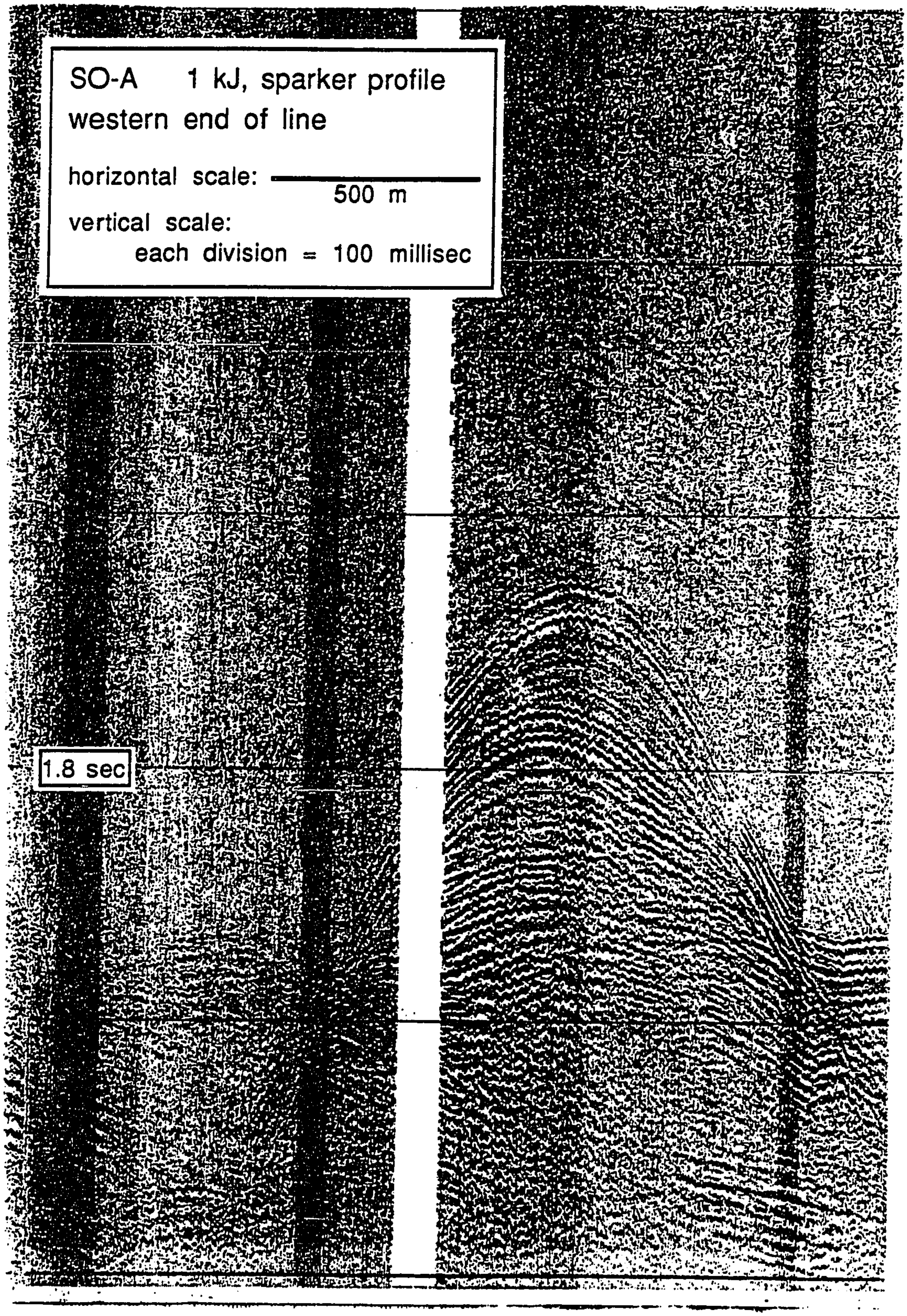

E
WESTERN SOUTH ORKNEY PLATEAU SO-A
W
Slope-fan Complex
Prograding Complex
SLUMPS
POSSIBLE SLUMP
—1 SEC
—2 SEC
sea bottom reflector
selected sub-bottom reflectors
0
2
4 km
V.E. - 10x

Figure 45. Seismic data from profile SO-A, western end, showing an isolated "mound" at approximately 1300 meters depth. The "mound" is about 100 meters high and 1 kilometer in length. Reflectors are parabolic, suggesting reflection from, essentially, a point source.

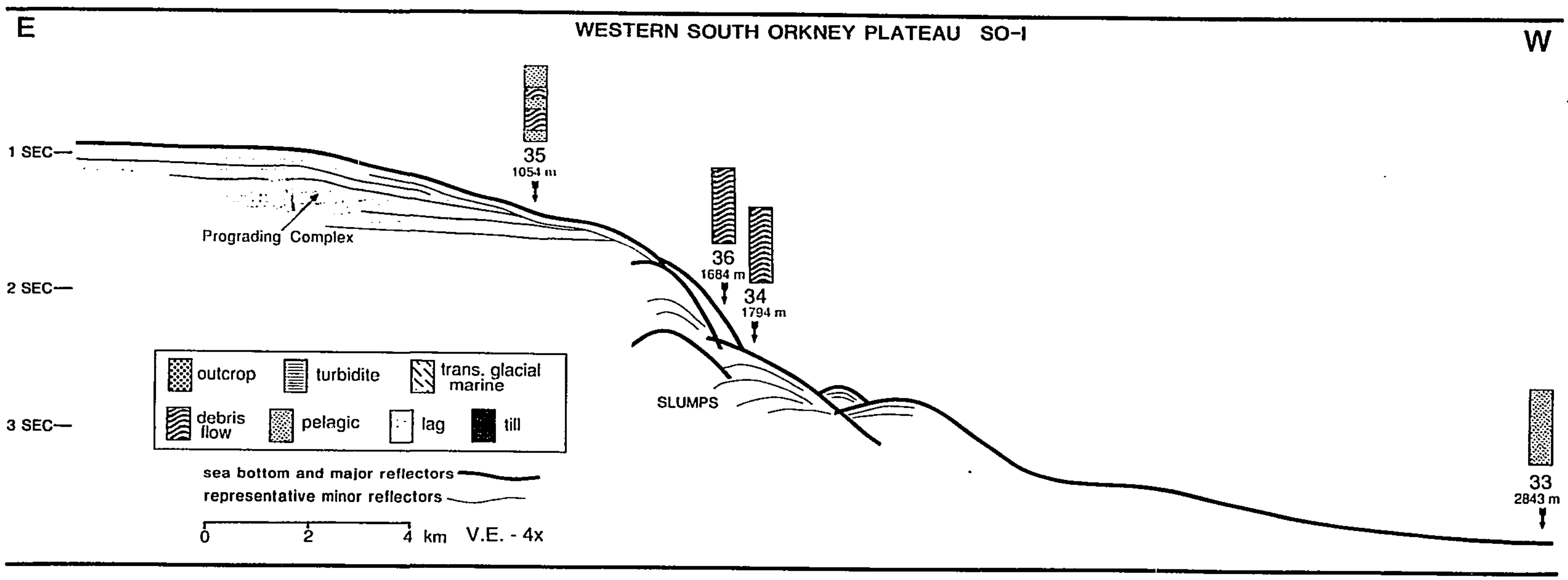

SO-A 1 kJ, sparker profile
western end of line
horizontal scale:
500 m
vertical scale:
each division = 100 millisec
1.8 sec

package of seaward-dipping reflectors (figure 46). The pelagic drape probably represents the highstand systems tract. The underlying strata appear to consist of facies of the prograding complex. Erosion may have occurred by submarine currents being channeled between outer margin bathymetric highs. The slope on line I is steep (up to 14°), and detatched, mounded, convolute reflectors and side echoes indicate large-scale slumping. Core data show that smaller-scale gravity flow is also common. Cores 85-34 and -36 are mainly sediment gravity flow deposits. Core 85-35 appears to be mostly compound glacial marine sediment with a small section of sediment gravity flow. At the base of the slope, core 85-33, like 85-15, consists of an apparently undisturbed section of pelagic "sub-ice" sediments overlain by a compound glacial marine deposit.

Summary of slope profiles

Data from slope profiles show mainly facies of the lowstand wedge systems tract, created when sedimentation was high. During highstands the plateau was flooded and sediment supply was limited. Although it is not possible to correlate the seismic facies with specific glacial events, they appear to represent a change from predominantly glacial, or lowstand, conditions to present-day sea level and interglacial conditions. Normal faulting near the shelf break is evident on two of the slope lines, and because of the young age of the margin and minimal sedimentation, creates high-angle scarps which affect sedimentation on the margin. The faulting is typical of passive margin tectonics. The inception of faulting probably pre-dates all of the sediments recovered in piston cores except for the two outcrop recoveries. There is abundant evidence of slumping and/or sediment gravity flow on every slope line. Higher angle slopes tend to be more heavily disturbed. However, evidence for mass movement is seen on slopes with less than 2.5° gradient.

Figure 46. Seismic Line SO-I, 4.6 kJ single-channel sparker profile - South Orkney Plateau/Powell Basin margin. Location on figure 12.


E
WESTERN SOUTH ORKNEY PLATEAU SO-I
W
1 SEC
2 SEC
3 SEC
35
1054 m
36
1684 m
34
1794 m
33
2843 m
Prograding Complex
SLUMPS
outcrop
turbidite
trans. glacial marine
debris flow
pelagic
lag
till
sea bottom and major reflectors
representative minor reflectors
0
2
4 km
V.E. - 4x

Plateau Data - Description and stratigraphy

On the plateau, water depths were shallow enough to use 1 kilojoule of energy in the source pulse, and thus to vertically expand the record. This resulted in higher resolution, especially in the uppermost section, and allowed more detailed interpretation through the use of manual deconvolution.

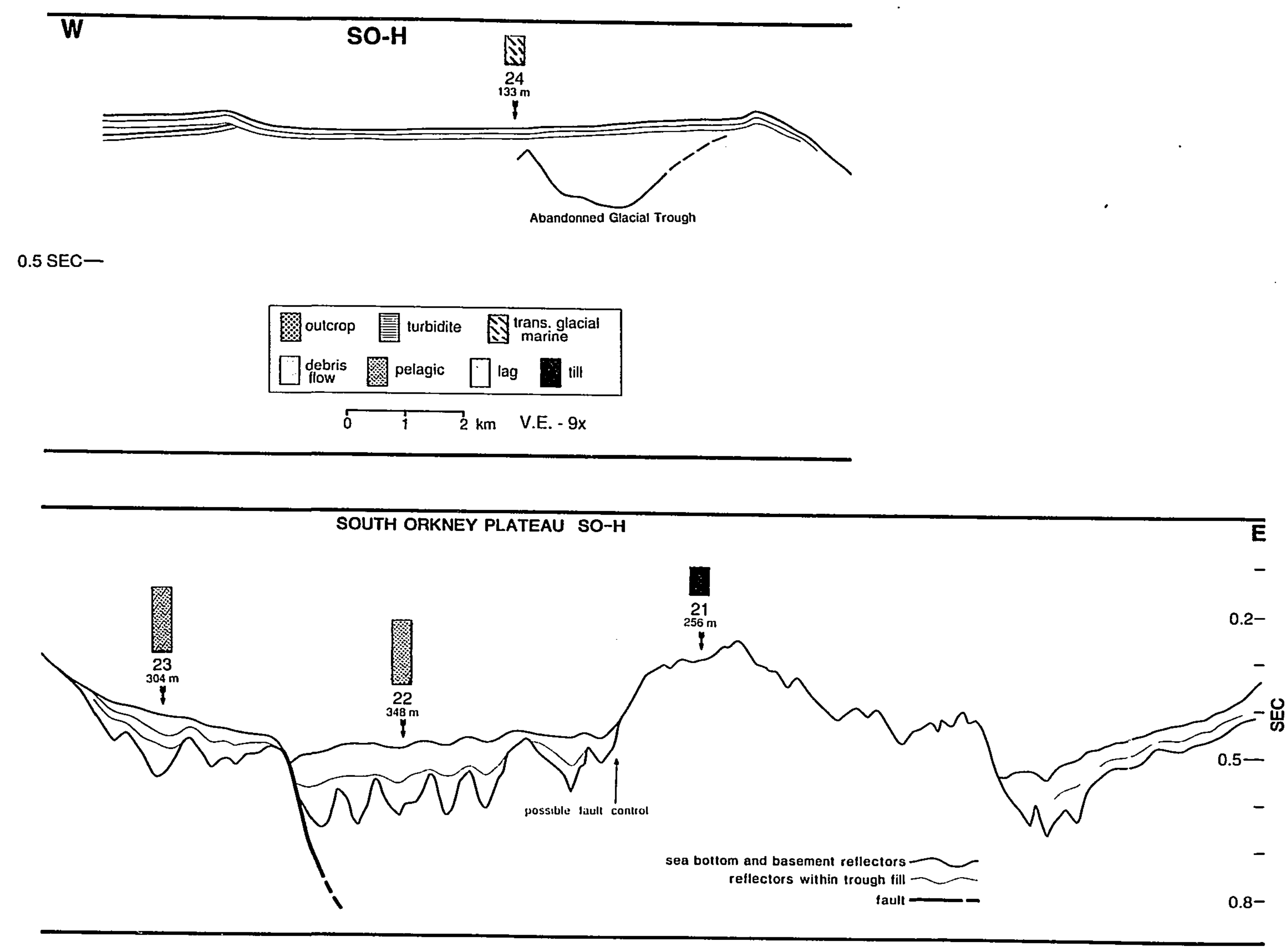
Plateau Line SO-H

Starting at its northern (eastern) end, line SO-H crosses both branches of the Signy Island Trough. The eastern branch is asymmetrical, and is asymmetrically filled (figure 47). There are at least two seismic sequences of fill within the trough, data are not good enough to discern more sequences.

The bathymetric high separating the two branches of the trough appears to be "acoustic basement" outcrop. The water-bottom reflector package contains the entire pulse pattern of the source (figure 48). This indicates that there is no interference from a second reflection for at least the thickness of the reflector package (roughly 20-25 meters). Therefore, there is either no sediment overlying the basement, or there is less than can be resolved with these data. Also, the lack of penetration indicates a hard surface. At location 85-21, the core and bottom grab samples consist of an overcompacted diamicton, which is probably basal till. No overlying sediments were recovered.

The western branch of the trough and its fill are also assymmetrical (figure 49). At least two, possibly three seismic sequences comprise the sediment fill, which onlaps onto the basement in several locations. Although the sedimentary fill is fairly thick (up to 130 milliseconds or roughly 90 - 100 meters), the surface irregularities reflect the ruggedness of the underlying basement. This indicates rapid sedimentation. The uppermost fill sequence (60 - 70 milliseconds) is very homogeneous, as indicated by the absence of reflectors within the unit. Basement of the entire trough and dividing high is very rugged.

Figure 47. Seismic Line SO-H, 1 kJ single-channel sparker profile - South Orkney Plateau. Location on figure 12.



W
SO-H
24
133 m
Abandonned Glacial Trough
0.5 SEC
outcrop
turbidite
trans. glacial marine
debris flow
pelagic
lag
till
0 1 2 km
V.E. - 9x
SOUTH ORKNEY PLATEAU SO-H
E
23
304 m
22
348 m
21
256 m
possible fault control
0.2
0.5
0.8
SEC
sea bottom and basement reflectors
reflectors within trough fill
fault

Figure 48. Seismic data from profile SO-H, showing the bathymetric high separating the two branches of the Signy Island Trough. The water-bottom reflector package contains the entire source pulse pattern, which indicates that no interference with the pulse occurred; i.e. there is no reflection from below the water bottom. This, and the lack of penetration at a shallow depth indicates a hard surface (basement outcrop) with no overlying sediment. Supporting this interpretation, probable basal till was recovered from location 85-21.

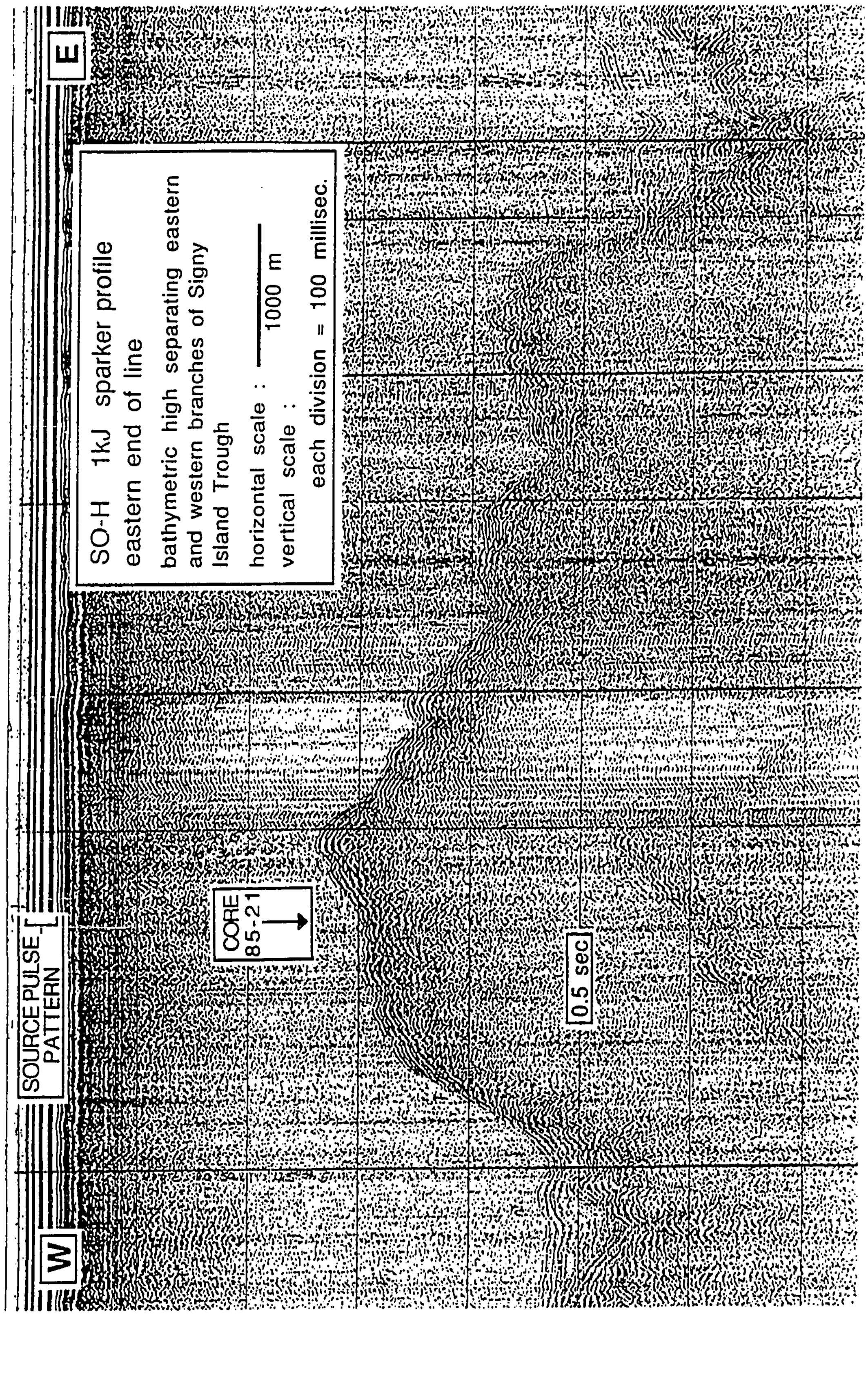
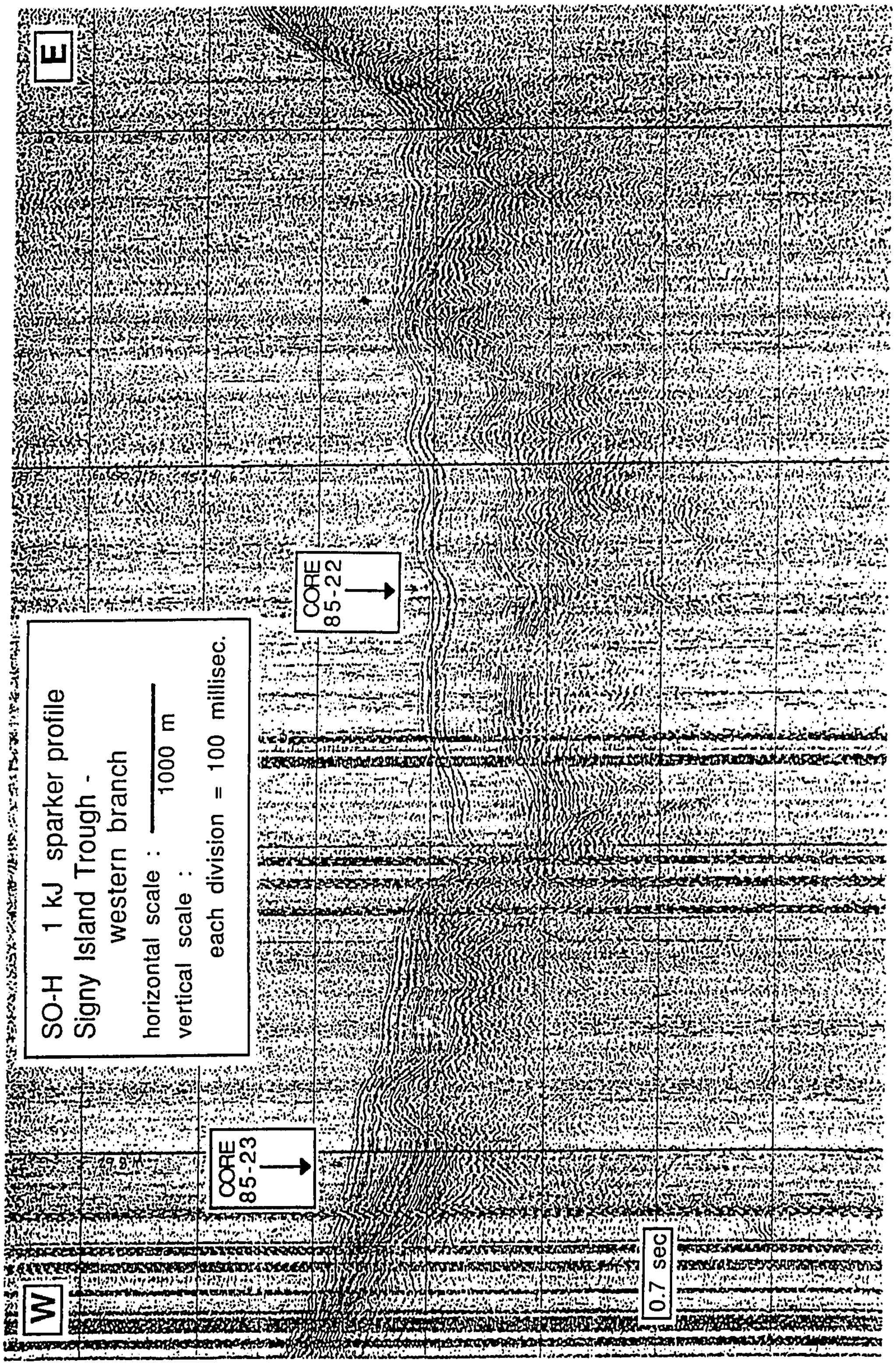

W
E
SOURCE PULSE PATTERN
SO-H 1kJ sparker profile
eastern end of line
bathymetric high separating eastern and western branches of Signy Island Trough
horizontal scale : 1000 m
vertical scale :
each division = 100 millisec.
CORE 85-21
0.5 sec

Figure 49. Seismic data from profile SO-H, showing the western branch of Signy Island Trough. At least two complete seismic sequences are present within the trough fill. The sedimentary fill at location 85-23 is approximately 70 milliseconds, or 60 meters thick. Using the sedimentation rates determined from ^{14}C dating for the Signy Island Trough, this corresponds to about 120 ka of deposition. The hummocky surface reflects the highly irregular basement within the trough. The fault cutting the trough is very recent, probably no more than a few thousand years old.

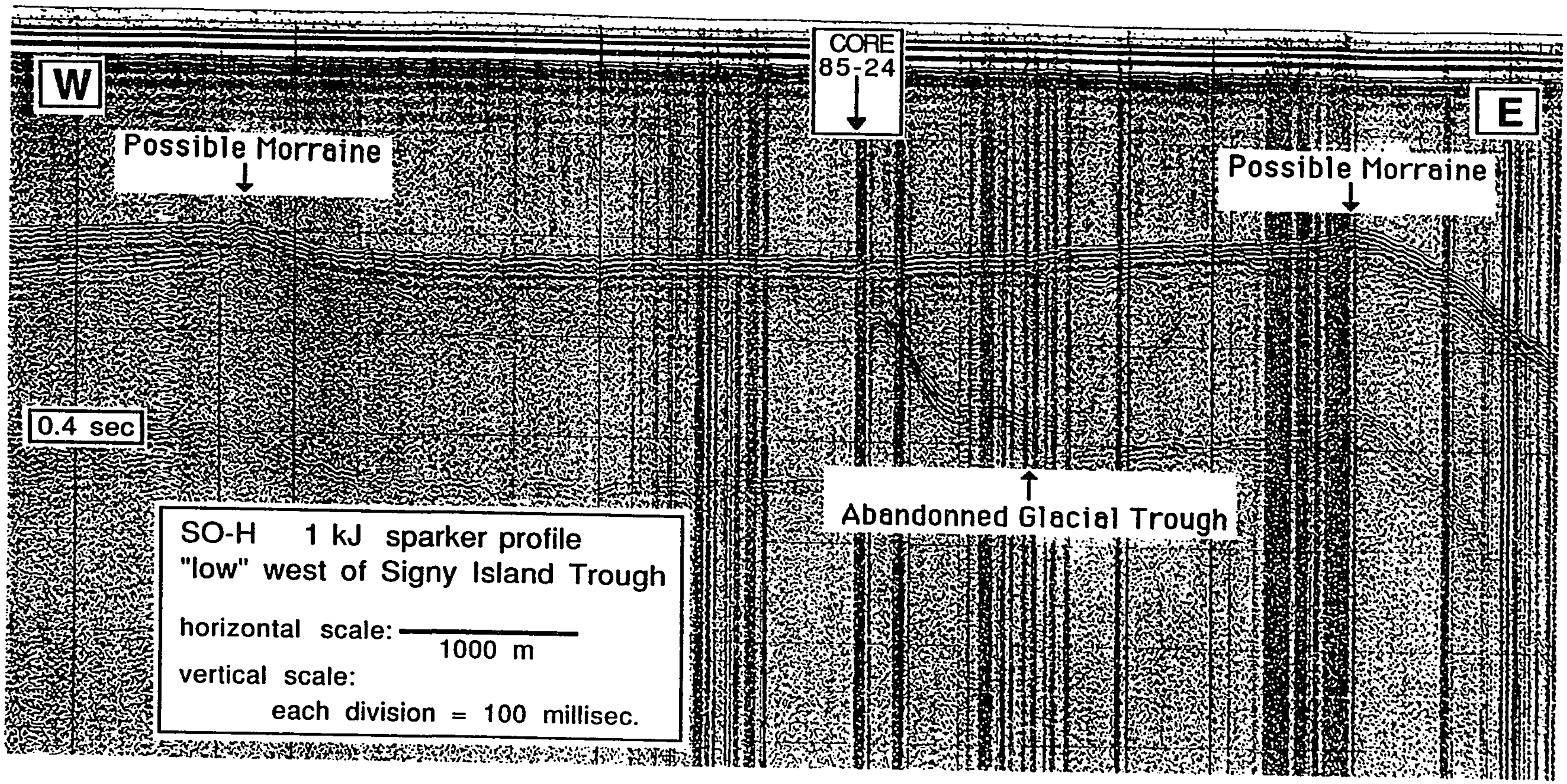

W
E
SO-H 1 kJ sparker profile
Signy Island Trough -
western branch
horizontal scale : 1000 m
vertical scale :
each division = 100 millisec.
CORE 85-23
CORE 85-22
0.7 sec

Nearly all of the basement surface is defined by diffractions, which indicate very steep dips and sharp peaks. The trough is generally U-shaped, however, the bottom of the trough is V-shaped on a smaller scale, and may indicate erosion by submarine currents after the trough was initially carved. A normal fault cuts the basement and nearly all of the trough fill. Sedimentation around the fault implies that it is very young, and may possibly be still active. Other parts of the trough are very steep-sided and may also be fault controlled.

West of the trough, core 85-24 is located on a smooth surface, within a slight assymmetrical low (figure 50). The "low" is bounded on each side by small mounds, possibly morraines. An underlying reflector is truncated at the western mound (or morraine). Penetration within the "low" is approximately 200 milliseconds, about equal to the depth of the first water-bottom multiple. There is a single reflector package at the surface, and then almost no coherent reflectors until the first multiple, which suggests homogeneous sediment (or rock) properties down-section. The only reflector that appears within this upper 200 milliseconds is a U-shaped feature within the eastern part of the "low". This feature is probably an abandoned glacial trough which was subsequently filled by glacial and/or glacial marine sediment. Only part of the source pulse pattern appears in the surface reflector package (i.e. there is interference with the pattern), which may indicate that a thin layer of sediment (thinner than the pulse pattern) overlies acoustic basement. The bathymetric low is probably also a glacial feature, planed off by the most recent ice advance that extended to this location.

Further west and south on line SO-H, the surface reflection is not as smooth as at core location 85-24. None of the surface reflector package matches the source pulse pattern, perhaps indicating multiple, thin layers of sediment overlying acoustic basement. Water depth also increases in this direction (west and south), and wind-driven current velocity wanes with depth, thus, more medium- and fine-grained sediments are deposited. The bottom grab sample recovered at location 85-25 consists of a gravelly, diatomaceous

Figure 50. Seismic data from profile SO-H, showing the bathymetric low west of the Signy Island Trough, bounded by mounds which appear to be lateral morraines. Truncated sub-surface reflectors and a probable abandonned glacial trough can be seen within the section.


W
E
CORE 85-24
Possible Morraine
Possible Morraine
Abandonned Glacial Trough
0.4 sec
SO-H 1 kJ sparker profile
"low" west of Signy Island Trough
horizontal scale: 1000 m
vertical scale:
each division = 100 millisec.

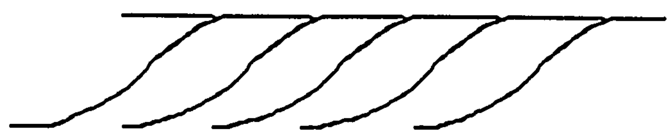
mud, and the core is interpreted as a transitional glacial marine deposit. Core 85-26 contains a diatom mud, which seems to be slightly thicker than that at location 85-24, overlying probable basal till.

South of location 85-26, there is another truncated reflector, and the character of the surface reflector package changes. From approximately 250 meters depth, seaward, the surface reflection is slightly rougher, and individual reflectors are more discontinuous. The surface reflector package is also broader, generally lower in amplitude, and has more "interference" in the source pulse pattern. Cores from this section of line SO-H (85-27, -28, and -29) are longer, and are mainly diatom-rich, compound glacial marine sediments which contain small to moderate amounts of IRD. In addition, low angle climbing toplap (figure 51) at the top of the surface reflector indicates sediment reworking by currents, and therefore implies an uncompacted sediment surface.

In summary, line SO-H shows evidence of glacial erosion, and thus, past glacial expansion near the islands in the form of glacially-carved troughs and a probable abandoned glacial trough. Westward and southward, subsurface reflectors are truncated to a water depth of about 240 meters, which may be the maximum depth of glacial erosion. Within the section shallower than 240 meters, relatively high-amplitude, continuous, surface reflectors indicate an overcompacted surface, which suggests basal till. Seaward of about 240 meters, reflection character and core recovery indicate marine or glacial marine sedimentation.

The only structural feature on line SO-H is the very recent normal fault within the western Signy Island Trough. Roughly 80 milliseconds, or 60 meters, of displacement is evident. Faulting obviously occurred after the trough was initially carved, which constrains its age at less than 400 ka, and probably less than 200 ka. It also appears to have displaced most of the existing sediment fill in the trough, and although the sedimentation rate is high within the trough, there is very little cover on the fault scarp.

TOPLAP



CLIMBING TOPLAP

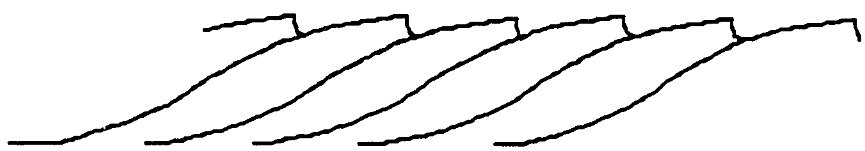


Figure 51. Schematic diagram of toplap and climbing toplap reflector patterns. Toplap is defined as termination of strata below an unconformity or downlap surface due to post-depositional erosion. Climbing toplap is formed in a similar way, probably due to current reworking of sediments after deposition (Vail, pers. comm., 1987).

Thus, movement on the fault has occurred within the last few thousand years.

More than one seismic sequence is observed within the fill in Signy Island Trough, indicating that multiple cycles of sea level fall and rise have occurred since the trough was carved. Sedimentation rates determined from ^{14}C dating of sediments within the trough suggest that the fill within the trough (60-65 milliseconds) represents about 100 ka of sedimentation. If true, this indicates that the trough may have been carved (or re-carved) about 100 ka ago, during the earliest Wisconsin. This correlates with radiolarian studies by Hays, et. al. (1976) which indicate a cold climatic peak at about 105 ka B.P.

CHAPTER 7. CONCLUSIONS

1. Piston cores collected from the western South Orkney Plateau penetrated basal tills and transitional glacial marine sediments at depths shallower than 250 meters, and at a slightly greater depth from the high separating the two branches of Signy Island Trough. Cores collected from depths greater than 250 meters on the plateau are compound and residual glacial marine sediments. Seismic data also indicate the past presence of grounded ice to a depth of about 240 meters. These data and investigations of maximum ice expansion by Sugden and Clapperton (1977) suggest that ice has been grounded on the plateau to a present depth of approximately 240-250 meters.

2. Cores collected from the western margin (slope) of the South Orkney Plateau are mainly compound and residual glacial marine sediments, most of which have been affected by slumping and/or sediment gravity flow. Only about one-fourth of the cores collected are free of sediment gravity flow deposits. Large-scale slumping and sediment gravity flow disturbances are obvious on every slope seismic profile, as well. Higher angle slopes tend to be more heavily disturbed. However, evidence for mass movement is seen on slopes with less than 2.5° gradient. Thus, interpretations of glacial history or paleoceanographic changes in this kind of setting should be made with extreme caution.

3. Petrologic examination of ice-rafted clasts from the plateau shows evidence for glacial erosion of the islands. Eighty-nine percent of clasts from plateau samples are probable locally-derived IRD, only 11% are exotic. In slope cores and grab samples, at least 45% of clasts are exotic. Relative percentage of locally-derived clasts is greatest near the islands and decreases seaward. Ninety percent of plateau pebbles plot within Boulton's (1978) basal transport field, which also indicates basal debris transport.

4. Textural data from plateau surface sediments (133 to 411 m) show relatively well-sorted dominant modes, and a distinct fining-with-depth trend, which indicates that wind-driven marine currents on the plateau are redistributing sediments in a predictable pattern to at least 400 meters depth. The current-derived modes also indicate that total grain size analysis is necessary to accurately differentiate IRD sands from sands derived by other means.

5. Seismic profiles from the slope show evidence of passive margin tectonics, such as shelf margin faults, outer margin intrusive and/or extrusive features, and large-scale slumping. These data support previous tectonic work on the margin by King (1983).

6. Seismic profiles show facies of the prograding complex and slope-fan complex of the lowstand wedge systems tract, representing rising sea level on a tectonically subsiding margin. Although it is not possible to correlate the systems tracts with specific glacial events, they apparently represent the change from predominantly glacial, or lowstand, conditions during the late Wisconsin to present-day sea level and interglacial conditions.

6. Carbon-14 dating of shell material from two horizons in core 85-23 enabled calculation of a sedimentation rate of approximately 50 cm/ka for this core.

7. Core 85-23 was collected from the Signy Island Trough, and is estimated from the above sedimentation rate to be 6 ka old at its base. Textural and compositional homogeneity indicates that there has been no sedimentological change and thus no significant change in ice cover over this area during the past 6 ka.

8. Seismic data and sedimentation rates determined by ^{14}C dating suggest that the Signy

Island Trough may have been carved (or re-carved) approximately 100 ka ago, during the earliest Wisconsin. This correlates with radiolarian studies which indicate a cold climatic peak at about 105 ka B.P. (Hays, et. al., 1976).

9. Many cores collected from the slope contain evidence which supports an interval of deposition under increased floating ice cover during the late Wisconsin(?). Textural and mineralogical investigations indicate that the nature of this expanded ice cover was probably perennial pack ice rather than a massive ice shelf. The only true transitional glacial marine sediments collected (i.e. deposited under a coherent ice shelf) were in cores recovered from less than about 250 meters of water.

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APPENDIX A

CARBON - 14 DATING

DEEP FREEZE 1985 CORE 85-23

Core 85-23, located on the western side of Signy Island Trough in 304 meters of water (figure 26), recovered 289 cm of partially laminated, diatomaceous mud containing abundant, small pelecypod shells. This core provides an opportunity to use radiocarbon dating to constrain and compare with biostratigraphic age-dates, and to help establish sedimentation rates in this area. Knowledge of sedimentation rates is critical to the study of Late Pleistocene - Holocene geologic/glacial history of this region. Previous studies of sedimentation in the Antarctic Peninsula region have typically used paleomagnetic and/or paleontologic methods to date cores and infer rates of deposition. These rates have then been used to reconstruct changes in bottom water velocity (Huang, et. al., 1982), climatic variations and sea-ice cover (Cooke and Hayes, 1982), and the glacial history of the continent (Osborn, et. al., 1983). A limit to these applications is that sedimentation rates have generally been inferred from small amounts of data or extrapolated from other areas. The abundance of diatoms in Antarctic shelf cores suggests the use of biostratigraphic dating. However, diatom biostratigraphy in the Antarctic is controversial (Burkle and Abrams, 1986), and several different zonations have been proposed by different authors, including Donahue (1970), Abbott (1974), McCollum (1975), Gombos (1976), and Schroder (1976). Biostratigraphic zonations for other microfossil groups in the Antarctic are rare.

Sedimentation rates published for the Antarctic region vary greatly depending on the depositional environment. DeMaster (1982) dated deep sea sediments in the South Atlantic using $^{230}Th/^{231}Pa$ ratios, and determined sedimentation rates of 1-3 cm/1000 years. Flux rates to sediment traps in the Bransfield Basin (Dunbar, 1984) suggest sedimentation rates there as high as a meter or more per 1000 years. Pb-210 dating in basins of the Antarctic Peninsula determined rates which range from 1 - 3 m/1000 years (DeMaster, unpub.). However, to date, no sedimentation rates for the South Orkney Plateau have been published.

Traditional methods of ^{14}C dating have been problematic in the Antarctic. Difficulties arise from : (1) the small amount, or lack of preserved carbonate material in most Antarctic cores, (2) contamination, either by recrystallization of aragonite to calcite or by bacterial uptake of recent CO_2, and (3) ^{14}C depletion in the marine carbon reservoir. South Orkney Plateau core 85-23 contained a relatively large amount of calcium carbonate in the form of abundant, small (5-10 mm) pelecypods *(Tellina)*, including several distinct layers of horizontal to sub-horizontally lying, articulated shells (Appendix B). X-radiography revealed faint lamination in several intervals, indicating that little, if any disturbance of the stratigraphy occurred upon recovery of the core. The second problem, contamination, is corrected for in the lab technique by leaching the outer layers of the shells with HCl before dating. The third problem is much more difficult to address. Southern Ocean waters are known to be depleted in ^{14}C. Thus, ^{14}C ages of organisms which obtain carbon from the marine carbon reservoir may be older than the true ages of the organisms (Mabin, 1985). Due to ^{14}C depletion, surface waters in the Antarctic have apparent ^{14}C ages of up to 1500 years B.P., and deep waters have apparent ages of up to 2500 years B.P. (Mabin, 1986). Dates obtained using ^{14}C methods on modern Antarctic specimens (seals, penguins, whales, shells, kelp) are inconsistent and range from 1500 years B.P. to futuristic ages; but less inconsistency is noted for organisms which have restricted diets and limited depth ranges (Mabin, 1986).

Omoto (1983) estimated the reservoir correction for Antarctic marine organisms to be between 800 years and 3000 years. A compilation of values for $\partial^{14}C$ in surface waters around Antarctica shows wide variation, with the greatest depletions closest to the continent or ice edge (Omoto, 1983). Stuiver and Ostlund (1980) list $\partial^{14}C$ values for water at various depths from two stations near the South Orkney Plateau (Sta. 78 - 61°3'S/62°58'W, and Sta. 82 - 56°15'S/24°55'W). Values above approximately 200 meters depth (within the well-mixed surface layer) are probably useless because of contamination by adding ^{14}C produced in nuclear weapons testing since 1955 (Mabin, 1985; 1986). Values of $\partial^{14}C$ at depths below 200 meters are fairly consistent, and their averages give reservoir correction factors which range between +1333 yrs. and +1362 yrs. Depth at which the pelecypod shells grew is uncertain. However, the Tellinidae are benthic organisms (Babin, 1980), so unless they were growing during a glacial maximum, their growth depth was probably similar to the depth at location 85-23 today (≈300 m). Since the reservoir correction for depths below 200 meters is consistent and more reliable than for shallower depths, the correction factor for deeper waters is applied to the core 85-23 dates.

Age determinations were made with shell material from 2 horizons in the core; (1) the interval 83.5-86 cm, and (2) the interval 264-269 cm. The large intervals (2.5 and 5 cm) were neccessary to obtain enough carbonate material for the dating technique. Age determined for the upper sample was 9570 +2180, -1720 ^{14}C years B.P., age determined for the lower sample was 11,535 +900, -810 ^{14}C years B.P. The average of the two correction factors calculated from Stuiver and Ostlund's (1980) data is 1348, or approximately 1350 years. Thus, the upper date is 9570 - 1350 = 8220 years, and the lower date is 11,535 - 1350 = 10,185 years. Because of sample size, the date for the lower sample is more reliable. A sedimentation rate calculated using the corrected lower age, and assuming that the top of the core is equivalent to the sea floor surface, is 26 cm/1000 years, only slightly higher than the uncorrected rate of about 25 cm/1000 years, i.e. the correction factor makes little difference in the calculated sedimentation rates. However, the discrepancy in sedimentation rates determined from upper and lower samples is large. The sedimentation rate calculated between the two age dates is 92 cm/1000 years (ignoring the error bars).

10185 yrs - 8220 yrs = 1965 yrs

180 cm ÷ 1965 yrs = 92 cm/1000 yrs

Since the upper date is less reliable than the lower date and has large error bars, this calculation is very approximate, and is probably too high by a factor of at least two. As much as 2 meters of the uppermost sediment may be lost during piston coring operations in soft sediment. However, if the sedimentation rate of 92 cm/1000 years were accurate for the entire core, at least 8 meters of the core top would have to be missing. The discrepancy in sedimentation rates calculated from the upper and lower ages may be due to errors inherent in ^{14}C dating small amounts of shell material from the Antarctic Ocean, or it may be due to an actual change in sedimentation rate. The most reasonable assumption is that sedimentation rates have changed during the depositional history of the core. A possible cause of a change in sedimentation rate is change in the primary production of phytoplankton and/or meltwater sedimentation brought on by climatic warming. Based on the data and assumptions, an average sedimentation rate of 55 cm/1000 years is proposed for the core.

$$265 \text{ cm} + 300 \text{ cm (core missing)} = 565 \text{ cm (to lower date)}$$

$$565 \text{ cm} \div 10185 \text{ yrs} = 55 \text{ cm}/1000 \text{ yrs}$$

A sedimentation rate of approximately 50 cm/1000 years is not unreasonable for this setting. The core is located only 16 km from Coronation Island and 11 km from Signy Island in one of the deeper parts of the Signy Island Trough. There is evidence that a significant amount of material is being eroded from the islands today by glacial action (see Chapter 4 - Glacial Regime and History). Given the relatively low latitude, meltwater erosion may also produce a large quantity of sediment on a seasonal basis. The Gulf of Alaska, at a north latitude nearly identical to that of the South Orkney Islands, has average Holocene shelf sedimentation rates of approximately 1000cm ka^{-1}, and maximum rates of nearly 3000cm ka^{-1} (Anderson and Molnia, 1986). The extremely high sedimentation rates in the Gulf of Alaska are primarily due to high precipitation (>400 cm/year) and elevation

(Anderson and Molnia, 1986), and probably meltwater erosion as well, since many of the glaciers are retreating. Precipitation accumulation on the South Orkney Islands is also high, at least on the northern and northwestern sides, and at high elevations on the larger islands (Marr, 1935) although undoubtedly not as high as in the Gulf of Alaska region. Both areas are affected by frequent low pressure storms which add moisture to the glacier systems (Lamb, 1964; Molnia, 1986).

The latitude of the South Orkney Plateau and the biogenic content of the Signy Island Trough sediment suggest a high siliceous productivity rate. Whitaker (1982) found high productivity near Signy Island (2-4.8 g C m^{-2} d^{-1}) which is comparable with other neritic areas of the Antarctic, but lasting only during an 8 - 10 week summer diatom bloom. Annual production estimates for the neritic environment in this area range from 86 g C m^{-2} to 289 g C m^{-2}, but oceanic production is thought to be much lower (Horne, et. al., 1969; Whitaker, 1982). Another probable source of sediment accumulating in the Signy Island Trough is the fine-grained material being swept off the plateau by marine currents into the deeper trough. Cores taken from the plateau near the trough at depths of 150-250 meters indicate that marine currents are actively removing fine-grained (clay to coarse silt) sediment from these areas. The trough is at least 350 meters deep in its axis and is thus a likely place for accumulation of this sediment.

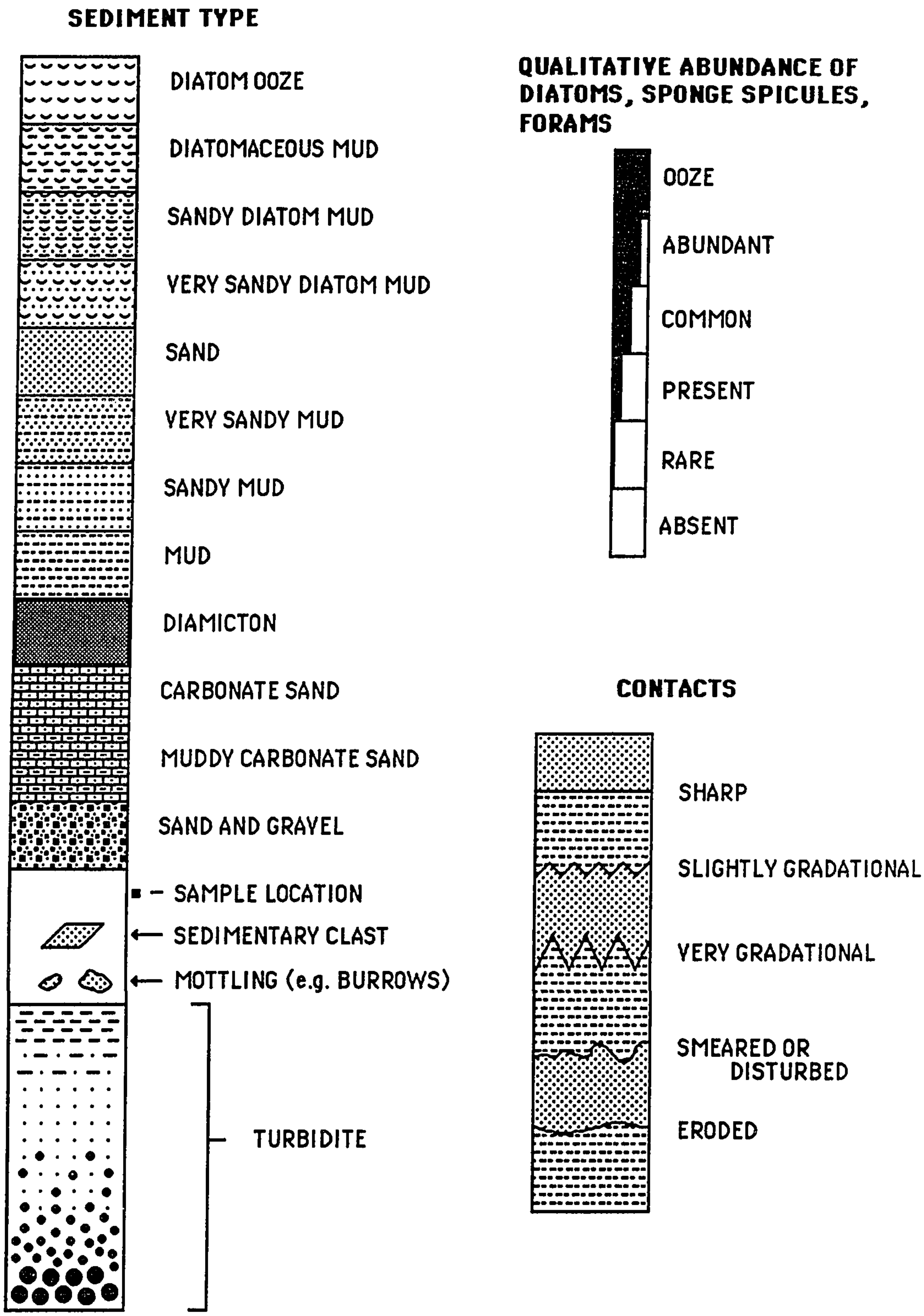
APPENDIX B
DESCRIPTIVE CORE LOGS

Deep Freeze 85 - South Orkney Plateau

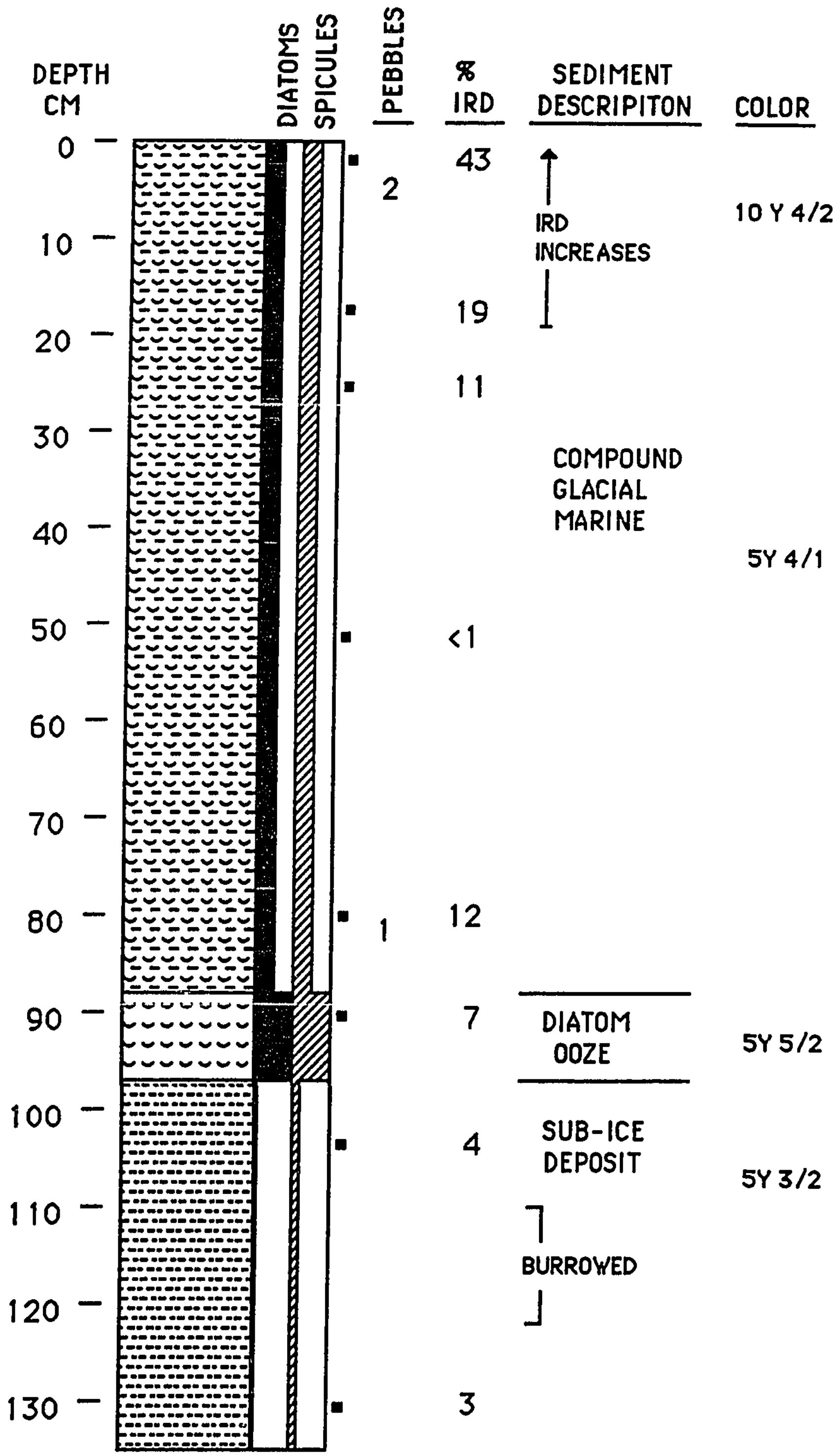
DEEP FREEZE 1985 CORE RECOVERY AND STATION INFORMATION
SOUTH ORKNEY PLATEAU

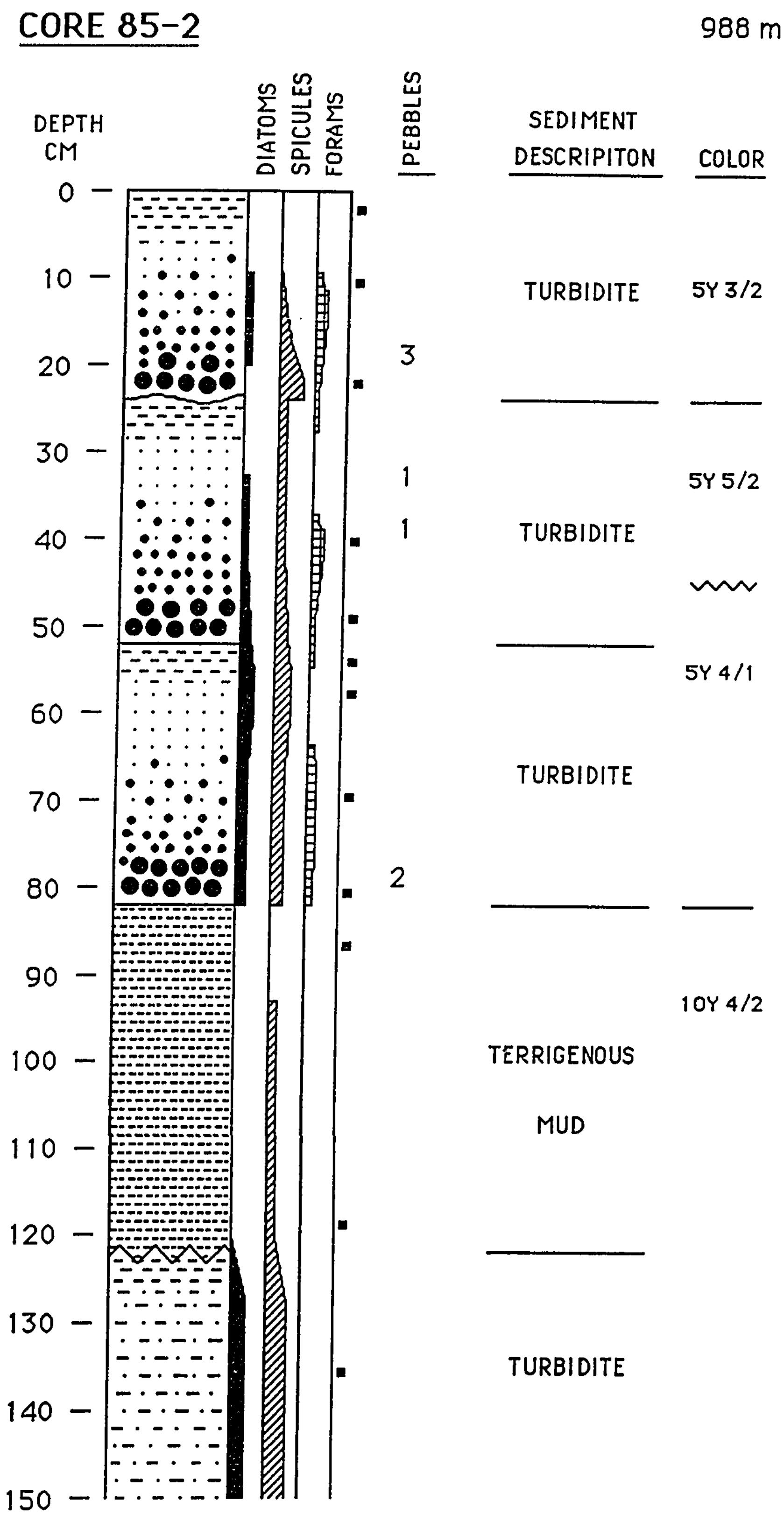
STATION NO.	LAT/LONG	WATER DEPTH (meters)	CORE RECOVERY (cm)	TRIGGER CORE/ GRAB
1	61°34.3'S/47°29.9'W	2504	135	TC
2	61°32.9'S/47°14.4'W	988	324	TC
3	61°29.7'S/47°02.5'W	576	123	GRAB
4	61°31.6'S/47°01.7'W	553	144	-
5	61°27.6'S/46°45.6'W	411	104	GRAB
6	61°42.2'S/47°35.9'W	2196	11	GRAB
7	61°43.9'S/47°31.1'W	1573	NR	GRAB
8	61°43.7'S/47°28.1'W	1235	127	GRAB
9	61°42.6'S/47°21.9'W	1243	127	-
10	61°42.3'S/47°16.3'W	1364	168	GRAB
11	61°40.1'S/47°07.6'W	1360	45	-
12	61°40.6'S/46°57.8'W	962	277	-
13	61°39.6'S/46°54.0'W	732	132	-
14	61°42.0'S/46°46.0'W	512	10	-
15	61°55.6'S/47°14.3'W	2397	102	TC
16	61°55.3'S/47°04.7'W	2004	42	TC
17	61°54.7'S/47°05.6'W	1482	260	-
18	61°51.9'S/47°03.3'W	1261	145	TC
19	61°52.6'S/46°57.3'W	1151	BAGGED	TC
20	61°45.5'S/46°50.6'W	768	40	TC
21	60°49.5'S/45°36.2'W	256	BAGGED	TC
22	60°50.0'S/45°41.3'W	348	556	-
23	60°49.1'S/45°44.7'W	304	289	TC
24	60°50.6'S/45°53.9'W	133	BAGGED	GRAB
25	60°51.5'S/46°06.7'W	155	22	GRAB
26	61°00.3'S/46°18.1'W	220	41	GRAB
27	61°09.2'S/46°22.2'W	249	199	GRAB
28	61°18.9'S/46°28.3'W	295	79	-
29	61°29.1'S/46°31.5'W	357	62	GRAB
30	61°38.2'S/46°21.4'W	311	21	GRAB
31	61°46.4'S/46°11.6'W	416	120	-
32	61°55.7'S/45°58.9'W	448	BAGGED	GRAB
33	62°20.4'S/46°29.5'W	2843	113	TC
34	62°12.1'S/46°20.8'W	1794	271	-
35	62°10.6'S/46°12.2'W	1054	281	-
36	62°11.8'S/46°19.7'W	1684	272	TC

EXPLANATION

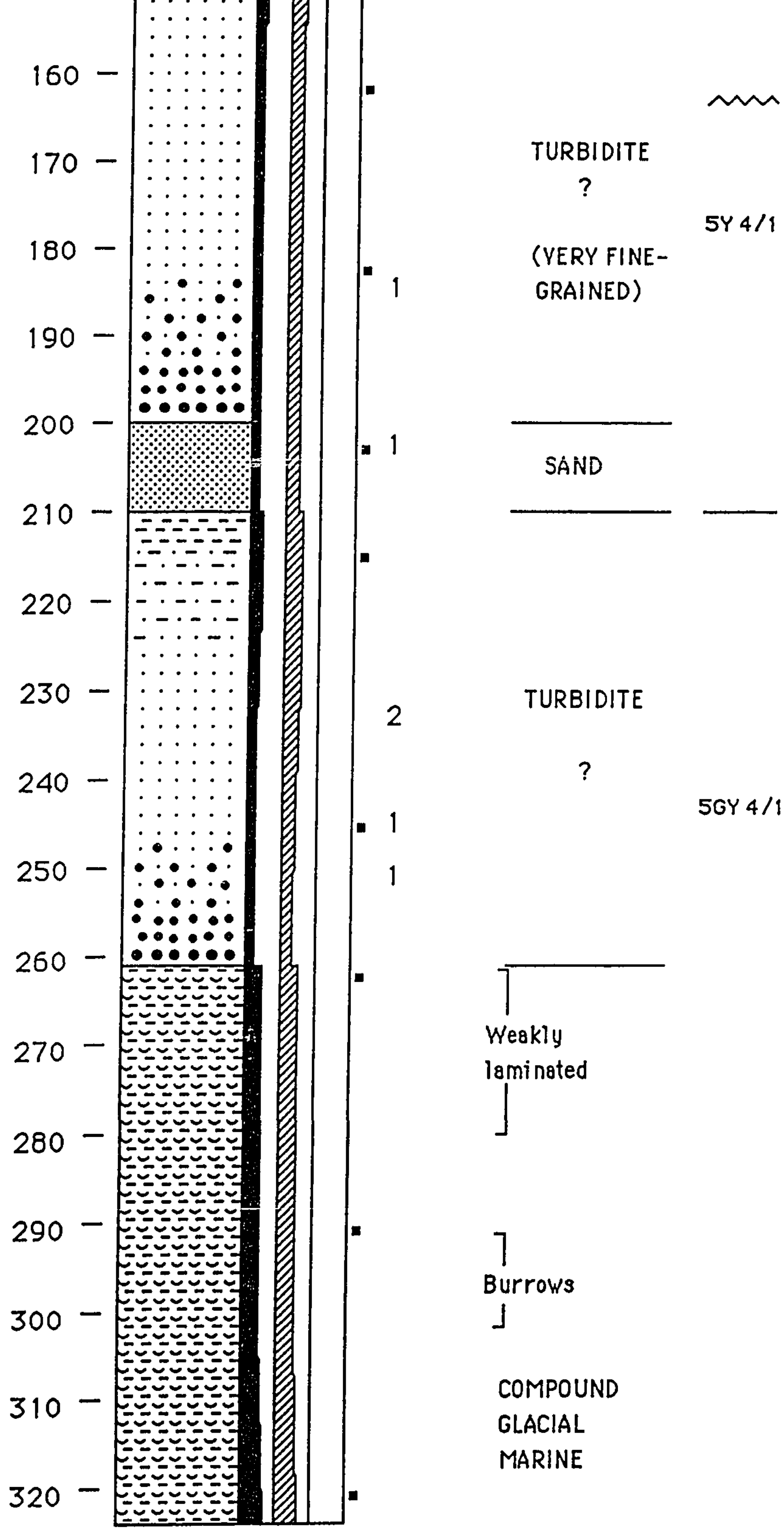


CORE 85-1 2504 m



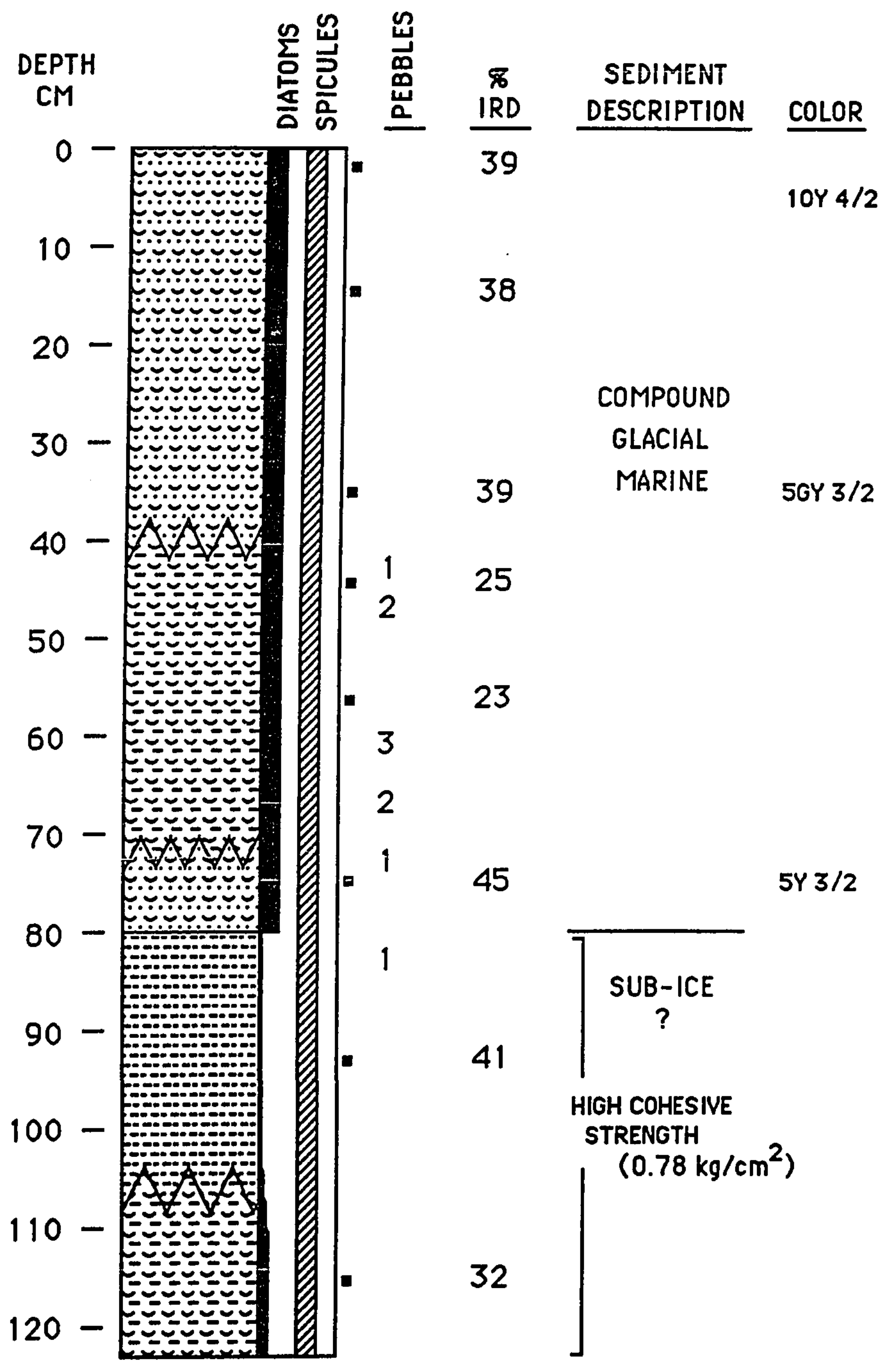

CORE 85-2
988 m
DEPTH CM
DIATOMS
SPICULES
FORAMS
PEBBLES
SEDIMENT DESCRIPITON
COLOR
0
10
20
30
40
50
60
70
80
90
100
110
120
130
140
150
3
1
1
2
TURBIDITE
5Y 3/2
5Y 5/2
TURBIDITE
5Y 4/1
TURBIDITE
10Y 4/2
TERRIGENOUS MUD
TURBIDITE

CORE 85-2


150
160
170
180
190
200
210
220
230
240
250
260
270
280
290
300
310
320
1
1
2
1
1
TURBIDITE
?
(VERY FINE-
GRAINED)
5Y 4/1
SAND
TURBIDITE
?
5GY 4/1
Weakly
laminated
Burrows
COMPOUND
GLACIAL
MARINE

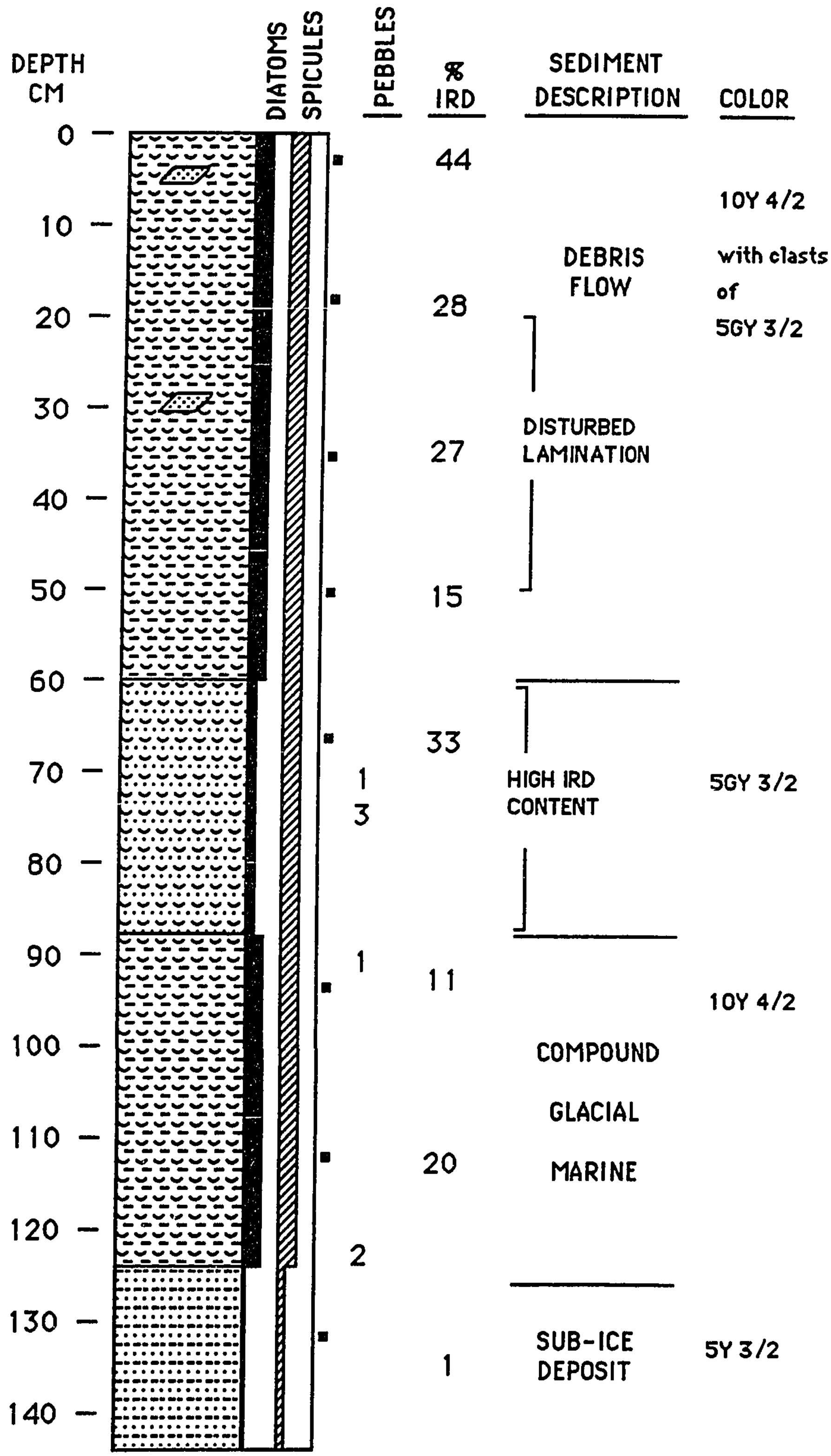
576 m

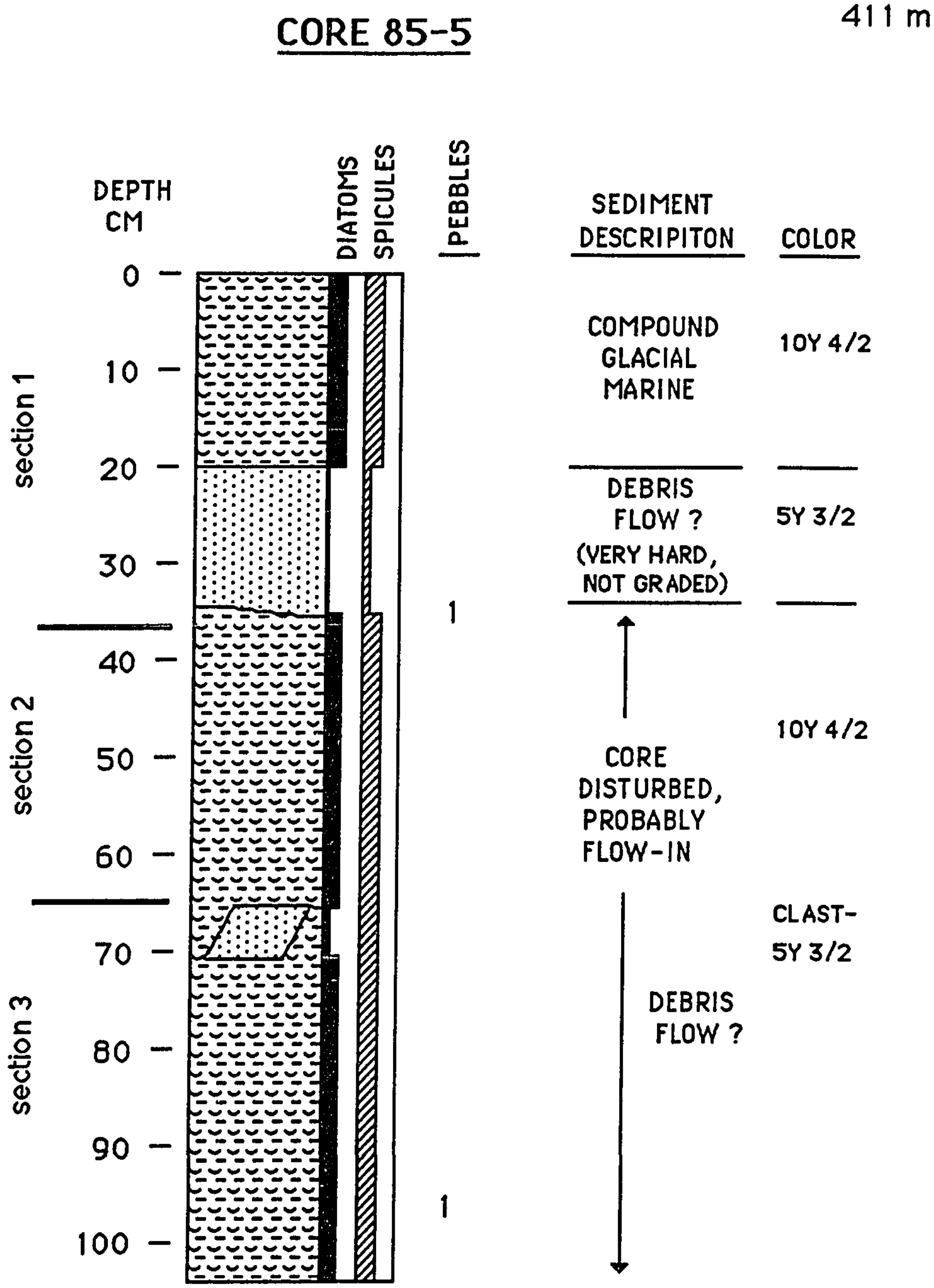
CORE 85-3



CORE 85-4

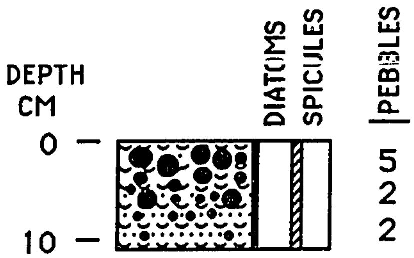
553 m



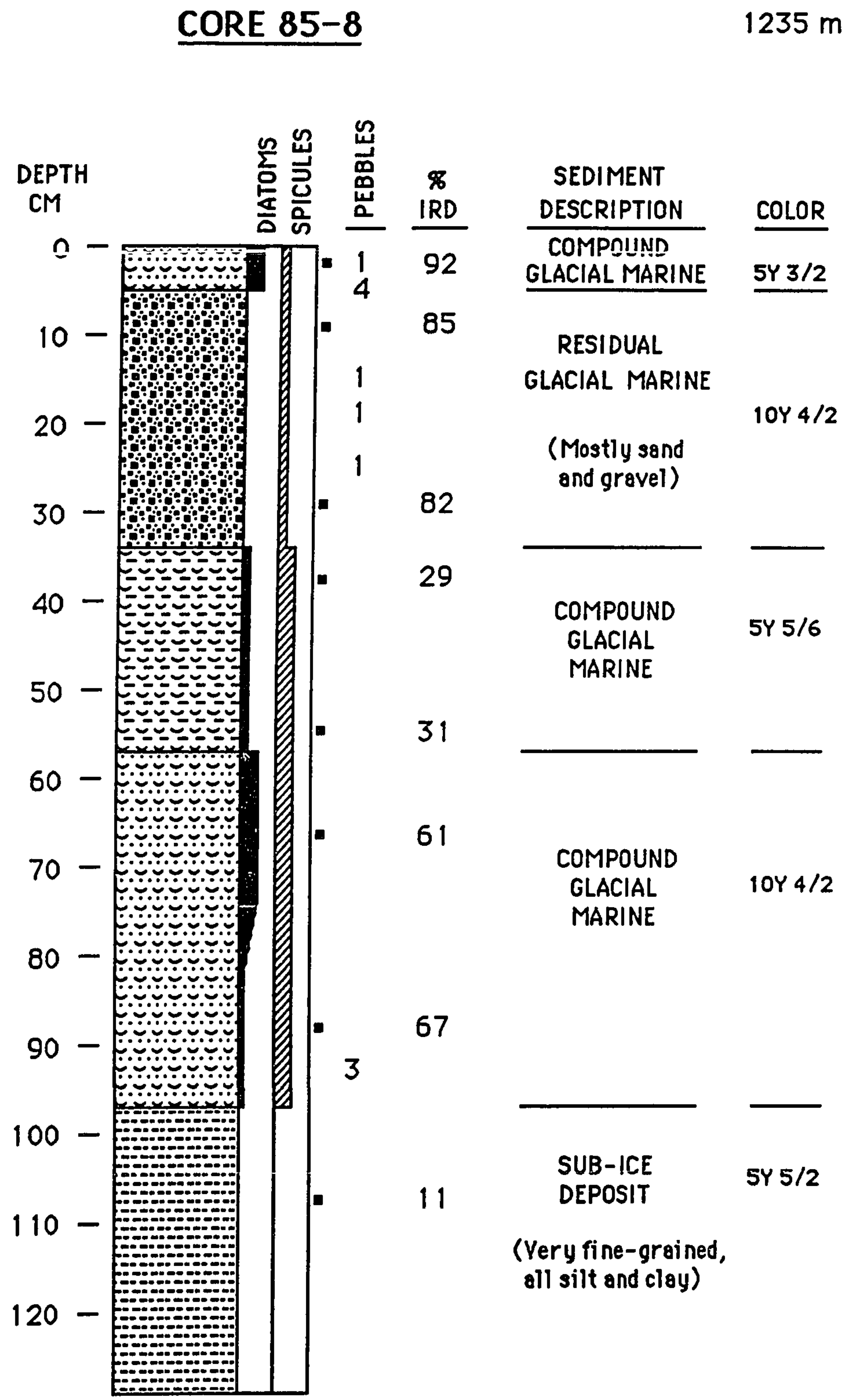

CORE 85-5
411 m
DEPTH
CM
DIATOMS
SPICULES
PEBBLES
SEDIMENT
DESCRIPITON
COLOR
0
10
20
30
40
50
60
70
80
90
100
section 1
section 2
section 3
1
1
COMPOUND
GLACIAL
MARINE
10Y 4/2
DEBRIS
FLOW ?
(VERY HARD,
NOT GRADED)
5Y 3/2
10Y 4/2
CORE
DISTURBED,
PROBABLY
FLOW-IN
CLAST-
5Y 3/2
DEBRIS
FLOW ?

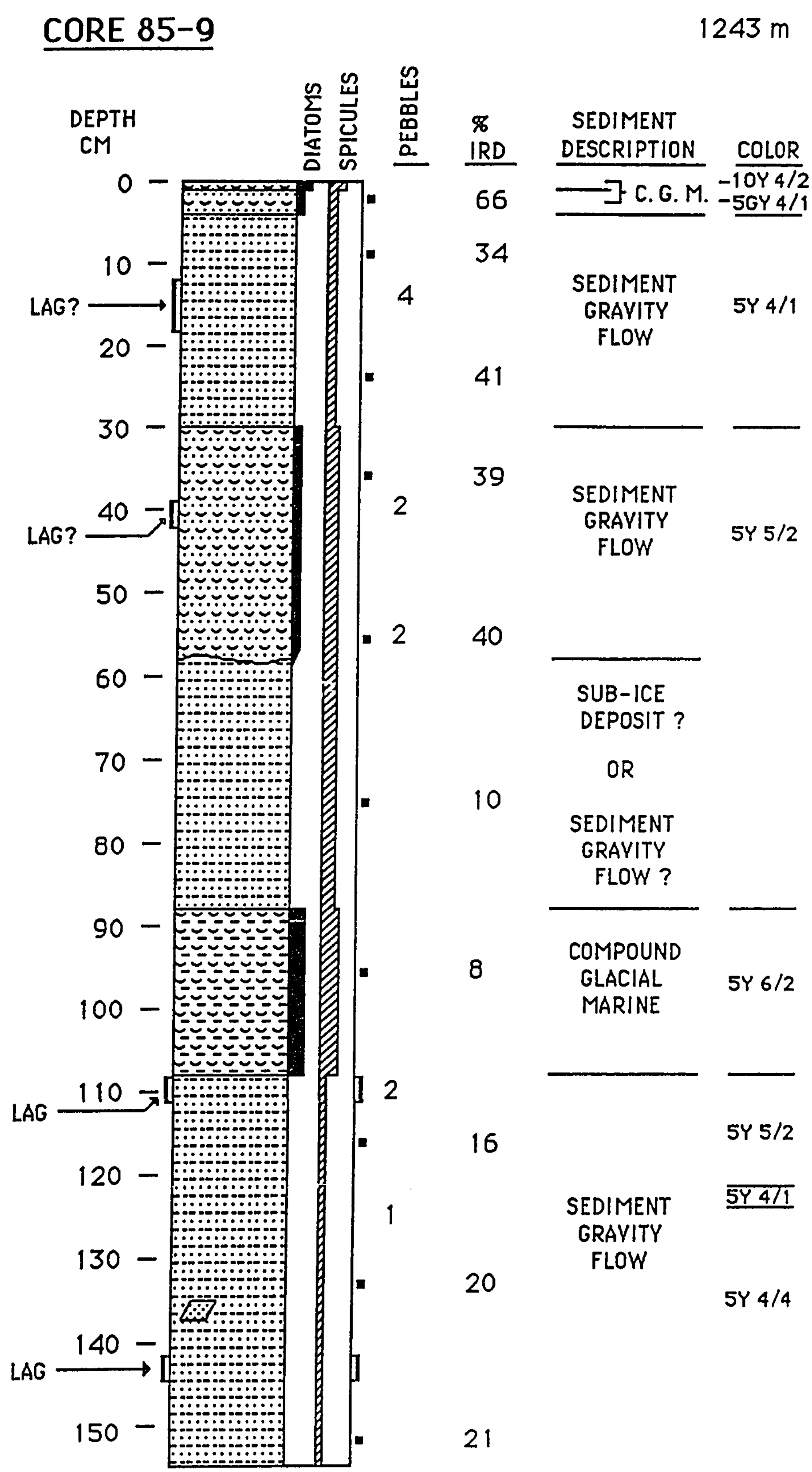
CORE 85-6

2196 m



SEDIMENT DESCRIPTION	COLOR
DEBRIS FLOW INVERSELY GRADED, UNSORTED	5Y 5/2

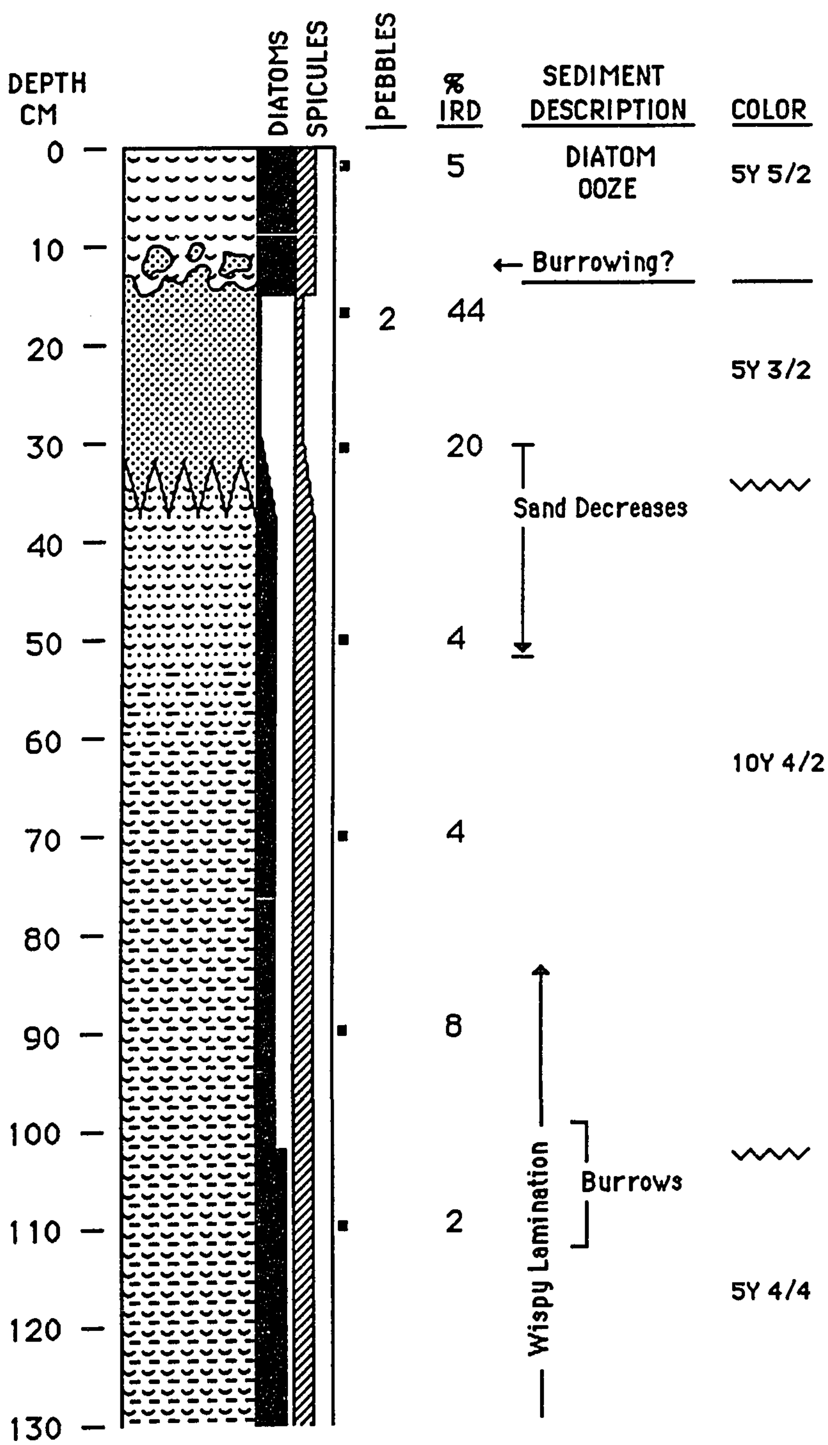

CORE 85-8
1235 m
DEPTH CM
DIATOMS
SPICULES
PEBBLES
% IRD
SEDIMENT DESCRIPTION
COLOR
0
10
20
30
40
50
60
70
80
90
100
110
120
1
4
1
1
1
3
92
85
82
29
31
61
67
11
COMPOUND GLACIAL MARINE
5Y 3/2
RESIDUAL GLACIAL MARINE
(Mostly sand and gravel)
10Y 4/2
COMPOUND GLACIAL MARINE
5Y 5/6
COMPOUND GLACIAL MARINE
10Y 4/2
SUB-ICE DEPOSIT
(Very fine-grained, all silt and clay)
5Y 5/2



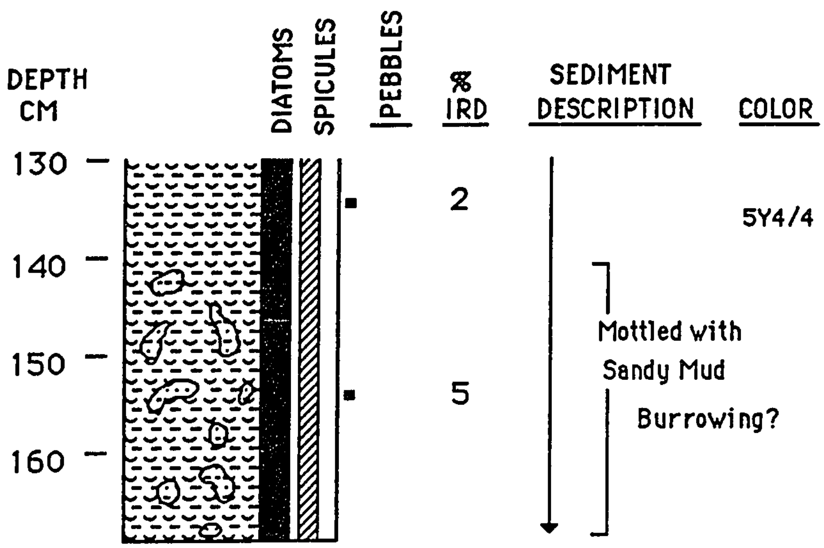
CORE 85-9
1243 m
DEPTH CM
DIATOMS
SPICULES
PEBBLES
% IRD
SEDIMENT DESCRIPTION
COLOR
0
10
20
30
40
50
60
70
80
90
100
110
120
130
140
150
LAG?
LAG?
LAG
LAG
4
2
2
2
1
66
34
41
39
40
10
8
16
20
21
C. G. M.
-10Y 4/2
-5GY 4/1
SEDIMENT GRAVITY FLOW
5Y 4/1
SEDIMENT GRAVITY FLOW
5Y 5/2
SUB-ICE DEPOSIT ?
OR
SEDIMENT GRAVITY FLOW ?
COMPOUND GLACIAL MARINE
5Y 6/2
5Y 5/2
5Y 4/1
SEDIMENT GRAVITY FLOW
5Y 4/4

CORE 85-10

1364 m

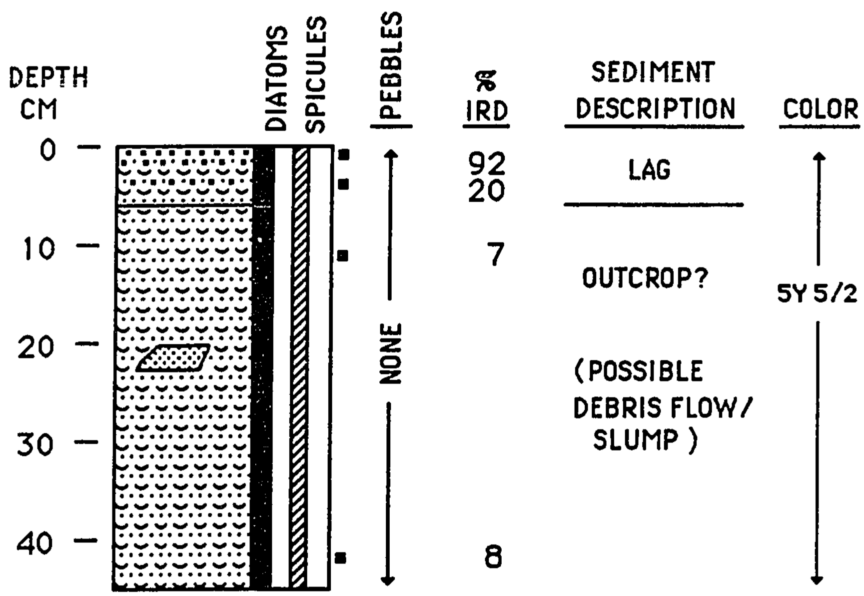


CORE 85-10


DEPTH
CM
DIATOMS
SPICULES
PEBBLES
%
IRD
SEDIMENT
DESCRIPTION
COLOR
130
140
150
160
2
5
5Y4/4
Mottled with
Sandy Mud
Burrowing?

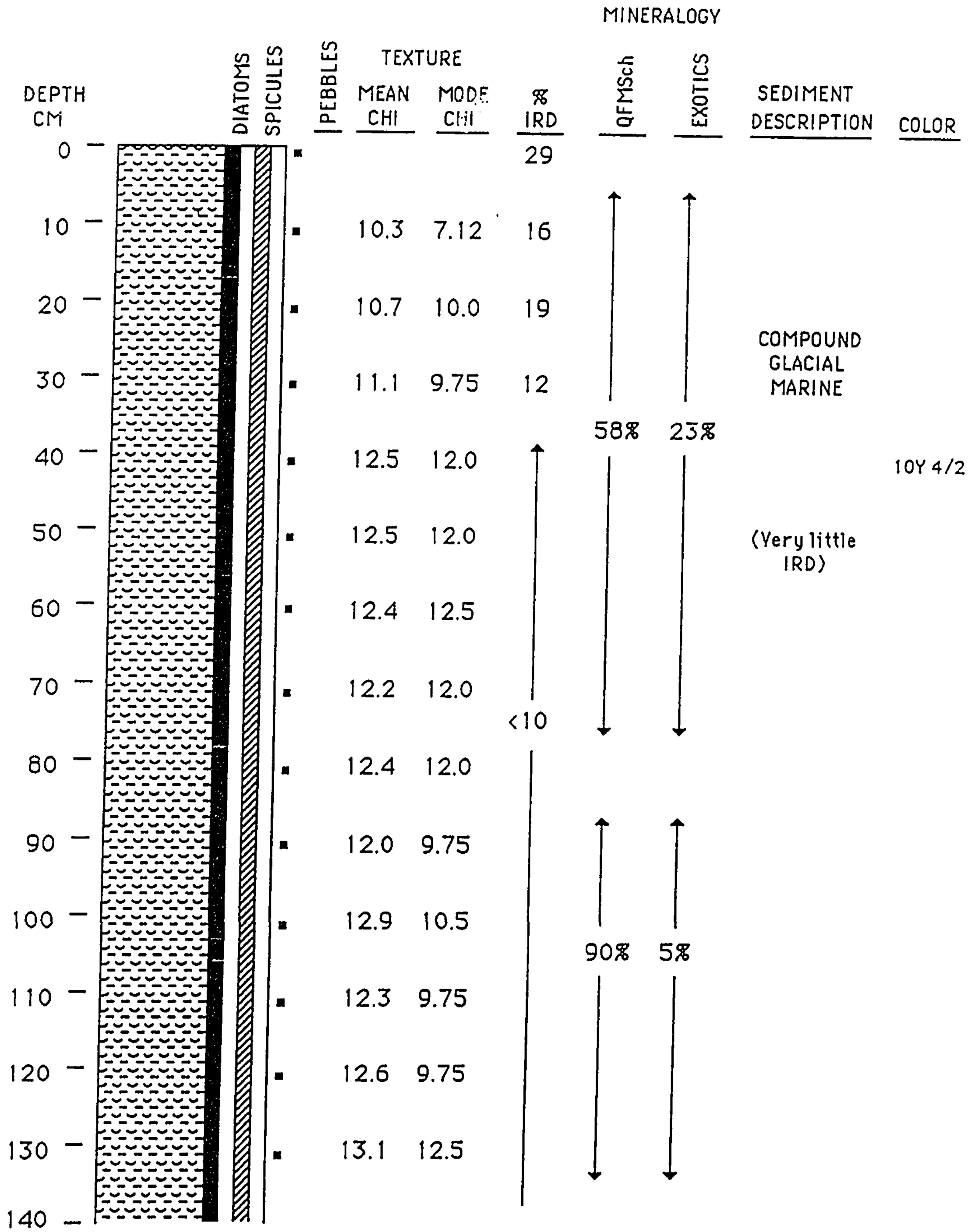
CORE 85-11

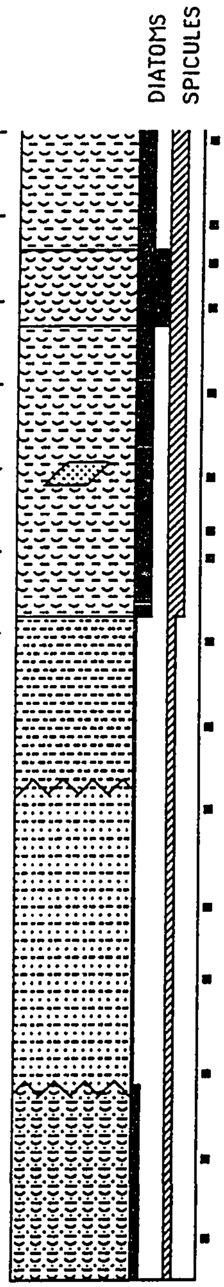
1360 m



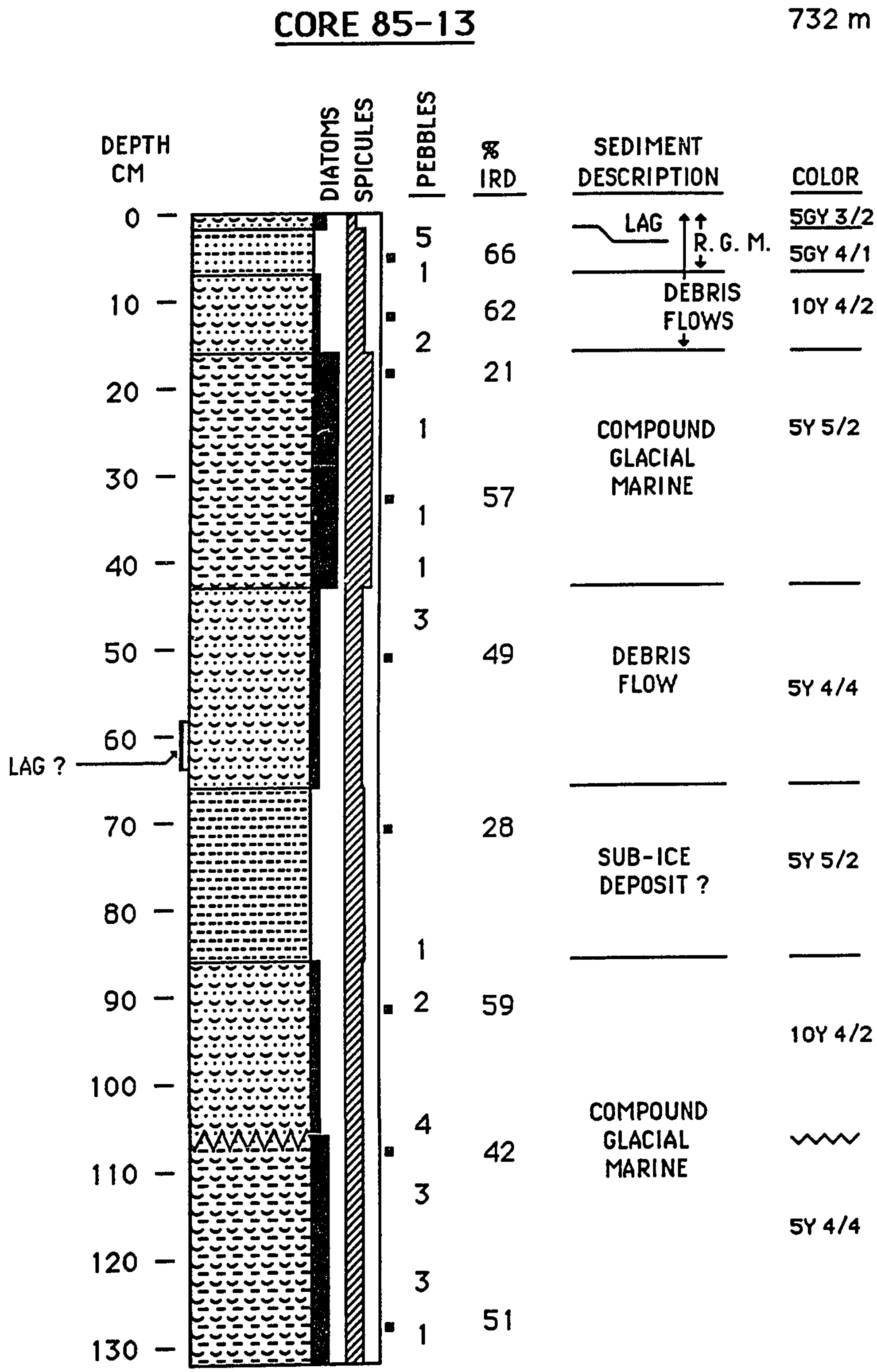
962 m

CORE 85-12



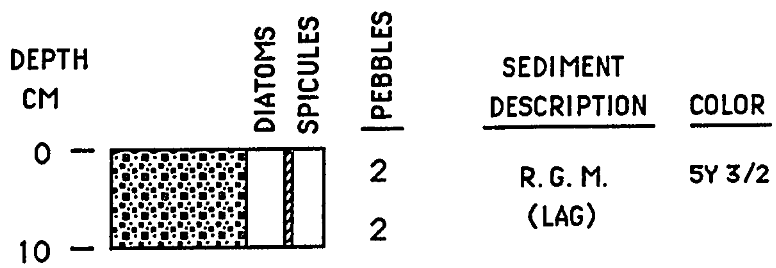


DEPTH CM	PEBBLES	TEXTURE MEAN CHI	TEXTURE MODE CHI	% IRD	MINERALOGY QFMSch	MINERALOGY EXOTICS	SEDIMENT DESCRIPTION	COLOR
140		12.3	11.5	<10	65%	14%		
150		12.6	11.5					
		12.0	9.75				DIATOM OOZE	5Y 5/2
160		12.4	12.0					
170		12.5	12.5				DEBRIS FLOW	5Y 3/2
180		10.7	11.0	19				
		10.6	9.75	20				
190		10.6	9.75	18				
	1							
200		9.3	10.0	40	70%	12%	SUB-ICE DEPOSIT	5GY 4/1
210		9.3	9.75	37	77%	12%		
220		7.8	6.37	58	68%	18%		
230	1	8.0	5.87	62	72%	11%		
240	1 1	7.6	6.0	69	72%	16%		
250	2 1	7.8	7.25	64	65%	24%		
260	3	7.7	6.87	65	65%	23%	COMPOUND GLACIAL MARINE	
270		7.8	7.37	62	67%	22%		


CORE 85-13
732 m
DEPTH CM
DIATOMS
SPICULES
PEBBLES
% IRD
SEDIMENT DESCRIPTION
COLOR
0
10
20
30
40
50
60
70
80
90
100
110
120
130
LAG ?
5
1
2
1
1
1
3
1
2
4
3
3
1
66
62
21
57
49
28
59
42
51
LAG
R. G. M.
DEBRIS FLOWS
COMPOUND GLACIAL MARINE
DEBRIS FLOW
SUB-ICE DEPOSIT ?
COMPOUND GLACIAL MARINE
5GY 3/2
5GY 4/1
10Y 4/2
5Y 5/2
5Y 4/4
5Y 5/2
10Y 4/2
5Y 4/4

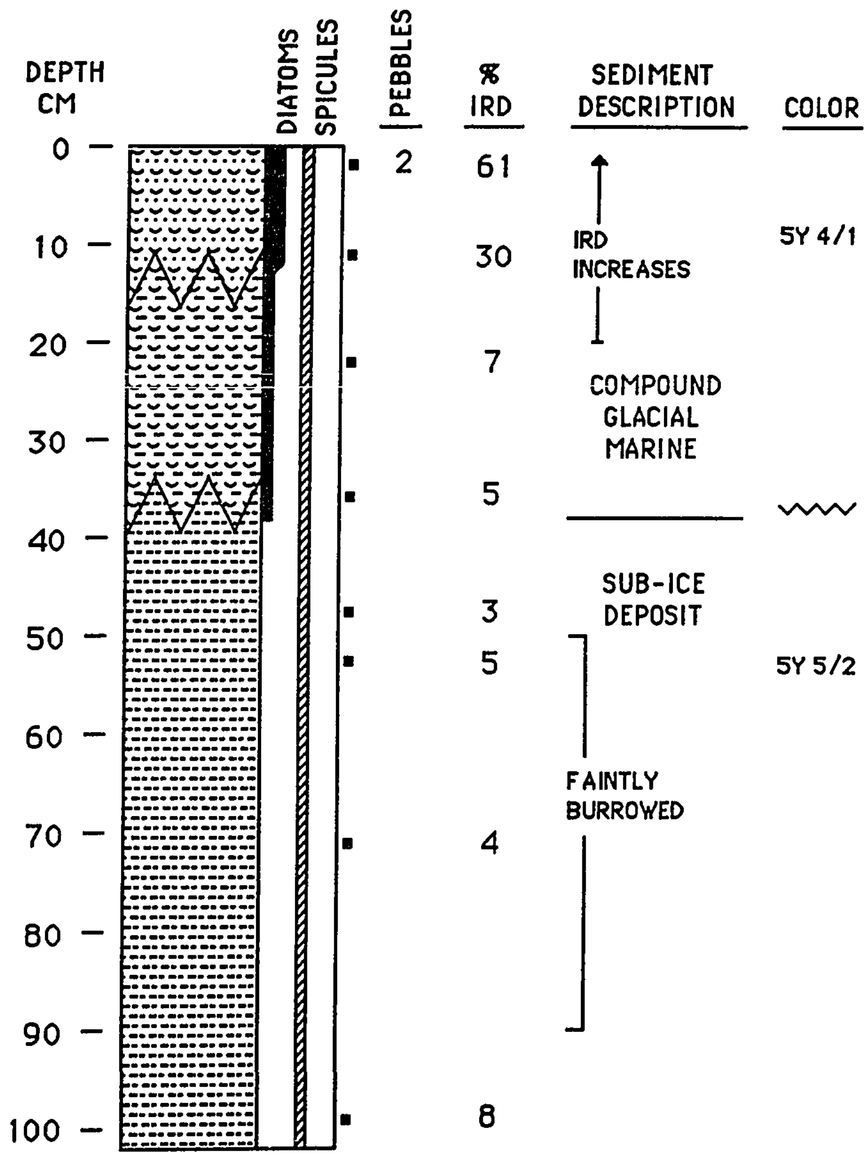
CORE 85-14

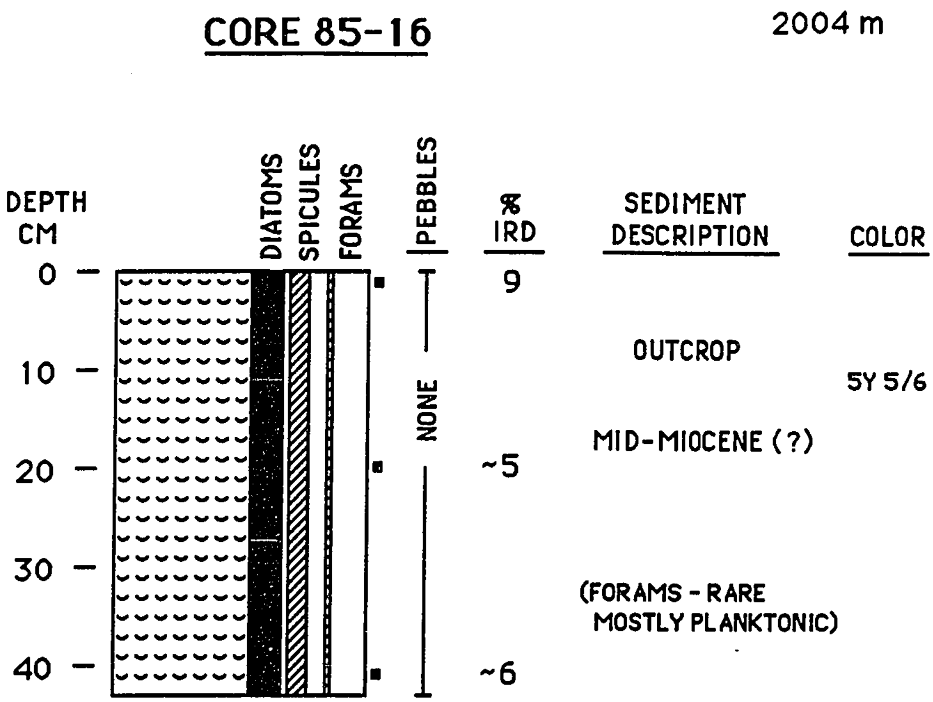
512 m

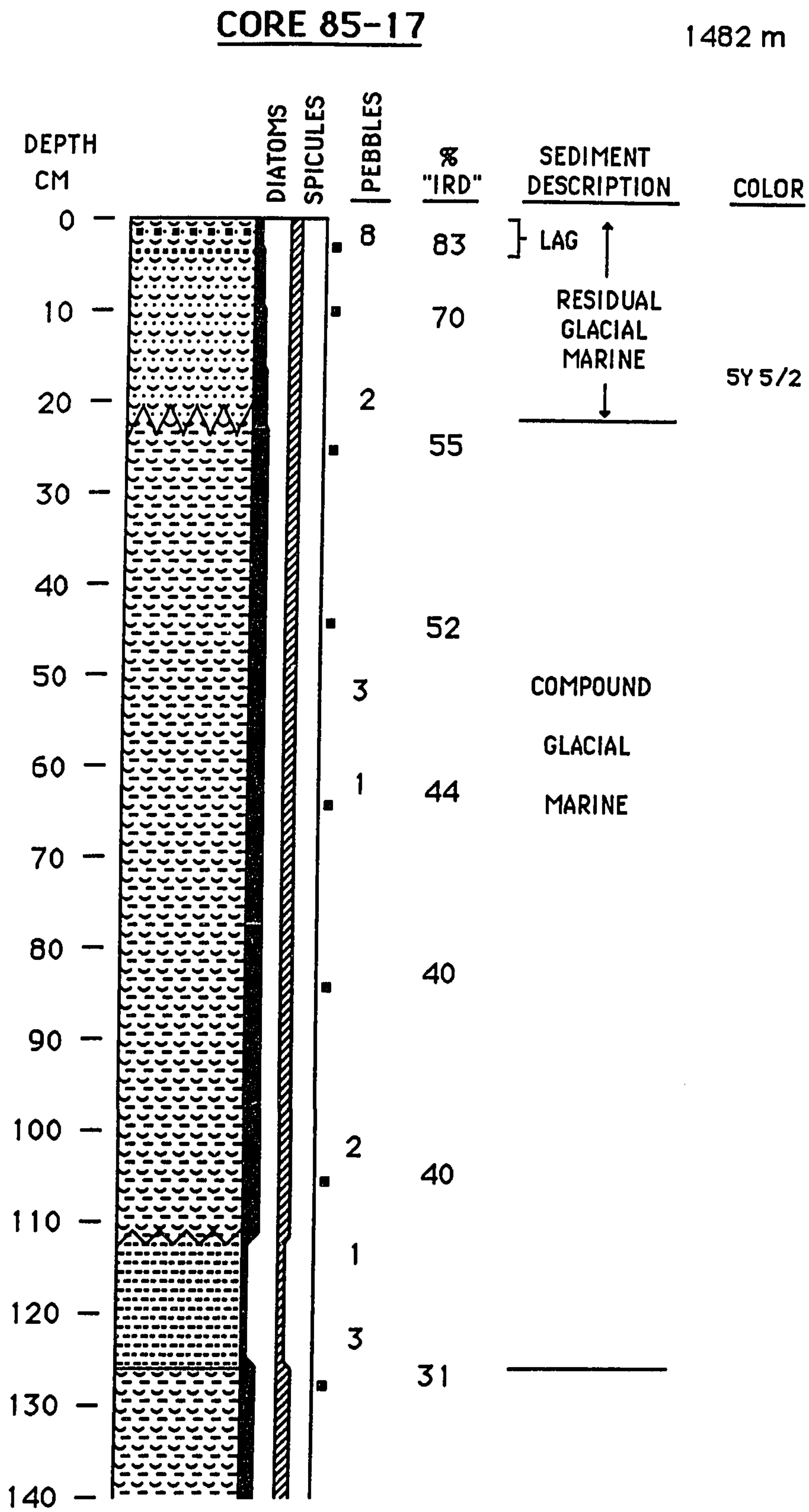


CORE 85-15

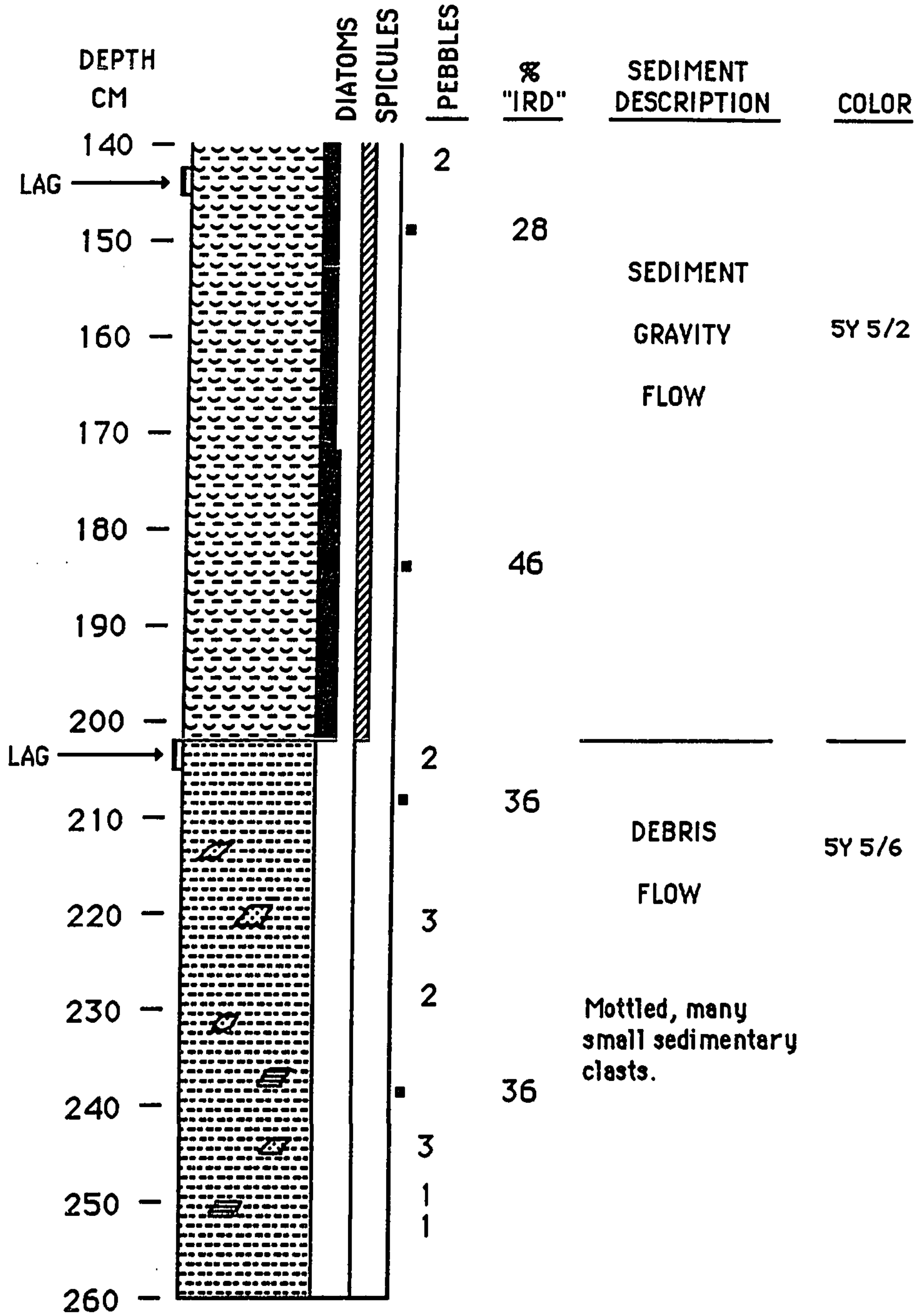
2397 m

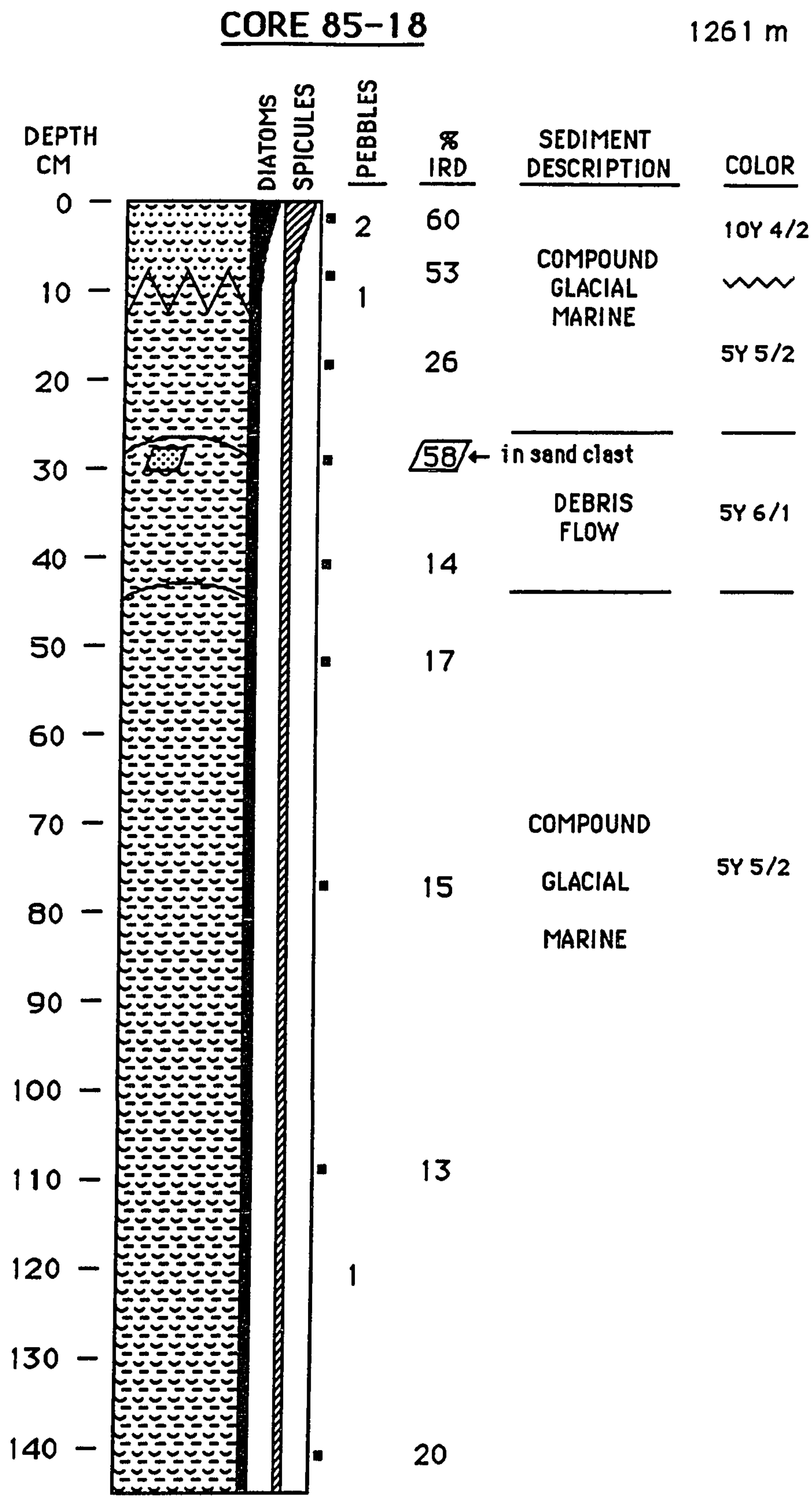



CORE 85-16
2004 m
DEPTH CM
DIATOMS
SPICULES
FORAMS
PEBBLES
% IRD
SEDIMENT DESCRIPTION
COLOR
0
10
20
30
40
NONE
9
~5
~6
OUTCROP
MID-MIOCENE (?)
(FORAMS - RARE MOSTLY PLANKTONIC)
5Y 5/6


CORE 85-17
1482 m
DEPTH CM
DIATOMS
SPICULES
PEBBLES
% "IRD"
SEDIMENT DESCRIPTION
COLOR
0
10
20
30
40
50
60
70
80
90
100
110
120
130
140
8
2
3
1
2
1
3
83
70
55
52
44
40
40
31
LAG
RESIDUAL GLACIAL MARINE
COMPOUND GLACIAL MARINE
5Y 5/2

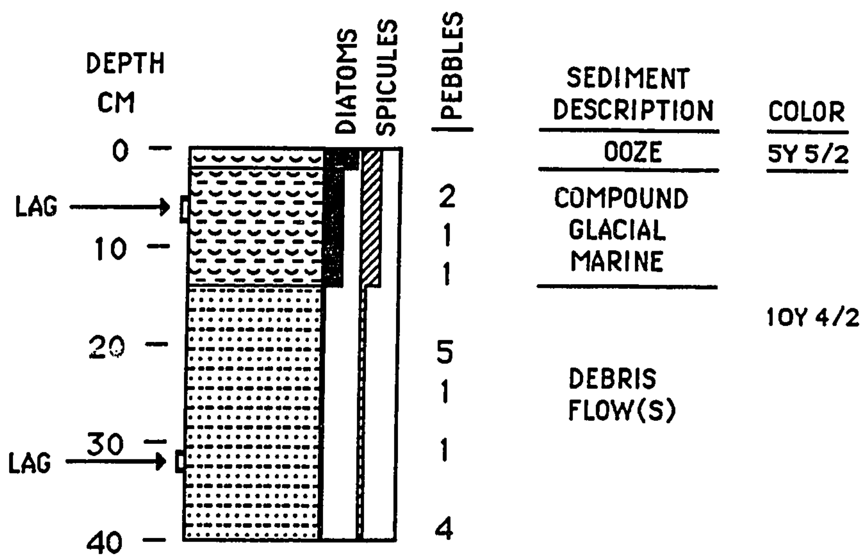
CORE 85-17-2


DEPTH
CM
DIATOMS
SPICULES
PEBBLES
%
"IRD"
SEDIMENT
DESCRIPTION
COLOR
140
150
160
170
180
190
200
210
220
230
240
250
260
LAG
LAG
2
28
46
2
36
3
2
36
3
1
1
SEDIMENT
GRAVITY
FLOW
5Y 5/2
DEBRIS
FLOW
5Y 5/6
Mottled, many
small sedimentary
clasts.


CORE 85-18
1261 m
DEPTH CM
DIATOMS
SPICULES
PEBBLES
% IRD
SEDIMENT DESCRIPTION
COLOR
0
10
20
30
40
50
60
70
80
90
100
110
120
130
140
2
1
1
60
53
26
58
14
17
15
13
20
COMPOUND GLACIAL MARINE
10Y 4/2
5Y 5/2
in sand clast
DEBRIS FLOW
5Y 6/1
COMPOUND GLACIAL MARINE
5Y 5/2

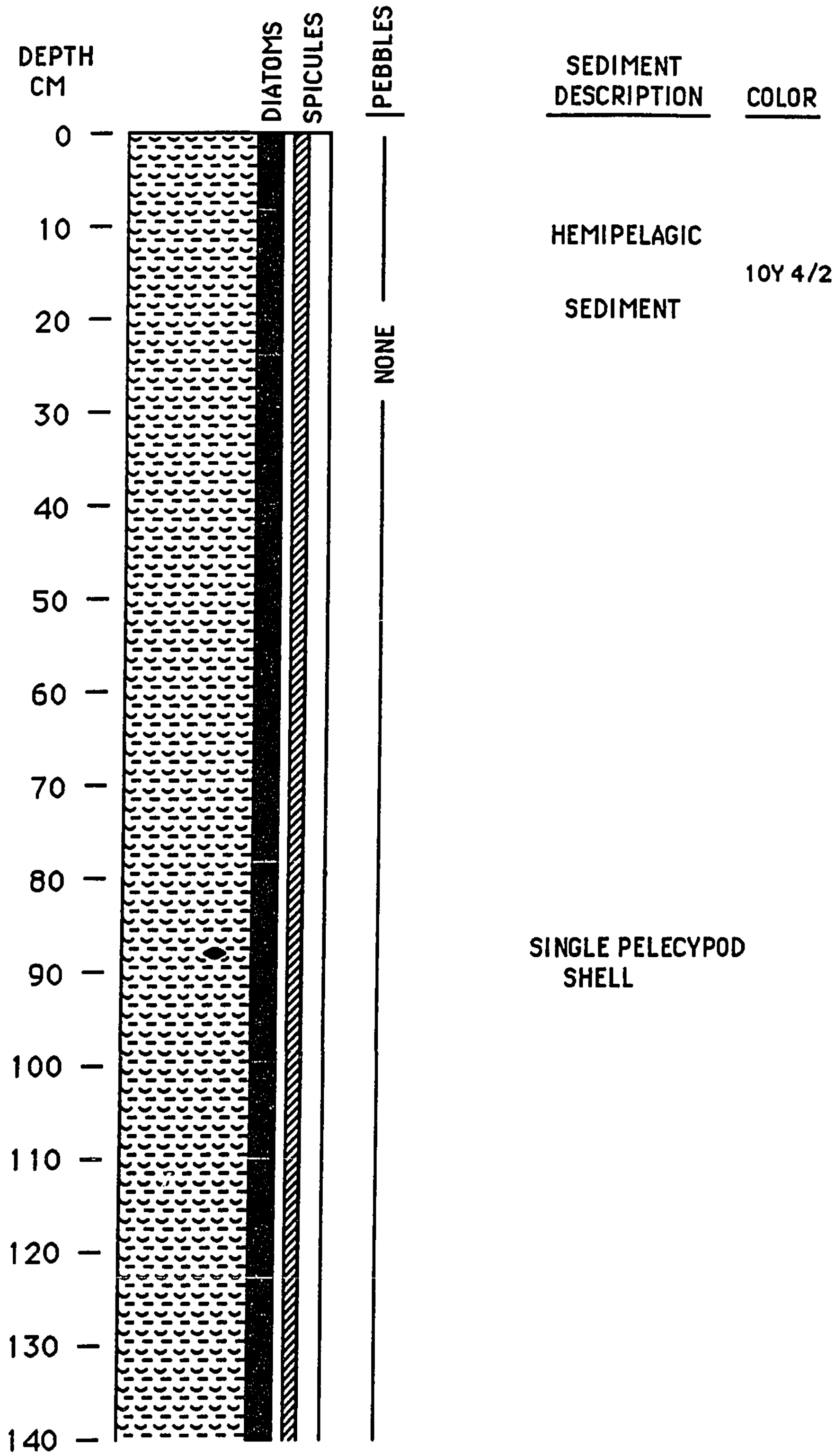
CORE 85-20

768 m

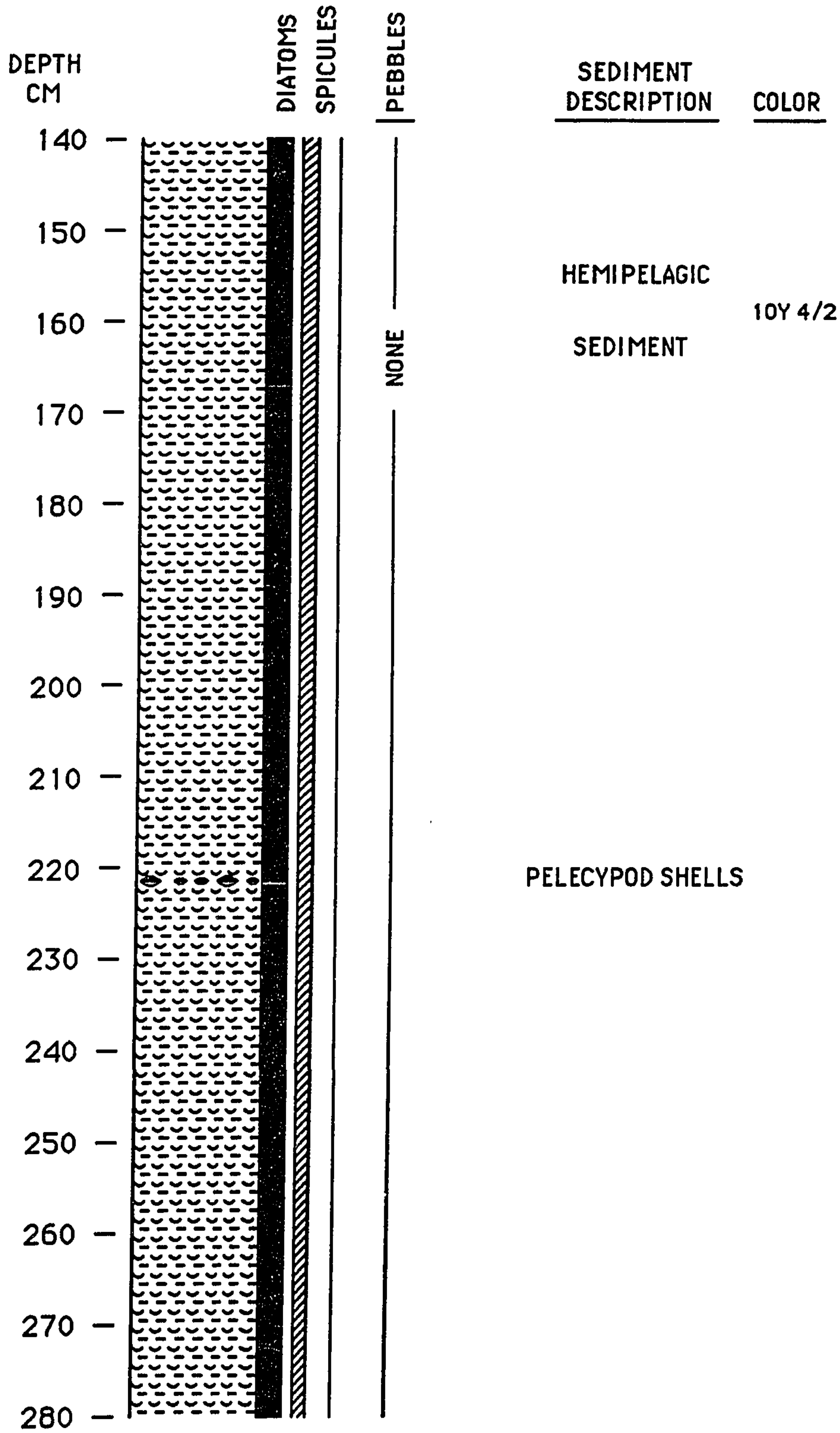


CORE 85-22

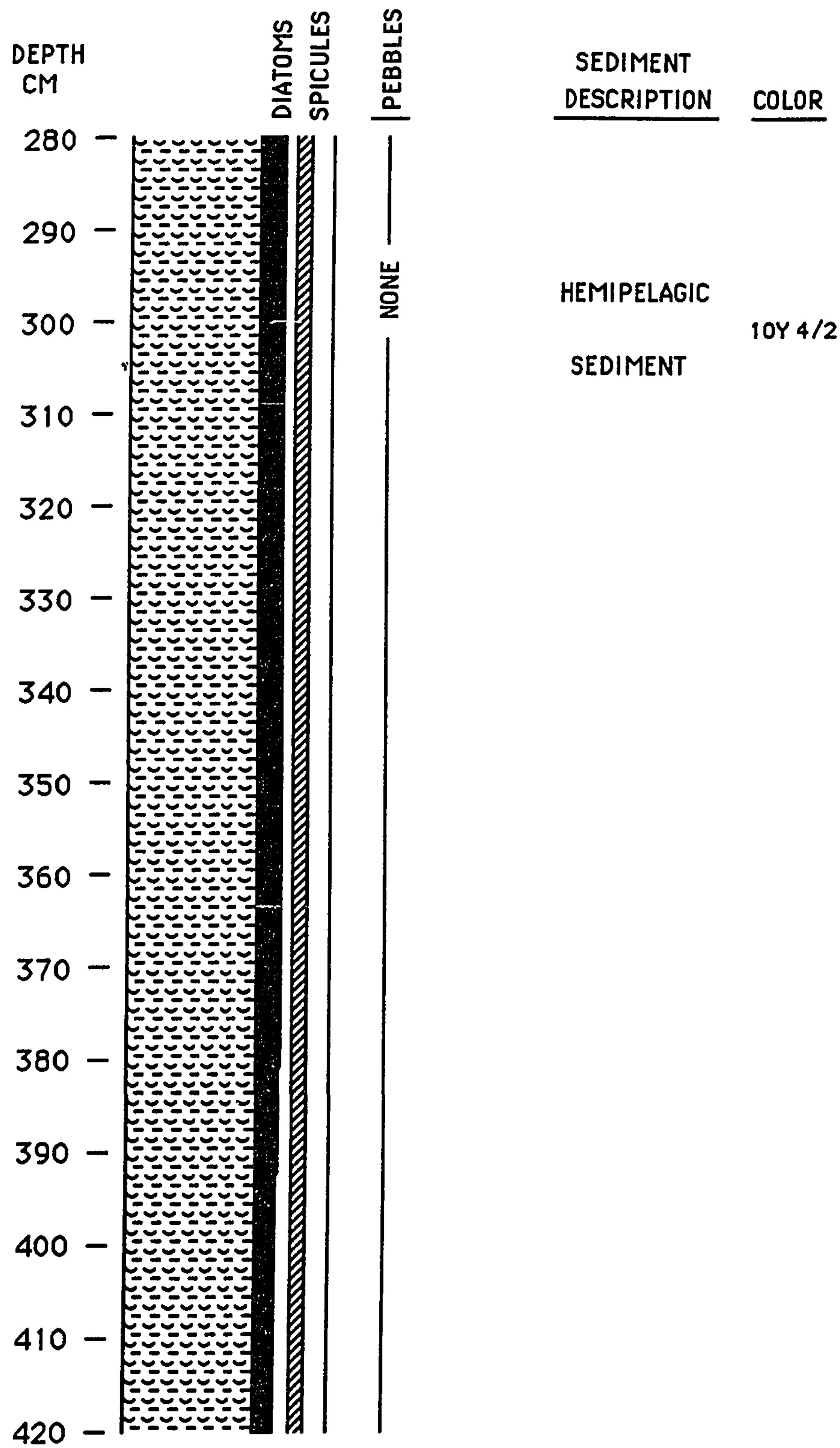
348 m



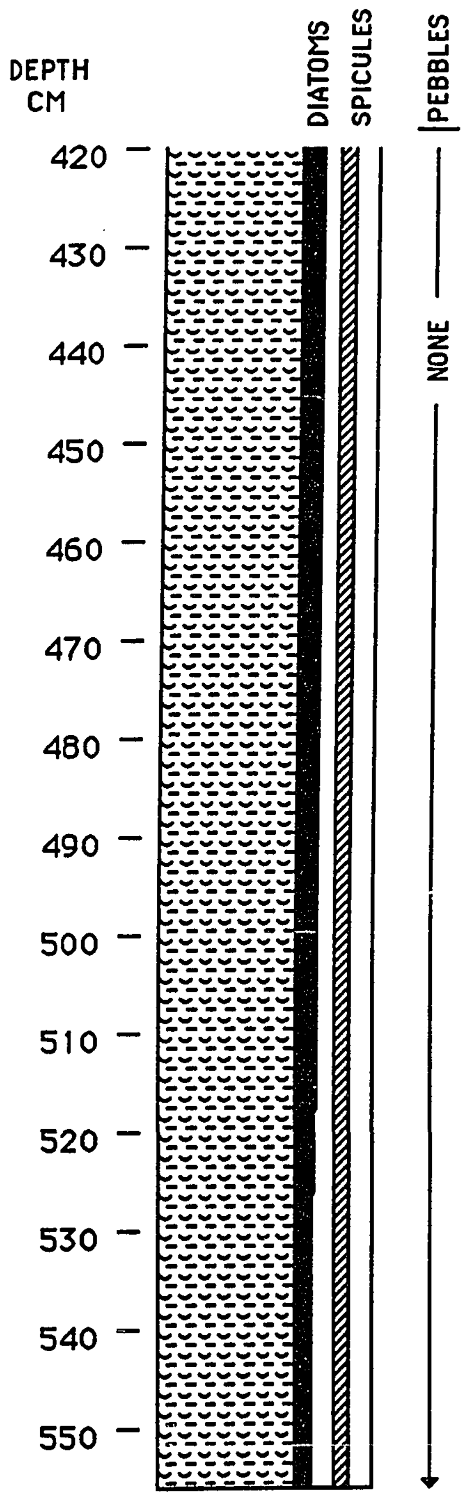
CORE 85-22-2


DEPTH CM
DIATOMS
SPICULES
PEBBLES
SEDIMENT DESCRIPTION
COLOR
140
150
160
170
180
190
200
210
220
230
240
250
260
270
280
NONE
HEMIPELAGIC SEDIMENT
10Y 4/2
PELECYPOD SHELLS

CORE 85-22-3


DEPTH
CM
280
290
300
310
320
330
340
350
360
370
380
390
400
410
420
DIATOMS
SPICULES
PEBBLES
NONE
SEDIMENT
DESCRIPTION
COLOR
HEMIPELAGIC
SEDIMENT
10Y 4/2

CORE 85-22-4



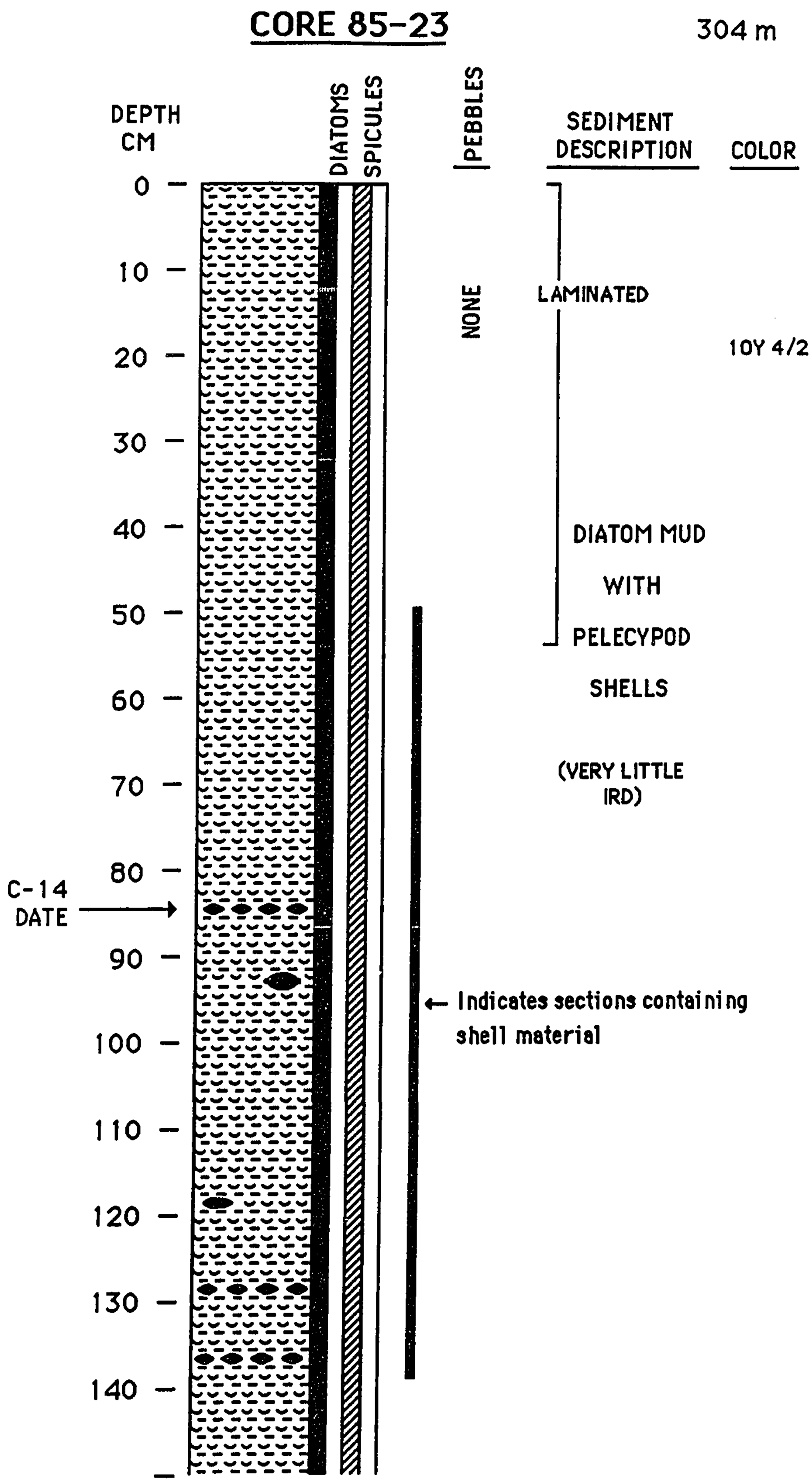
SEDIMENT DESCRIPTION

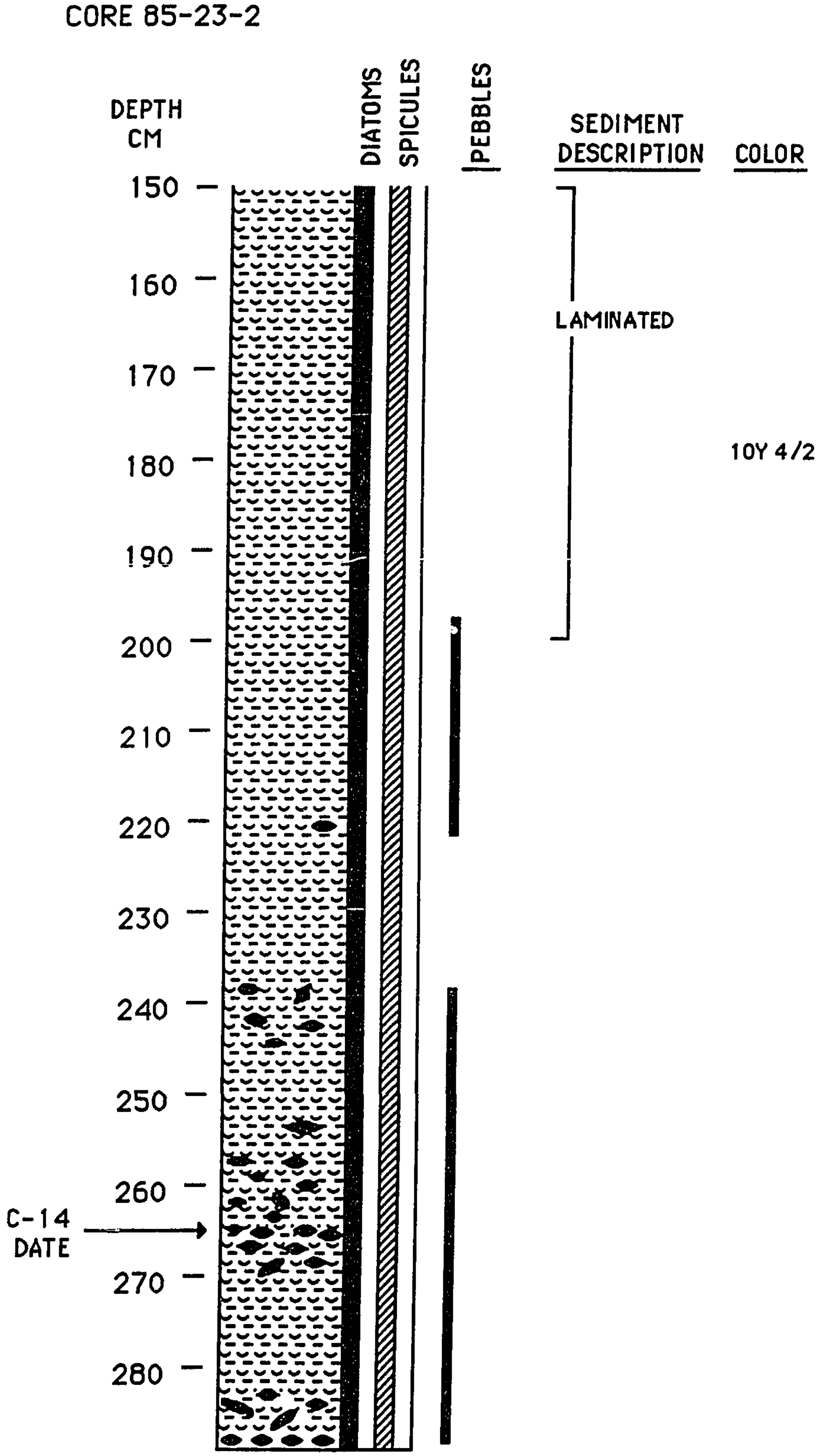
HEMIPELAGIC SEDIMENT

(Slight decrease in diatom content at base of core)

COLOR

10Y 4/2


CORE 85-23
304 m
DEPTH CM
DIATOMS
SPICULES
PEBBLES
SEDIMENT DESCRIPTION
COLOR
0
10
20
30
40
50
60
70
80
90
100
110
120
130
140
C-14 DATE
NONE
LAMINATED
10Y 4/2
DIATOM MUD
WITH
PELECYPOD
SHELLS
(VERY LITTLE IRD)
← Indicates sections containing shell material


CORE 85-23-2
DEPTH CM
DIATOMS
SPICULES
PEBBLES
SEDIMENT DESCRIPTION
COLOR
150
160
170
180
190
200
210
220
230
240
250
260
270
280
LAMINATED
10Y 4/2
C-14 DATE

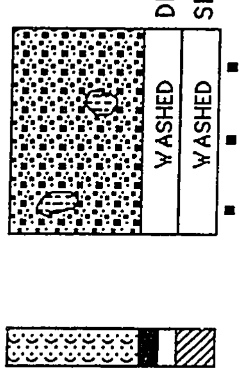
CORE 85-24

133 m

	DIATOMS / SPICULES	PEBBLES	% IRD	MINERALOGY QFMSch	MINERALOGY DOLERITE	SEDIMENT DESCRIPTION	COLOR
BAGGED CORE		0		21%	75%	TRANSITIONAL GLACIAL MARINE	10Y 4/2
BOTTOM GRAB		1	73	21%	72%		

CORE 85-25

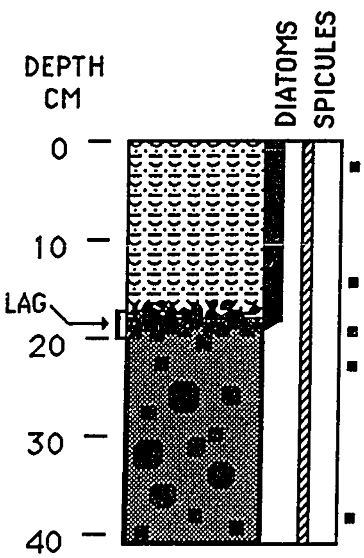
155 m



DEPTH CM	DIATOMS	SPICULES	TEXTURE MEAN CHI	TEXTURE MODE CHI	MINERALOGY QFMSch	MINERALOGY DOLERITE	SEDIMENT DESCRIPTION	COLOR
0–10	WASHED	WASHED			94%	2%	TRANSITIONAL GLACIAL MARINE ?	MOTTLED 5Y 3/2 & 10Y 4/2
10					94%	2%		
20					95%	2%	(WASHED)	
BOTTOM GRAB			8.52	6.87	91%	2%	COMPOUND GLACIAL MARINE	
			[IRD- 51%]					

CORE 85-26

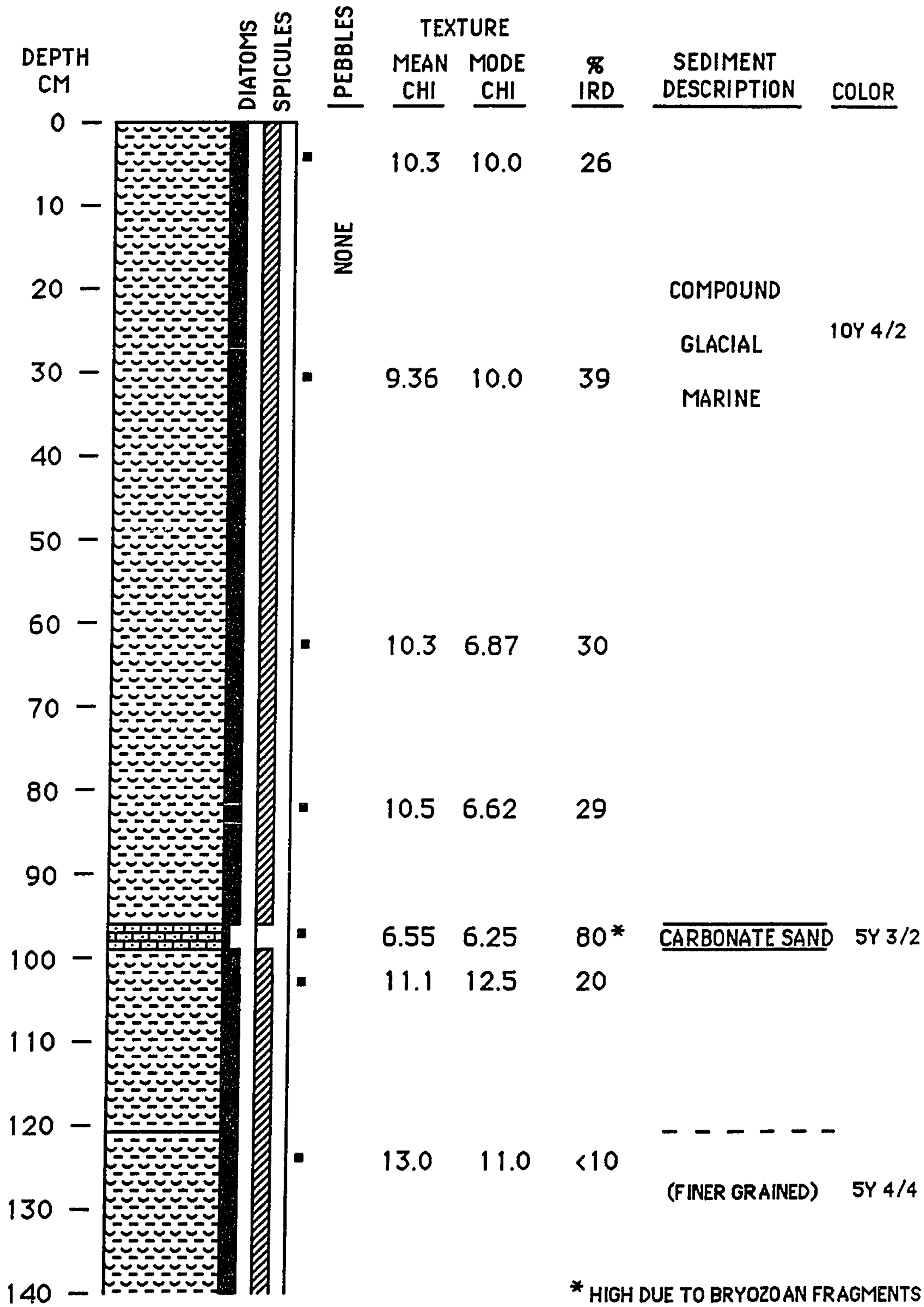
220 m



PEBBLES	TEXTURE MEAN CHI	TEXTURE MODE CHI	% IRD	MINERALOGY QFMSch	MINERALOGY DOLERITE	SEDIMENT DESCRIPTION
1	6.02	6.75	56	86%	9%	COMPOUND GLACIAL MARINE
1						
	6.41	7.5	31			
2	6.64	8.12	55	76%	9%	
	6.92	7.87	35	80%	12%	DIAMICTON
1						BASAL TILL ?
4						
	6.73	6.87	46	86%	8%	

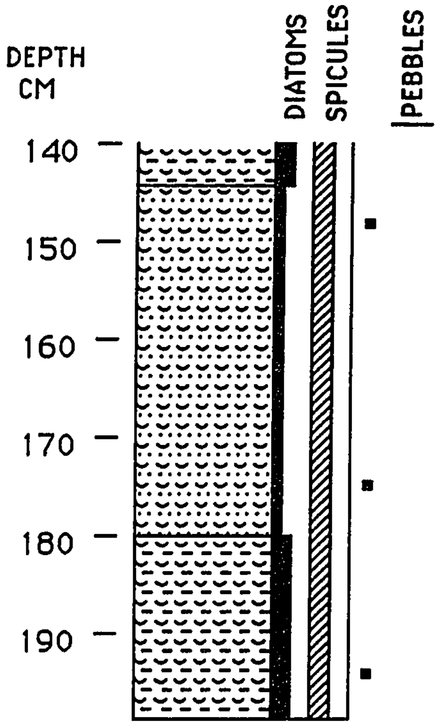
CORE 85-27

249 m

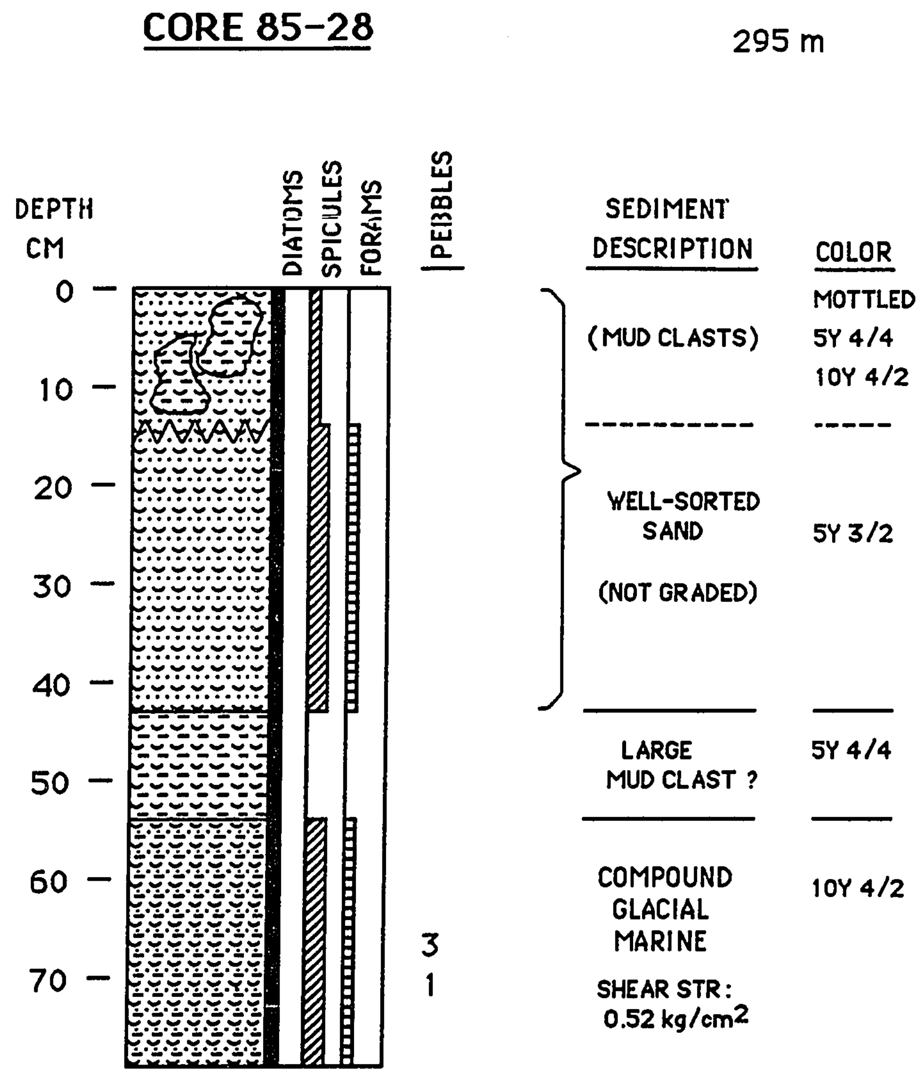


* HIGH DUE TO BRYOZOAN FRAGMENTS

CORE 85-27-2

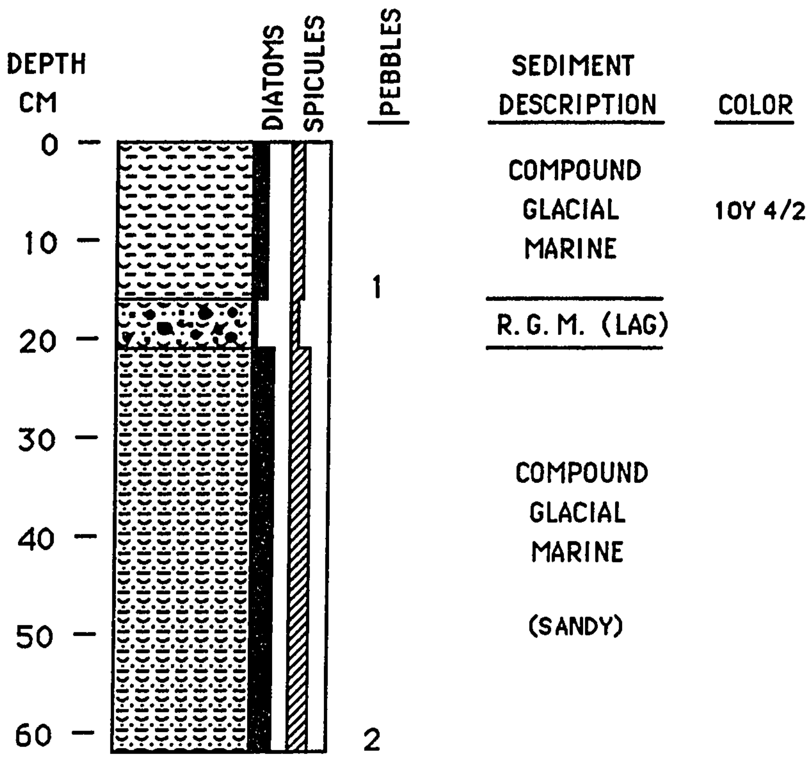


TEXTURE MEAN CHI	TEXTURE MODE CHI	% IRD	SEDIMENT DESCRIPTION	COLOR
10.1	13.5	35	SUB-ICE DEPOSIT ?	10Y 4/2
8.5	6.75	57		
11.3	11.0	16	COMPOUND GLACIAL MARINE	5Y 4/4


CORE 85-28
295 m
DEPTH
CM
0
10
20
30
40
50
60
70
DIATOMS
SPICULES
FORAMS
PEBBLES
3
1
SEDIMENT
DESCRIPTION
COLOR
(MUD CLASTS)
MOTTLED
5Y 4/4
10Y 4/2
WELL-SORTED
SAND
(NOT GRADED)
5Y 3/2
LARGE
MUD CLAST ?
5Y 4/4
COMPOUND
GLACIAL
MARINE
SHEAR STR:
0.52 kg/cm2
10Y 4/2

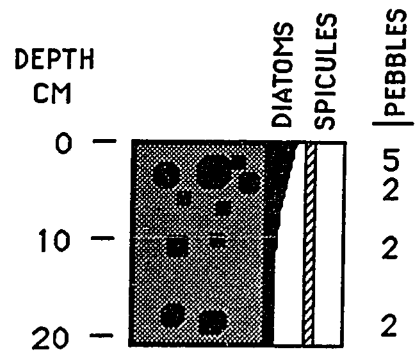
CORE 85-29

357 m

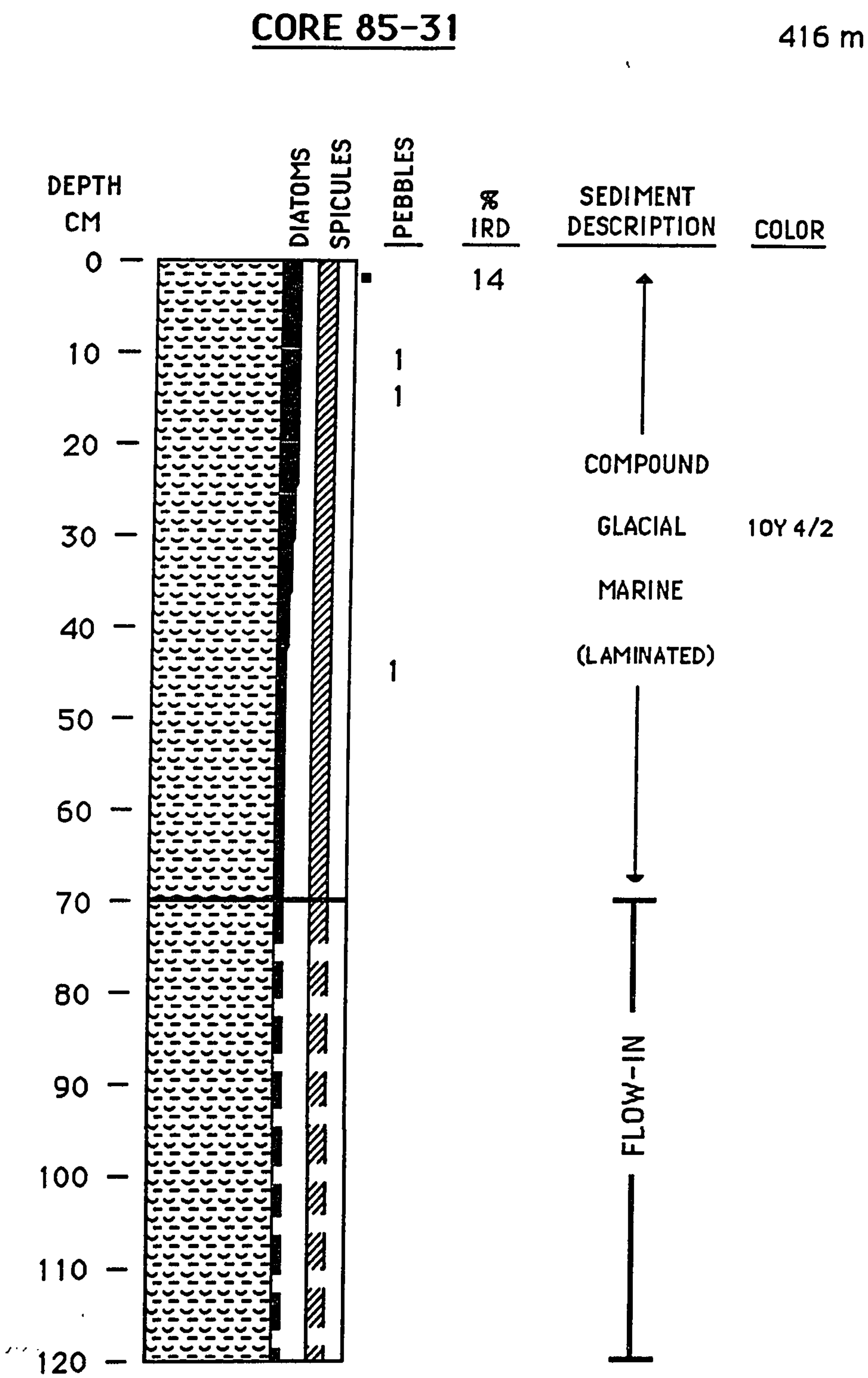


311 m

CORE 85-30



SEDIMENT DESCRIPTION	COLOR
DIAMICTON	10Y 4/2


CORE 85-31
416 m
DEPTH CM
DIATOMS
SPICULES
PEBBLES
% IRD
SEDIMENT DESCRIPTION
COLOR
0
10
20
30
40
50
60
70
80
90
100
110
120
14
1
1
1
COMPOUND
GLACIAL
MARINE
(LAMINATED)
10Y 4/2
FLOW-IN

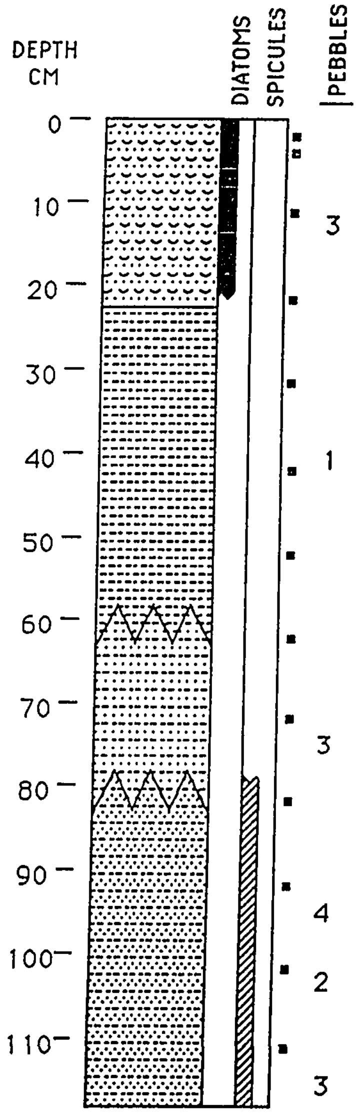
CORE 85-32

411 m

	DIATOMS / SPICULES	PEBBLES	% IRD	TEXTURE MEAN CHI	TEXTURE MODE CHI	SEDIMENT DESCRIPTION	COLOR
BOTTOM GRAB		0	~0	12.5	10.5	DIATOM OOZE	5Y 4/4

CORE 85-33

2843 m

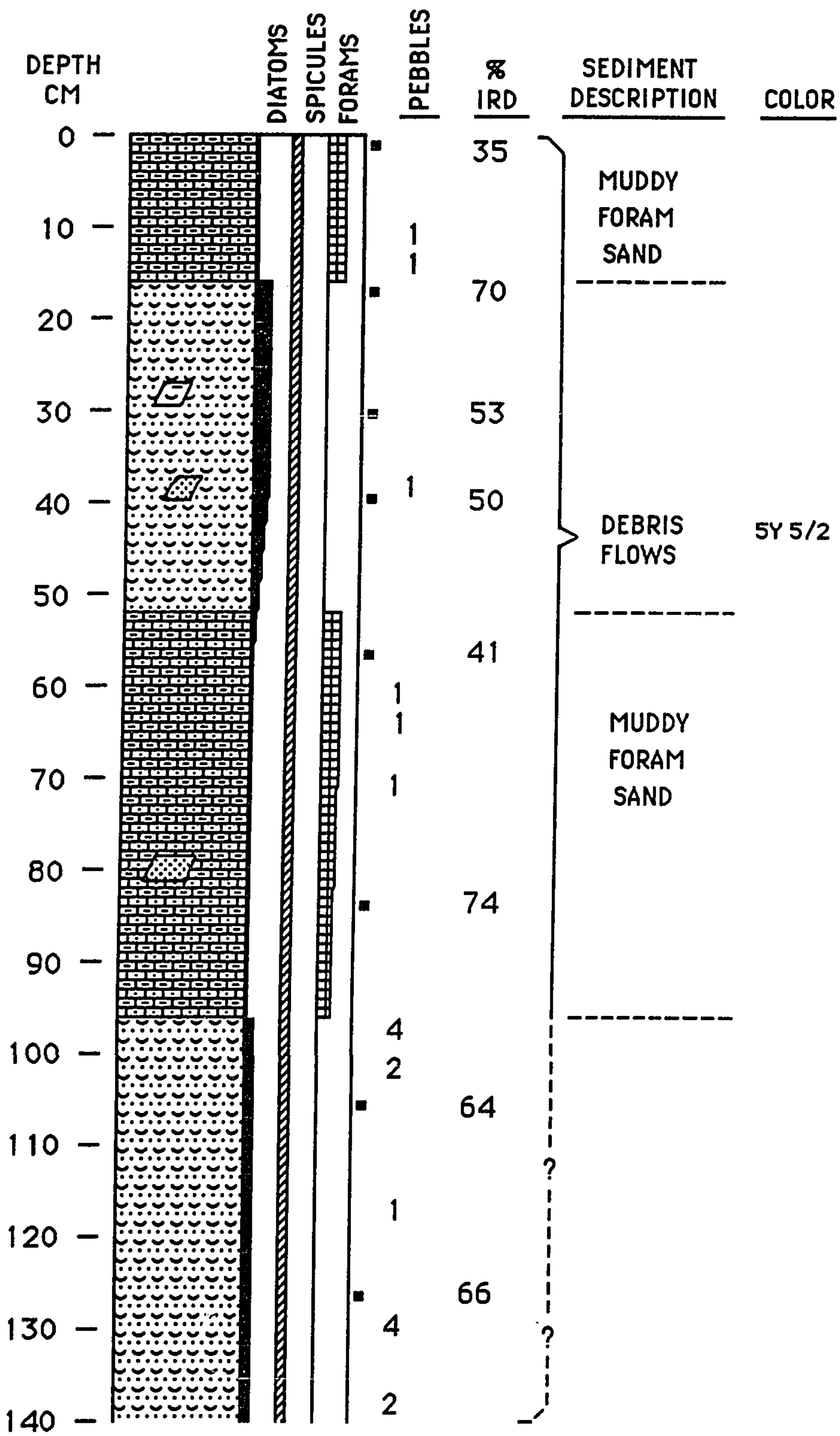


PEBBLES	% IRD	TEXTURE MEAN CHI	TEXTURE MODE CHI	MINERALOGY QFMSch	MINERALOGY EXOTICS
	73	7.0	5.75	72%	15%
	69	7.0	6.25		
3	76	7.2	6.0	63%	24%
	32	10.0	5.87	74%	16%
	15	10.9	9.75		
1	17	10.8	9.75	80%	5%
	24	10.4	11.0		
	34	9.3	10.5	71%	16%
3	57	8.2	6.12	71%	16%
	58	7.8	3.37	67%	20%
4	58	8.2	5.0	74%	12%
2	59	8.1	6.0	71%	15%
3	54	8.1	6.0	69%	18%

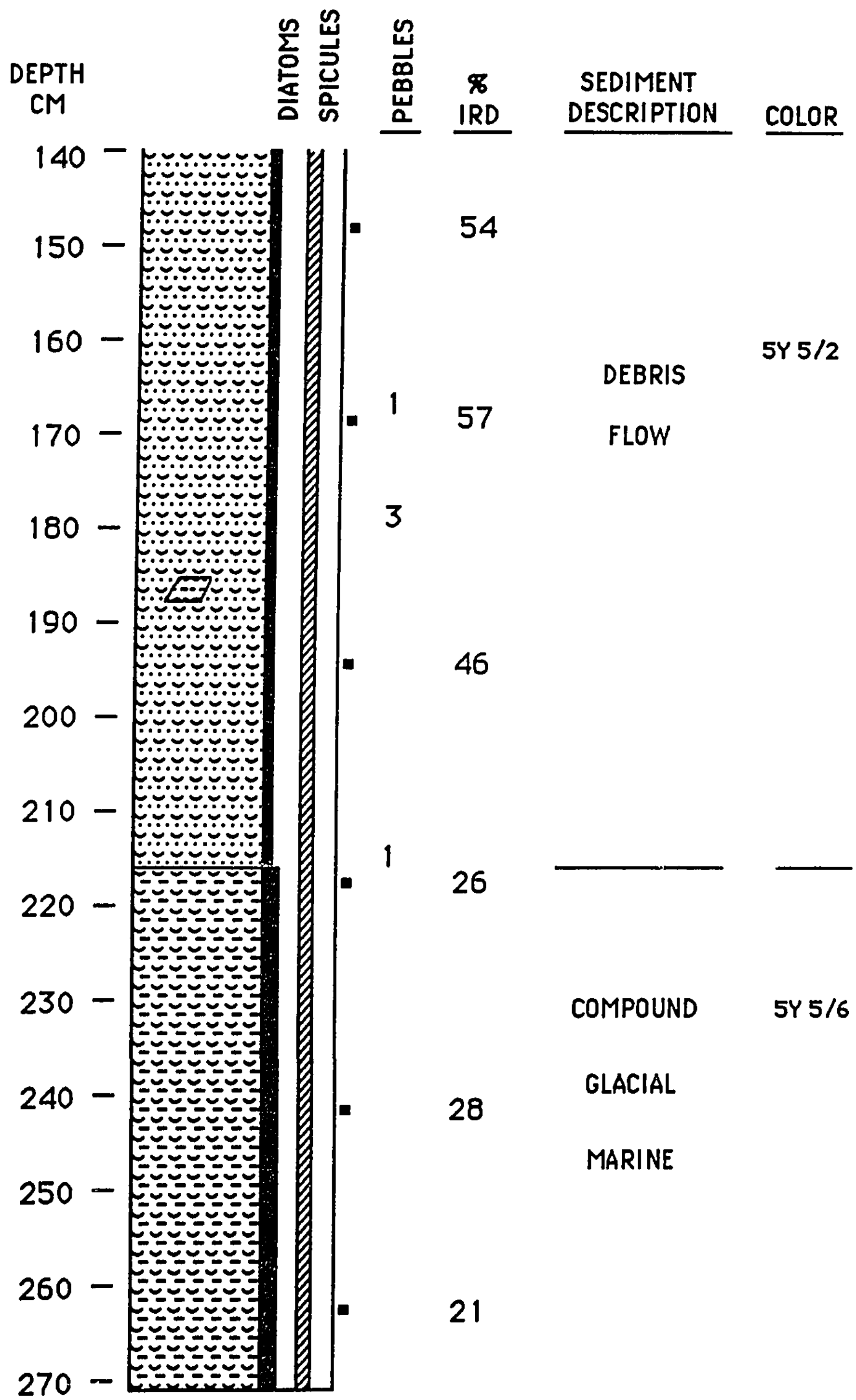
SEDIMENT DESCRIPITON	COLOR
COMPOUND GLACIAL MARINE	5Y 4/1
"SUB-ICE" DEPOSIT; SLIGHLTY BURROWED; ?	5Y 5/2
COMPOUND GLACIAL MARINE ?	5Y 4/1

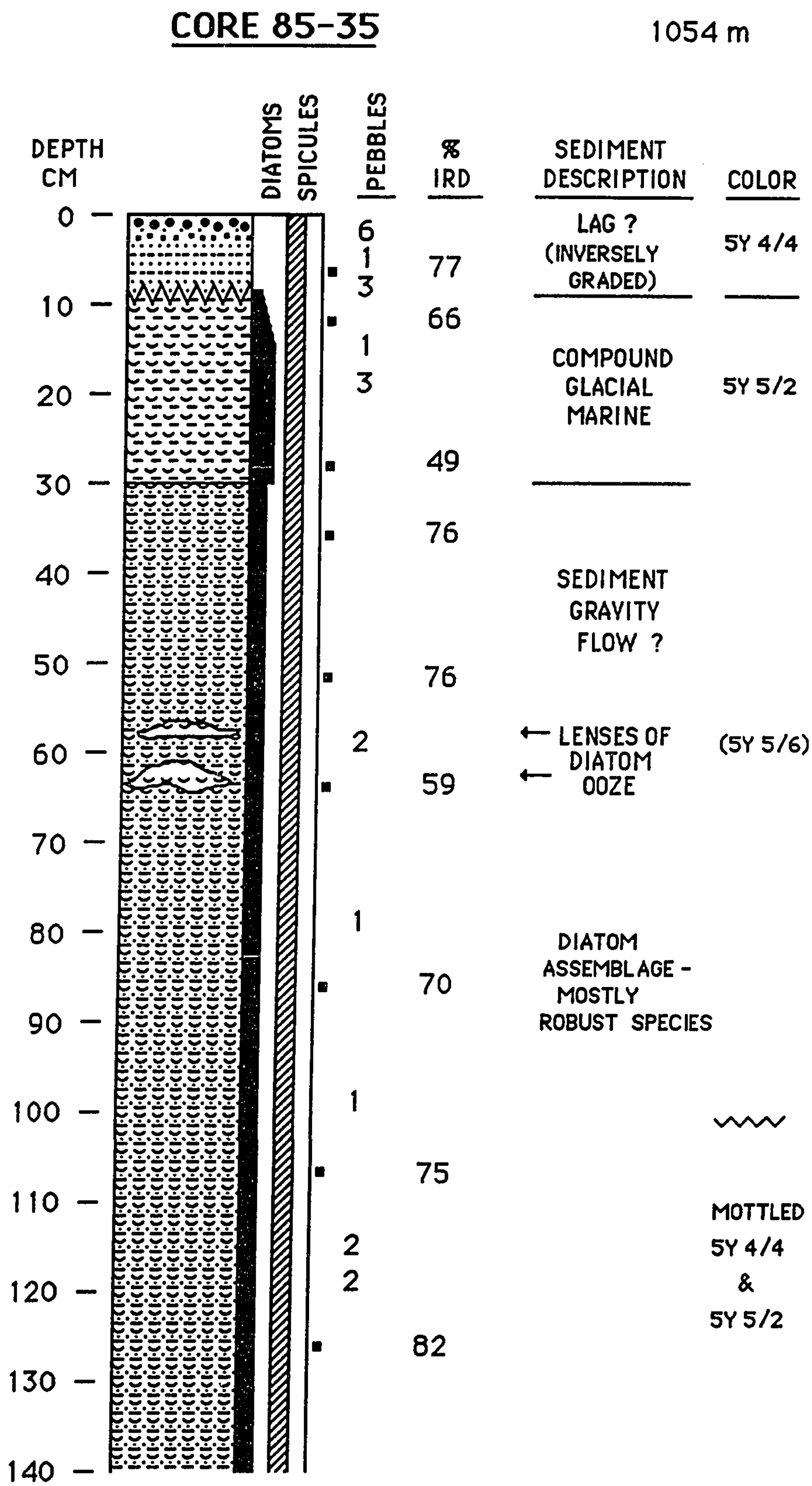
CORE 85-34

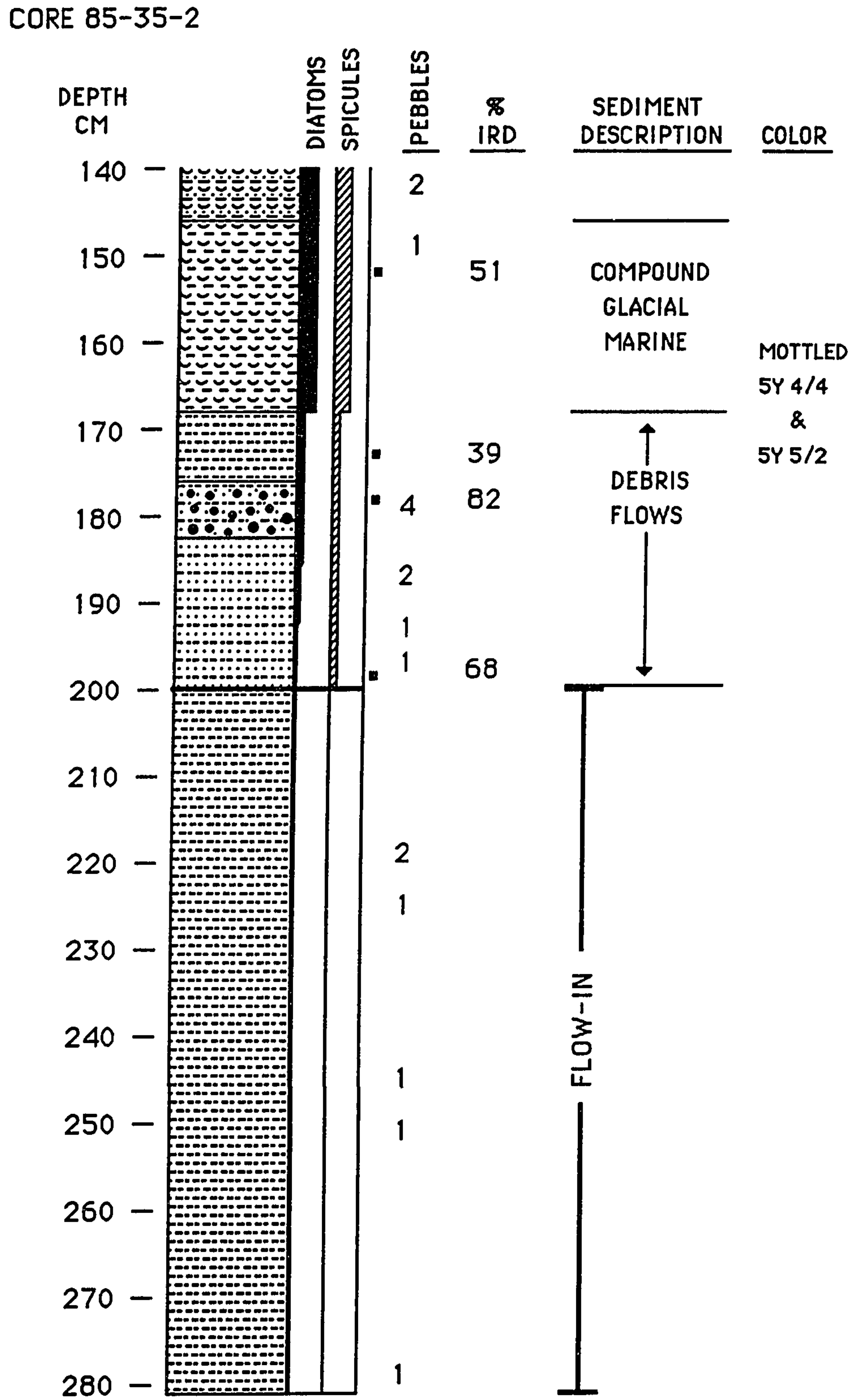
1794 m

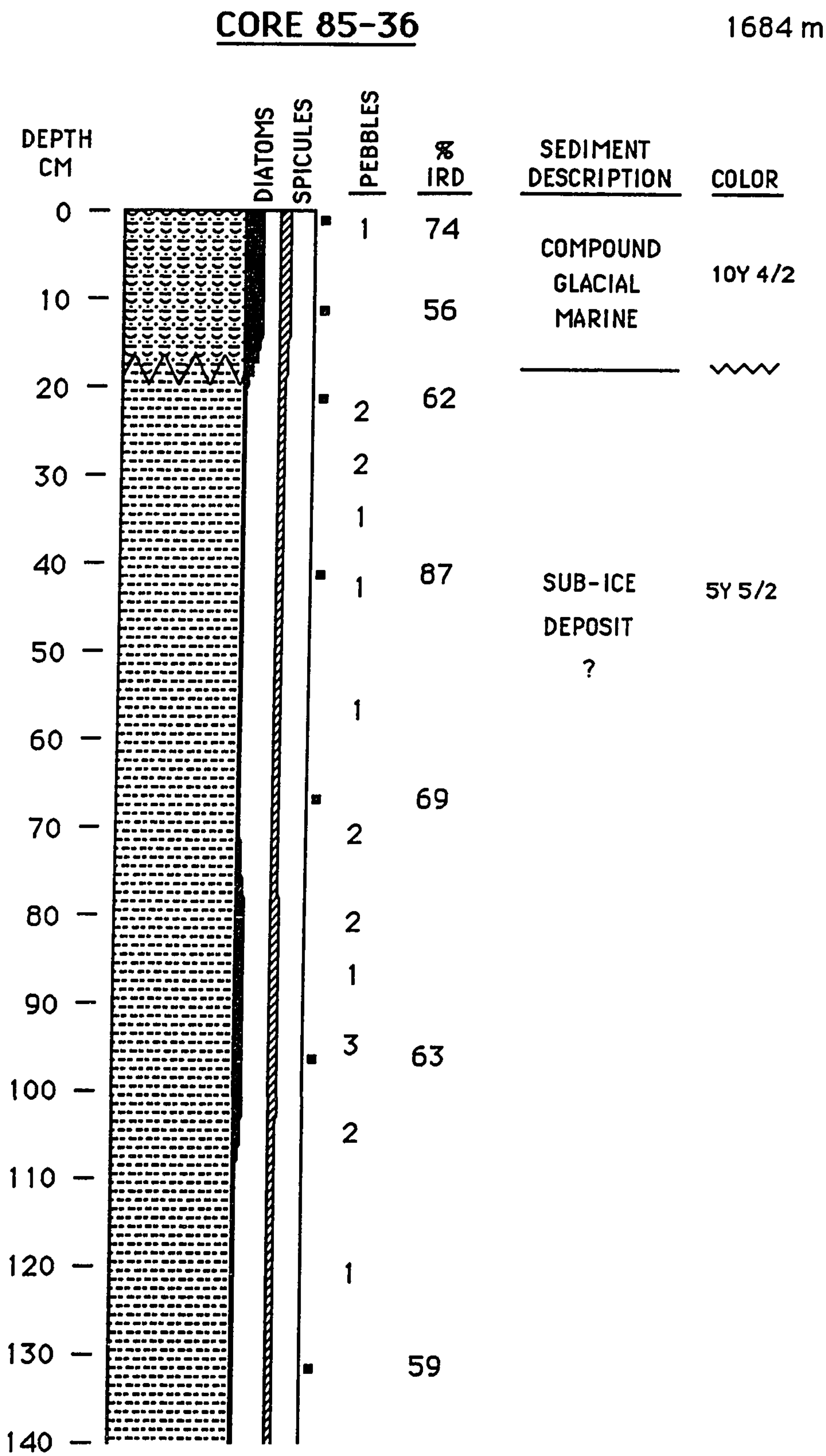


CORE 85-34-2

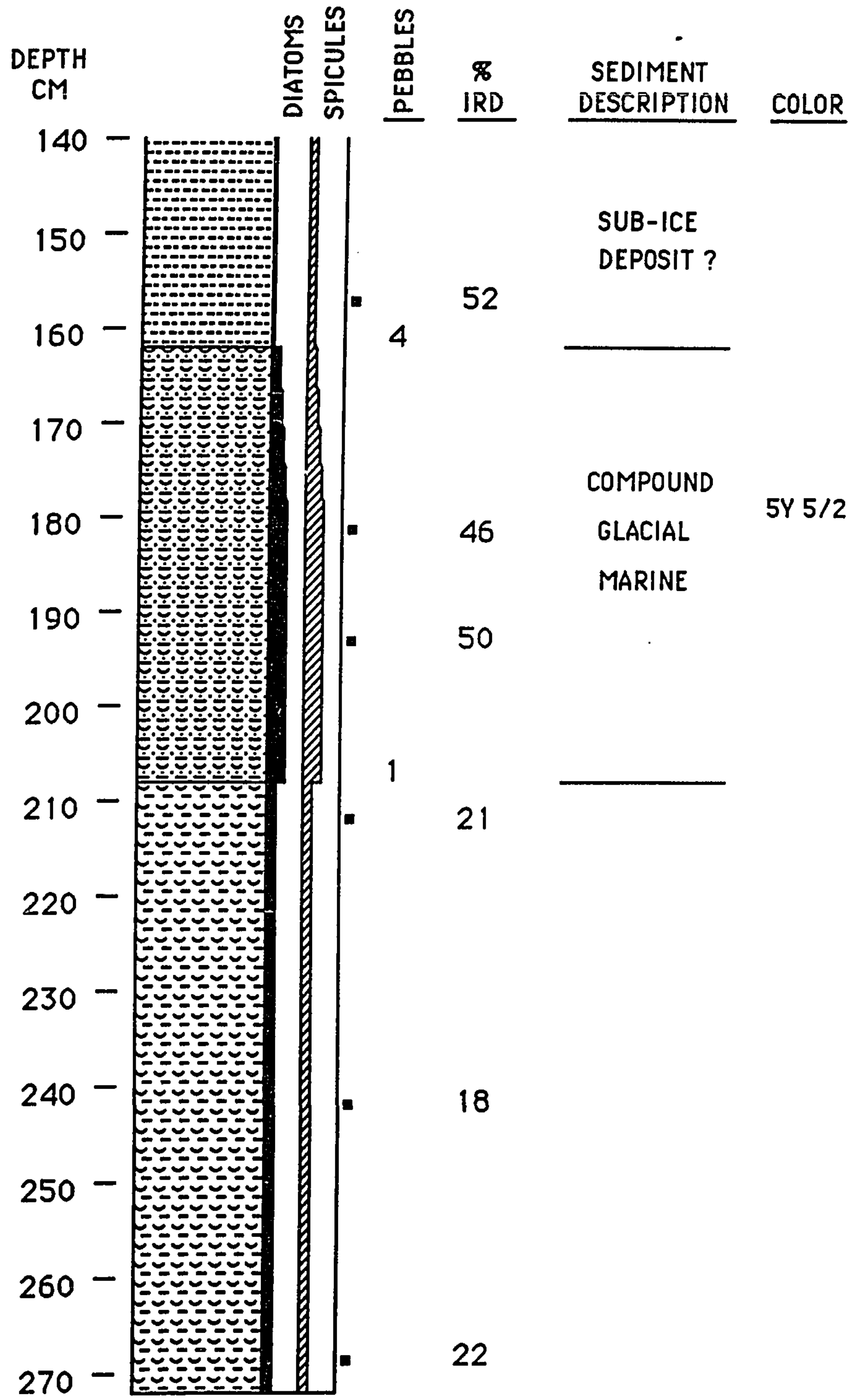

DEPTH CM
DIATOMS
SPICULES
PEBBLES
% IRD
SEDIMENT DESCRIPTION
COLOR
140
150
160
170
180
190
200
210
220
230
240
250
260
270
54
1
57
3
46
1
26
28
21
DEBRIS FLOW
5Y 5/2
COMPOUND GLACIAL MARINE
5Y 5/6


CORE 85-35
1054 m
DEPTH CM
DIATOMS
SPICULES
PEBBLES
% IRD
SEDIMENT DESCRIPTION
COLOR
0
10
20
30
40
50
60
70
80
90
100
110
120
130
140
6
1
3
1
3
2
1
1
2
2
77
66
49
76
76
59
70
75
82
LAG ? (INVERSELY GRADED)
5Y 4/4
COMPOUND GLACIAL MARINE
5Y 5/2
SEDIMENT GRAVITY FLOW ?
LENSES OF DIATOM OOZE
(5Y 5/6)
DIATOM ASSEMBLAGE - MOSTLY ROBUST SPECIES
MOTTLED
5Y 4/4
&
5Y 5/2


CORE 85-35-2
DEPTH CM
DIATOMS
SPICULES
PEBBLES
% IRD
SEDIMENT DESCRIPTION
COLOR
140
150
160
170
180
190
200
210
220
230
240
250
260
270
280
2
1
51
COMPOUND GLACIAL MARINE
MOTTLED 5Y 4/4 & 5Y 5/2
39
DEBRIS FLOWS
4
82
2
1
1
68
2
1
FLOW-IN
1
1
1


CORE 85-36
1684 m
DEPTH CM
DIATOMS
SPICULES
PEBBLES
% IRD
SEDIMENT DESCRIPTION
COLOR
0
10
20
30
40
50
60
70
80
90
100
110
120
130
140
1
74
56
2
62
2
1
1
87
1
69
2
2
1
3
63
2
1
59
COMPOUND GLACIAL MARINE
10Y 4/2
SUB-ICE DEPOSIT ?
5Y 5/2

CORE 85-36-2


DEPTH CM
DIATOMS
SPICULES
PEBBLES
% IRD
SEDIMENT DESCRIPTION
COLOR
140
150
160
170
180
190
200
210
220
230
240
250
260
270
52
4
46
50
1
21
18
22
SUB-ICE DEPOSIT ?
COMPOUND GLACIAL MARINE
5Y 5/2

APPENDIX C
TEXTURAL DATA - SOUTH ORKNEY PLATEAU

CORE/ - Core number
DEPTH - Depth in core in centimeters or sample type
- BG - bottom grab
- BC - bagged core
- CC - core catcher
- CN - cutter nose
- TC - trigger core (top)

* - sieve analysis only
◊ - sieve and settling tube analysis only (<4.75 phi)
(no symbol) - total grain size analysis

G:S-cZ:m-fZ:C -
Gravel : Sand and coarse Silt : medium to fine Silt : Clay
<-1 phi : -1 to 4.75 phi : 4.75 to 8.0 phi : >8 phi

[ ] - medium to fine Silt and Clay, grouped

CORE/ DEPTH	MEAN CHI	MODE CHI	STD DEV CHI	MEAN PHI	MODE PHI	STD DEV PHI	G:S-cZ:m-fZ:C PERCENTS
01/02	9.2	9.75	5.9	4.5	3.5	2.4	1 : 41 : 52 : 6
01/16*							- : 29 : [71]
01/24*							- : 13 : [87]
01/53*							- : 8 : [92]
01/81*							1 : 28 : [71]
01/91*							- : 28 : [72]
01/106*							- : 15 : [85]
01/131*							- : 15 : [85]
02/02	9.8	9.75	5.7	4.8	5.0	2.4	- : 34 : 60 : 6
02/10*							1 : 55 : [44]
02/23*							6 : 47 : [47]
02/28*							1 : 24 : [75]
02/40*							- : 60 : [40]
02/49*							8 : 68 : [23]
02/54*							- : 63 : [37]
02/58*							3 : 47 : [50]
02/70*							4 : 57 : [39]
02/81*							- : 58 : [42]
02/86*							- : 9 : [91]
02/118*							- : 4 : [96]
02/136*							- : 27 : [73]
02/162*							- : 28 : [72]
02/183*							1 : 44 : [54]
02/203*							1 : 71 : [29]
02/215*							- : 48 : [52]
02/246*							- : 62 : [38]
02/263*							- : 26 : [74]
02/291*							- : 39 : [61]
02/321*							3 : 40 : [57]
03/BG	8.9	7.1	4.8	4.3	3.5	2.2	- : 55 : 42 : 3
04/03	9.0	7.5	6.0	4.3	3.75	2.4	- : 51 : 46 : 3
04/05	7.8	0.0	5.8	3.6	3.75	2.4	- : 75 : 24 : 1
04/CN*							9 : 61 : [30]
05/BG	10.0	12.0	4.1	5.0	6.0	2.0	- : 37 : 59 : 4
06/BG◊	5.2	5.1	3.1	2.1	2.25	1.75	26 : 57 : [16]
07/BG◊	4.1	2.9	2.3	1.3	1.75	1.5	11 : 89 : [0]
08/BG◊	4.7	5.0	2.6	1.8	2.5	1.6	12 : 80 : [8]

CORE/ DEPTH	MEAN CHI	MODE CHI	STD DEV CHI	MEAN PHI	MODE PHI	STD DEV PHI	G:S-cZ:m-fZ:C PERCENTS
09/02	5.7	7.4	3.3	2.5	3.5	1.8	12 : 59 : 26 : 3
10/BG	10.3	10.0	4.3	5.1	5.0	2.1	- : 28 : 66 : 6
11/01◊	4.5	3.0	2.5	1.6	2.25	1.6	27 : 66 : [6]
12/01	10.0	7.6	4.6	4.9	3.75	2.1	- : 36 : 59 : 5
12/10	10.3	7.1	4.7	5.0	5.5	2.2	- : 34 : 60 : 5
12/20	10.7	10.0	4.2	5.3	5.25	2.0	- : 27 : 66 : 8
12/30	11.1	9.75	3.9	5.5	6.0	2.0	- : 18 : 73 : 9
12/40	12.5	12.0	2.0	6.2	6.0	1.4	- : 16 : 74 : 10
12/50	12.4	12.0	2.2	6.2	6.0	1.5	- : 11 : 78 : 10
12/60	12.4	12.5	1.9	6.2	6.25	1.4	- : 13 : 77 : 10
12/70	12.2	12.0	2.1	6.0	6.0	1.4	- : 13 : 79 : 8
12/80	12.4	12.0	2.3	6.1	6.0	1.5	- : 11 : 79 : 10
12/90	12.0	9.75	2.9	5.9	5.0	1.7	- : 15 : 73 : 12
12/100	12.9	10.5	2.2	6.4	5.25	1.5	- : 12 : 70 : 18
12/110	12.3	9.75	2.5	6.1	5.75	1.6	- : 11 : 76 : 13
12/120	12.6	9.75	2.5	6.2	6.0	1.6	- : 13 : 76 : 10
12/130	13.1	12.5	1.7	6.5	6.25	1.3	- : 15 : 65 : 20
12/140	12.3	11.5	2.2	6.1	6.0	1.5	- : 12 : 78 : 10
12/150	12.6	11.5	1.9	6.3	6.0	1.4	- : 11 : 76 : 13
12/155	12.0	9.75	2.2	6.0	6.0	1.5	- : 10 : 81 : 9
12/161	12.4	12.0	2.3	6.2	6.0	1.5	- : 10 : 79 : 11
12/170	12.5	12.5	2.0	6.2	6.5	1.4	- : 19 : 69 : 12
12/180	10.7	11.0	4.2	5.2	5.5	2.1	3 : 23 : 67 : 7
12/186	10.6	9.75	5.3	5.2	5.5	2.3	2 : 23 : 66 : 9
12/192	10.6	9.75	4.9	5.2	5.0	2.2	- : 26 : 65 : 9
12/200	9.3	10.0	5.6	4.5	5.0	2.4	4 : 44 : 47 : 5
12/210	9.3	9.75	5.5	4.5	5.0	2.3	1 : 46 : 47 : 6
12/220	7.8	6.4	5.9	3.7	3.0	2.4	1 : 67 : 29 : 3
12/232	8.0	5.9	5.4	3.8	3.25	2.3	5 : 62 : 30 : 3
12/240	7.6	6.0	5.2	3.6	2.75	2.3	9 : 64 : 25 : 2
12/251	7.8	7.25	5.0	3.7	3.5	2.2	2 : 71 : 24 : 3
12/261	7.7	6.9	4.6	3.7	3.25	2.1	1 : 75 : 22 : 2
12/271	7.8	7.4	4.9	3.7	3.5	2.2	1 : 72 : 25 : 2
12/CC*							6 : 74 : [20]
13/01◊	4.6	5.4	3.0	1.7	2.25	1.7	5 : 81 : [14]
14/01	8.4	0.0	6.6	4.0	5.0	2.6	- : 55 : 41 : 4
15/02	7.2	5.9	8.1	3.2	2.75	2.8	4 : 65 : 27 : 4
15/11*							- : 42 : [58]
15/22*							- : 15 : [85]

CORE/ DEPTH	MEAN CHI	MODE CHI	STD DEV CHI	MEAN PHI	MODE PHI	STD DEV PHI	G:S-cZ:m-fZ:C PERCENTS
15/35*							- : 12 : [88]
15/48*							- : 7 : [93]
15/52*							- : 12 : [88]
15/71*							- : 9 : [91]
15/99*							- : 15 : [85]
16/01	11.3	10.5	4.7	5.6	5.25	2.2	- : 13 : 74 : 13
16/20	12.1	9.75	2.5	6.0	5.0	1.6	- : 7 : 85 : 7
16/41	12.0	10.0	2.5	5.9	5.0	1.6	- : 8 : 85 : 6
17/04◊	4.7	2.9	3.8	1.7	0.25	1.9	41 : 45 : [13]
18/02*							9 : 67 : [23]
18/08*							3 : 67 : [30]
18/19*							1 : 38 : [62]
18/29*							3 : 65 : [32]
18/41*							1 : 22 : [77]
18/52*							1 : 25 : [75]
18/79*							4 : 22 : [74]
18/109*							- : 20 : [80]
18/142*							2 : 28 : [70]
19/TC	7.8	6.25	6.7	3.7	3.0	2.6	9 : 59 : 29 : 3
20/01	7.9	7.4	6.7	3.7	3.5	2.6	0 : 66 : 30 : 4
21/BC◊	3.8	2.75	3.4	1.0	0.0	1.8	65 : 30 : [5]
21/CC◊	4.3	0.0	5.1	1.4	-0.75	2.25	6 : 74 : [10]
21/CN◊	4.0	0.0	4.3	1.1	0.5	2.1	57 : 31 : [11]
24/BG	6.9	3.5	5.6	3.1	3.0	2.4	4 : 74 : 21 : 1
24/BC*							20 : 50 : [30]
25/BG	8.5	6.9	6.6	4.1	3.25	2.6	2 : 54 : 42 : 2
26/BG	9.4	9.75	6.1	4.6	5.0	2.5	6 : 40 : 51 : 3
26/03◊	6.0	6.75	3.6	2.7	3.5	1.9	15 : 48 : [37]
26/15◊	6.4	7.5	4.1	2.9	3.75	2.1	2 : 37 : [61]
26/20◊	6.6	8.1	3.4	3.1	4.0	1.8	30 : 33 : [37]
26/23◊	6.9	7.9	2.8	3.25	3.75	1.7	2 : 45 : [53]
26/38◊	6.7	6.9	2.8	3.1	3.75	1.7	13 : 42 : [45]
27/BG	10.5	12.0	6.2	5.1	6.25	2.5	- : 31 : 60 : 9
27/04	10.3	10.0	6.4	5.0	5.25	2.5	- : 32 : 60 : 8
27/31	9.4	0.0	7.8	4.4	3.5	2.8	- : 44 : 47 : 9

CORE/ DEPTH	MEAN CHI	MODE CHI	STD DEV CHI	MEAN PHI	MODE PHI	STD DEV PHI	G:S-cZ:m-fZ:C PERCENTS
27/63	10.3	6.9	7.6	4.9	3.25	2.8	- : 35 : 52 : 13
27/82	10.5	6.6	6.7	5.0	7.25	2.6	- : 34 : 53 : 13
27/97	6.5	6.25	4.6	3.0	3.0	2.1	- : 87 : 11 : 1
27/103	11.1	12.5	5.4	5.4	6.25	2.3	- : 24 : 65 : 11
27/124	13.0	11.0	2.0	6.5	5.75	1.4	- : 11 : 71 : 18
27/148	10.0	13.5	7.5	4.9	6.75	2.7	- : 40 : 51 : 9
27/175	8.5	6.75	6.3	4.1	3.25	2.5	- : 61 : 34 : 5
27/194	11.3	11.0	5.0	5.5	5.75	2.2	- : 19 : 64 : 16
28/BG	9.16	7.6	5.2	4.5	3.75	2.3	1 : 49 : 47 : 3
28/02*							- : 95 : [5]
28/03*							- : 41 : [59]
28/18*							- : 91 : [9]
28/42*							- : 84 : [16]
28/48*							- : 41 : [59]
28/61*							1 : 48 : [51]
28/75*							3 : 51 : [46]
29/BG	9.7	8.0	4.9	4.7	3.75	2.2	- : 39 : 57 : 4
29/03*							- : 39 : [61]
29/18*							20 : 43 : [37]
29/30*							1 : 53 : [47]
29/57*							- : 52 : [48]
30/BG	8.3	6.1	7.3	3.9	3.5	2.7	2 : 58 : 35 : 4
30/03*							23 : 56 : [21]
30/12*							32 ; 46 : [22]
30/19*							25 : 47 : [29]
31/02	11.0	13.0	5.0	5.4	6.5	2.2	- : 20 : 74 : 6
31/16*							- : 24 : [76]
31/29*							- : 14 : [86]
31/48*							- : 15 : [85]
31/67*							- : 28 : [72]
31/77*							- : 22 : [78]
32/BG	12.5	10.5	3.0	6.2	6.75	1.7	- : 4 : 82 : 14
32/BC*							20 : 50 : [30]
33/01	7.0	5.75	5.7	3.2	2.75	2.4	1 : 76 : 19 : 3
33/04	7.0	6.25	5.9	3.2	3.0	2.4	2 : 74 : 21 : 3
33/11	7.2	6.0	5.0	3.4	2.75	2.2	3 : 73 : 19 : 5
33/22	10.0	5.9	7.3	4.8	2.75	2.7	- : 34 : 54 : 12
33/31	10.9	9.75	4.9	5.4	5.0	2.2	- : 19 : 69 : 12

CORE/ DEPTH	MEAN CHI	MODE CHI	STD DEV CHI	MEAN PHI	MODE PHI	STD DEV PHI	G:S-cZ:m-fZ:C PERCENTS
33/41	10.8	9.75	5.2	5.3	5.0	2.3	- : 21 : 66 : 12
33/51	10.4	11.0	6.1	5.1	5.75	2.5	- : 27 : 57 : 16
33/61	9.35	10.5	6.5	4.5	5.25	2.6	- : 38 : 50 : 12
33/71	8.2	6.1	7.2	3.8	2.75	2.7	3 : 54 : 36 : 7
33/81	7.8	3.4	6.7	3.6	2.5	2.6	- : 61 : 34 : 5
33/91	8.2	5.0	7.8	3.8	3.25	2.8	5 : 54 : 33 : 8
33/100	8.1	6.0	7.2	3.8	2.75	2.7	6 : 54 : 35 : 5
33/110	8.1	6.0	9.0	3.7	2.75	3.0	1 : 54 : 31 : 14
34/01◊	5.5	5.75	3.1	2.3	2.75	1.8	- : 63 : [37]
35/06◊	4.8	4.9	3.2	1.8	2.0	1.8	45 : 35 : [20]
35/12	6.7	6.0	7.0	2.9	2.75	2.6	1 : 66 : 18 : 15
35/28	8.1	6.0	8.0	4.0	2.5	2.8	1 : 51 : 28 : 20
35/36◊	5.3	5.25	2.1	2.2	2.25	1.5	18 : 61 : [21]
35/52◊	5.7	5.75	1.7	2.5	2.75	1.3	2 : 77 : [21]
35/64	7.6	5.75	6.0	3.5	2.75	2.4	- : 63 : 19 : 18
35/86◊	5.5	6.4	1.9	2.4	2.75	1.4	2 : 72 : [26]
35/108◊	5.25	5.75	2.1	2.2	2.75	1.5	1 : 77 : [22]
35/126◊	5.1	5.75	2.2	2.1	2.5	1.5	6 : 78 : [16]
35/154	8.1	6.25	7.8	3.8	3.0	2.8	2 : 53 : 27 : 18
35/173	8.3	5.75	8.6	3.9	2.75	2.9	- : 42 : 28 : 30
35/182◊	5.1	5.75	3.1	2.0	2.75	1.8	60 : 24 : [16]
35/199◊	5.7	5.75	2.7	2.5	2.75	1.7	24 : 50 : [26]
36/01◊	4.9	5.1	2.8	1.9	2.25	1.7	9 : 68 : [23]
36/12◊	4.4	0.0	3.4	1.5	2.0	1.8	11 : 47 : [42]
36/21◊	4.6	5.1	3.9	1.6	2.25	2.0	5 : 62 : [33]
36/42◊	4.4	2.9	3.1	1.5	0.25	1.8	47 : 40 : [13]
36/68◊	5.1	4.0	3.0	2.0	2.5	1.7	6 : 67 : [27]
36/97◊	4.8	4.75	3.1	1.8	2.0	1.8	14 : 52 : [34]
36/131◊	5.2	5.5	2.8	2.2	2.25	1.7	9 : 54 : [37]
36/158◊	5.4	5.75	2.6	2.3	2.5	1.6	2 : 55 : [43]
36/182◊	5.3	0.0	3.4	2.2	2.75	1.8	1 : 48 : [51]
36/192◊	5.4	5.5	2.7	2.3	2.5	1.6	- : 55 : [45]
36/213◊	6.2	7.0	3.4	2.8	3.5	1.9	- : 25 : [75]
36/242◊	6.3	7.25	3.5	2.8	3.5	1.9	- : 21 : [79]
36/269◊	6.7	7.4	2.8	3.1	3.5	1.7	1 : 26 : [73]

APPENDIX D
MINERALOGY OF COARSE SAND (-1 to 1 phi)
Point counts on ≥300 grains

Lithology catagories are:

1 SCHIST (locally derived)
2 QUARTZ, FELDSPAR, and MICA (locally derived)
3 ROCK FRAGMENT - SEDIMENTARY or META- SEDIMENTARY (mostly locally derived)
4 ROCK FRAGMENT - IGNEOUS (locally derived)
5 ROCK FRAGMENT - IGNEOUS (exotic)
6 ROCK FRAGMENT - VOLCANIC (exotic)
7 OTHER (rare accessory minerals, e.g. garnet, fossil fragments, Mn nodule, etc.)

TOTAL = Total number of grains counted; 300+ grains or as many as sample contains.

MINERALOGY - COARSE SAND (-1 TO 1 PHI)
CORE 85-12

CORE/ DEPTH	SCHIST	QUARTZ FSP MICA	R.F. SED - MET-SED	R.F. IGN - LOCAL	R.F. IGN - EXOTIC	R.F. VOLC	OTHER	TOTAL
85-12/ 10-70 CM	6 15%	17 43%	8 20%	1 3%	0 -	8 20%	0 -	40
80-140 CM	13 16%	60 74%	4 5%	0 -	0 -	4 5%	0 -	81
150-190 CM	45 24%	77 41%	41 22%	12 7%	1 -	13 7%	0 -	189
200 CM	31 19%	83 51%	8 7%	18 11%	6 2%	17 10%	0 -	163
210 CM	40 25%	82 52%	3 4%	9 6%	10 3%	14 9%	1 <1%	159
220 CM	53 16%	152 47%	22 8%	35 11%	16 4%	46 14%	0 -	324
232 CM	75 24%	154 49%	24 8%	22 7%	16 5%	19 6%	6 2%	316
241 CM	67 21%	168 51%	18 5.5%	21 6%	33 10%	18 5.5%	0 -	325
251 CM	57 15%	183 50%	22 6%	20 5%	41 11%	47 13%	0 -	370
261 CM	37 12%	166 53%	20 6%	16 5%	39 12.5%	33 11%	0 -	311
271 CM	47 14%	170 52%	15 5%	22 7%	48 15%	24 7%	0 -	325
core catcher	78 22%	180 49%	55 15%	20 6%	2 <1%	20 6%	3 1%	358

MINERALOGY - COARSE SAND (-1 TO 1 PHI)
CORE 85-21

CORE/ DEPTH	SCHIST	QUARTZ FSP MICA	R.F. SED - MET-SED	R.F. IGN - LOCAL	R.F. IGN - EXOTIC	R.F. VOLC	OTHER	TOTAL
85-21/								
bagged	270	88	2	2?	0	0	2	364
core	74%	24%	<1%	<1%	-	-	<1%	
core	306	94	0	1?	0	0	2	403
catcher	76%	23%	-	-	-	-	-	
cutter	243	74	4	1?			4	326
nose	74%	23%	1%	-	-	-	1%	

MINERALOGY - COARSE SAND (-1 TO 1 PHI)
CORE 85-24

CORE/ DEPTH	SCHIST	QUARTZ FSP MICA	R.F. SED - MET-SED	R.F. IGN - LOCAL	R.F. IGN - EXOTIC	R.F. VOLC	OTHER	TOTAL
85-24								
bottom	43	25	9	241	0	0	1	319
grab	13%	8%	3%	75%	-	-	-	
bagged	45	30	5	265	0	0	2	347
core	13%	9%	1%	76%	-	-	-	

MINERALOGY - COARSE SAND (-1 TO 1 PHI)
CORE 85-25

CORE/ DEPTH	SCHIST	QUARTZ FSP MICA	R.F. SED - MET-SED	R.F. IGN - LOCAL	R.F. IGN - EXOTIC	R.F. VOLC	OTHER	TOTAL
85-25/ bottom	132	85	13	2	0	3	3	238
grab	55%	36%	5%	1%	-	1%	1%	
4 CM	172	135	10	4	0	1?	3	325
	53%	41%	3%	1%	-	-	1%	
12 CM	190	148	11	1	0	2	4	326
	58%	36%	3%	-	-	<1%	1%	
19 CM	210	94	11	1	0	2	2	320
	66%	29%	3%	-	-	<1%	<1%	

MINERALOGY - COARSE SAND (-1 TO 1 PHI)
CORE 85-26

CORE/ DEPTH	SCHIST	QUARTZ FSP MICA	R.F. SED - MET-SED	R.F. IGN - LOCAL	R.F. IGN - EXOTIC	R.F. VOLC	OTHER	TOTAL
85-26/ bottom grab	124 57%	50 23%	16 7%	25 11%	0 -	0 -	1 -	216
3 CM	181 64%	61 22%	13 5%	26 9%	- -	0 -	1 -	282
20 CM	94 54%	39 22%	27 15%	15 9%	0 -	0 -	0 -	175
23 CM	81 60%	27 20%	10 7%	16 12%	0 -	0 -	2 1%	136
38 CM	68 66%	21 20%	5 5%	8 8%	0 -	0 -	1 1%	103

MINERALOGY - COARSE SAND (-1 TO 1 PHI)
CORE 85-29 and 85-30

CORE/ DEPTH	SCHIST	QUARTZ FSP MICA	R.F. SED - MET-SED	R.F. IGN - LOCAL	R.F. IGN - EXOTIC	R.F. VOLC	OTHER	TOTAL
85-29/ 18 CM	107	111	26	39	6	31	0	319
	33%	35%	8%	12%	2%	10%	-	
85-30/ bottom	161	86	6	52	0	21	1	327
grab	49%	26%	2%	16%	-	6%	-	
3 CM	181	71	6	49	0	31	1	339
	53%	21%	2%	14%	-	9%	-	
12 CM	110	100	4	87	0	16	0	317
	35%	32%	1%	27%	-	5%	-	
19 CM	140	105	3	91	0	5	2	346
	40%	29%	<1%	28%	-	1%	-	

MINERALOGY - COARSE SAND (-1 TO 1 PHI)
CORE 85-33

CORE/ DEPTH	SCHIST	QUARTZ FSP MICA	R.F. SED - MET-SED	R.F. IGN - LOCAL	R.F. IGN - EXOTIC	R.F. VOLC	OTHER	TOTAL
85-33/ 1-3 CM	51 15%	198 57%	16 5%	42 12%	30 9%	11 3%	0 -	348
11-13 CM	18 6%	169 57%	10 3%	37 12%	44 15%	17 6%	0 -	295
22-24 CM	5 3%	121 70%	3 2%	18 8%	23 16%	0 -	0 -	170
31-33 CM	4	20	1	4	1	1	0	31
41-43 CM	3	24	1	6	1	0	0	35
51-53 CM	4	41	3	4	3	1	0	56
TOTAL 31-53 CM	11 9%	85 70%	5 4%	14 11%	5 4%	2 2%	0 -	122
61-63 CM	12 5.5%	142 65%	7 3%	21 10%	33 15%	2 1%	0 -	217
71-73 CM	24 7%	202 64%	6 2%	32 10%	43 13%	11 3%	0 -	318
81-83 CM	31 10%	177 57%	8 3%	30 10%	53 17%	9 3%	0 -	308
91-93 CM	27 9%	200 65%	22 7%	23 7%	23 7%	11 4%	0 -	306
100-102 CM	40 13%	183 58%	24 8%	19 6%	35 11%	12 4%	0 -	313
110-112 CM	40 13%	178 56%	16 5%	26 8%	41 13%	16 5%	0 -	317

APPENDIX E
SOUTH ORKNEY PLATEAU - PEBBLE DATA

Explanation

Pebble ID = core and pebble name

Depth (cm) = depth in core

Axes measured, from Boulton's (1978) method:
a-axis = longest axis of pebble
b-axis = intermediate length axis perpendicular to a-axis
c-axis = short axis perpendicular to both a- and b-axes

Sphericity calculation: (from Boulton, 1978)
sphericity = $[(\text{b-axis}) \times (\text{c-axis}) \div (\text{a-axis})^2]^{1/3}$

rnd = roundness value, using Krumbein's (1941) method
- S = well-developed striations
- F = faceted on three or more sides
- BR = broken or fractured, probably during coring

rock type =	META	PLUT	VOLC	SED
	metamorphic	plutonic	volcanic	sedimentary

sp. lithology = specific lithology

commments = relavent details such as texture, color, weathering, ferro-manganese coating, mineralogy.

G or GRAV = gravel-sized clast(s); not measured for roundness or sphericity

Pebble ID	Depth (cm)	a-axis	b-axis	c-axis	sphericity	rnd
85-1-A	5	17.90	14.45	6.90	0.68	1
85-1-B	5	11.35	10.30	5.30	0.75	3
85-1-C	82	16.15	8.30	3.90	0.50	5 S
85-2-A	34	28.00	25.40	14.60	0.78	1
85-2-B	15	24.40	18.75	13.60	0.75	2
85-2-C	17	36.00	25.00	19.70	0.72	3
85-2-D	19	22.90	17.60	13.90	0.78	3
85-2-E	39	14.50	10.60	8.00	0.74	5
85-2-F	76-78	21.70	11.30	7.90	0.57	4
85-2-G	"	17.80	13.90	7.90	0.70	3
85-2-H	185	21.80	13.80	12.90	0.72	3
85-2-I	204	18.90	17.40	13.30	0.87	5
85-2-J	228-237	10.50	8.10	5.20	0.73	4
85-2-K	"	11.30	6.40	3.70	0.57	4
85-2-L	245	15.40	13.20	5.70	0.68	3
85-2-M	252	19.90	12.90	4.20	0.52	2
85-3-A	44	15.45	13.30	6.90	0.73	2
85-3-B	45-47	12.40	7.90	4.70	0.62	2
85-3-C	"	13.70	9.70	8.70	0.77	5
85-3-D	63	20.80	13.10	12.65	0.73	5
85-3-E	"	18.70	13.00	9.60	0.71	4
85-3-F	"	11.90	8.50	5.60	0.70	4
85-3-G	68	14.20	9.80	7.90	0.73	3
85-3-H	"	10.50	5.10	3.60	0.55	4
85-3-I	73	21.70	17.20	14.00	0.80	5
85-3-J	82	20.30	14.10	7.25	0.63	2
85-4-A	72	36.60	26.50	20.30	0.74	5 F
85-4-B	76	19.10	17.50	11.70	0.82	2
85-4-C	"	15.25	12.80	9.00	0.79	3
85-4-D	"	17.50	9.10	7.60	0.61	3 F
85-4-E	90	40.65	36.00	23.80	0.80	6 F
85-4-F	122-125	31.90	24.40	20.00	0.78	4
85-4-G	"	18.50	17.60	6.20	0.68	5
85-5-A	36	11.70	9.00	7.80	0.80	2
85-5-B	96	8.50	8.10	5.20	0.84	2
85-6-A	0-3	29.20	27.70	9.00	0.66	2
85-6-B	"	17.85	11.75	8.25	0.67	3
85-6-C	"	25.80	22.00	12.35	0.74	3
85-6-D	"	21.20	11.10	10.45	0.64	2
85-6-E	"	16.30	9.00	8.10	0.65	2
85-6-F	5	16.40	12.90	11.90	0.83	5
85-6-G	"	16.20	5.80	4.90	0.48	2
85-6-H	10-11	14.75	8.30	5.80	0.60	4
85-6-I	"	8.90	6.20	4.70	0.72	3
85-8-A	3	16.20	10.40	7.20	0.66	3
85-8-B	5-8	32.00	25.90	10.60	0.64	1 F S
85-8-C	"	20.60	13.40	12.00	0.72	6
85-8-D	"	17.90	11.00	8.60	0.67	3
85-8-E	"	21.30	15.25	6.60	0.61	2
85-8-F	15					1 BR
85-8-G	20	27.50	25.00	10.20	0.70	6

ID	rock type	sp. lithology	comments
1-A	META	SCHIST	QTZ-MICA
1-B	META	QUARTZITE	COARSE-GRND, YELLOW-GREEN
1-C	META	PHYLLITE	
2-A	PLUT	GRANITE	
2-B	PLUT	GABBRO	
2-C	META	QUARTZITE	COARSE-GRAIN; GREEN
2-D	PLUT	DIORITE	
2-E	META	QUARTZITE	
2-F	VOLC	BASALT	
2-G	META	SCHIST	QTZ-MICA-HBD?
2-H	PLUT	GRANITE	
2-I	META	QUARTZITE	COARSE, LT.GRAY
2-J	VOLC	BASALT	
2-K	SED	MUDDY SS	FINE-GRN (SLIGHTLY META?)
2-L	PLUT	GRANITE	
2-M	VOLC	BASALT	PILOTAXITIC OR DICTYTAXITIC TEXT.
3-A	PLUT	GABBRO	V. WEATHERED
3-B	PLUT	GABBRO	
3-C	SED	QTZ ARENITE	SLIGHTLY META? (BIOTITE VEINS)
3-D	META	PHYLLITE	
3-E	VOLC	BASALT	PORPHYRITIC, VESICULAR
3-F	META	QUARTZITE	INCL OTHER MINERALS
3-G	PLUT	GABBRO	
3-H	VOLC	BASALT	
3-I	SED	SUB ARKOSE	SLIGHTLY META?
3-J	VOLC	BASALT	
4-A	META	QUARTZITE	
4-B	SED	SUB LITH-ARENITE	SLIGHTLY META?
4-C	PLUT	GRANITE	
4-D	META	SCHIST	W/QTZ,MICA,FSP
4-E	META	QUARTZITE	GRAY,W/ VEINS - PURE WHITE QTZ
4-F	VOLC	BASALT	PORPHYRITIC
4-G	VOLC	BASALT	FINE-GRN, LT.GREEN COATING
5-A	META	QUARTZITE	LOW-GRADE, MED-COARSE GRN
5-B	VOLC	BASALT	
6-A	META	PHYLLITE	
6-B	PLUT	GABBRO	ALTERED FE-MN COAT
6-C	SED	MUDDY SS	V.FINE-GRN, SLIGHTLY META?
6-D	META	PHYLLITE	
6-E	VOLC	BASALT	V.F.-GRN FE-MN COATED
6-F	META	META SUB ARKOSE	FE-MN COATED
6-G	SED	MUDDY SS	POORLY INDUR., MED-GRN,YELLOW
6-H	SED	SS	DIRTY, F.-GRN., GRAYWACKE?
6-I	VOLC	BASALT	V.F.-GRN.
8-A	VOLC	BASALT	F.-GRN,PORPHYRITIC,THIN MN COAT
8-B	VOLC	BASALT	F.-GRN.,PORPHYRITIC
8-C	VOLC	BASALT	F.-GRN., WEATHERED
8-D	VOLC	VOLCANICLASTIC CGL.	LITHIC (NON-VOLC.) FRAGS
8-E	VOLC	BASALT	F.-GRN.
8-F	VOLC	BASALT	APHANITIC; FRACTURED
8-G	META	QUARTZITE	YELLOW

85-8-H	25	19.10	12.30	9.90	0.69	5
85-8-I	90-93	22.25	15.60	13.40	0.75	5
85-8-J	"	18.50	14.50	11.25	0.78	5
85-8-K	"	15.25	11.60	7.90	0.73	4 F
85-9-A	12-16	29.35	10.20	6.75	0.43	4
85-9-B	"	22.15	17.10	16.00	0.82	3
85-9-C	"	15.60	9.30	5.10	0.58	4
85-9-D	"	20.40	16.90	11.90	0.78	5 F
85-9-E	40	23.20	17.90	13.20	0.76	4
85-9-F	"	8.90	8.80	5.10	0.83	2
85-9-G	54	38.80	29.60	19.10	0.72	6 F
85-9-H	58	15.15	11.40	7.60	0.72	4
85-9-I	110	22.80	10.50	9.80	0.58	2
85-9-J	"	13.70	11.50	8.20	0.79	4
85-9-K	125	49.60	44.40	14.20	0.64	2
85-10-A	18	11.05	10.10	4.00	0.69	5
85-10-B	"	9.20	6.30	3.45	0.64	2
85-12-A	198	11.80	8.15	8.05	0.78	5
85-12-B	230	17.30	15.00	7.00	0.71	6
85-12-C	240	14.70	10.70	8.40	0.75	4
85-12-D	243	13.40	7.75	5.40	0.62	3
85-12-E	247-250	56.90	45.50	41.60	0.84	6 F
85-12-F	251	20.30	20.20	13.75	0.88	6
85-12-G	255	23.45	18.20	8.90	0.67	3
85-12-H	258-259	26.50	14.20	9.80	0.58	2
85-12-I	"	15.55	15.30	11.20	0.89	1
85-12-J	"	12.75	10.40	7.00	0.77	4
85-13-A	2-5	29.00	17.80	12.00	0.63	5
85-13-B	"	20.20	9.60	6.50	0.53	5
85-13-C	"	21.60	14.30	10.90	0.69	6 F S
85-13-D	"	11.80	10.70	4.10	0.68	3
85-13-E	"	10.50	7.05	3.45	0.60	2
85-13-F	9	20.30	15.45	13.00	0.79	1
85-13-G	15	24.70	21.60	9.80	0.70	4 F
85-13-H	"	13.40	7.30	5.20	0.60	3
85-13-I	23-28	54.00	35.70	35.20	0.76	3
85-13-J	36	47.60	33.80	18.60	0.65	5 S
85-13-K	43					
85-13-L	48	18.50	18.10	13.15	0.89	5
85-13-M	"					
85-13-N	50	32.00	26.60	17.50	0.77	3
85-13-O	85	13.30	9.10	7.65	0.73	5
85-13-P	92	14.35	11.30	9.20	0.80	3
85-13-Q	"	12.95	8.95	5.10	0.65	3
85-13-R	105	28.90	21.60	8.55	0.60	1
85-13-S	"	13.05	10.60	7.00	0.76	3
85-13-T	106-107	29.60	11.05	9.20	0.49	1 F
85-13-U	"	12.70	10.35	10.00	0.86	2
85-13-V	112	28.65	20.00	10.25	0.63	5 S
85-13-W	114-116	23.55	13.20	18.60	0.76	4
85-13-X	"	16.35	9.00	6.40	0.60	5
85-13-Y	123	17.00	15.80	16.50	0.97	3

8-H	META	GREENSTONE	ANDESITIC
8-I	PLUT	GABBRO	FINE-GRN; W/OLIVINE
8-J	PLUT	GRANITE	ALTERED SOMEWHAT
8-K	SED	LITH-ARENITE	DIRTY, F.-GRN., GRAYWACKE?
9-A	META	PHYLLITE	
9-B	PLUT	GRANODIORITE	
9-C	META	SCHIST	MOSTLY MICA
9-D	VOLC	BASALT	W/PLAG. PHENOCRYSTS
9-E	META	QUARTZITE	LT.GRAY (IMPURE)
9-F	VOLC	BASALT	
9-G	META	META SUB LITH-ARENITE	DK.GRAY,ABNT MICA; FAINT LIN.
9-H	META	QUARTZITE	MED-GRAY,COARSE-GRN
9-I	META	META SUB ARKOSE	COARSE-GRN
9-J	META	QUARTZITE	MED-GRN., WHITE
9-K	PLUT	DIORITE	
10-A	VOLC	BASALT	V.F.-GRN
10-B	VOLC	BASALT	V.F.-GRN
12-A	VOLC	BASALT	
12-B	VOLC	BASALT	PORPHYRITIC
12-C	META	SCHIST	(VERY SMALL)
12-D	META	SCHIST	QTZ,FSP,MICA
12-E	META	QUARTZITE	WHITE, COARSE-GRN
12-F	PLUT	GRANITE	
12-G	META	QUARTZITE	DK. W/BANDS OF COARSE XLN QTZ
12-H	META	SUB-ARKOSE	
12-I	PLUT	GRANITE	W/ K FSP
12-J	META	PHYLLITE	
13-A	VOLC	BASALT	PORPHYRITIC
13-B	VOLC	BASALT	PORPHYRITIC
13-C	SED	LITH-ARENITE	V.F.-GRN
13-D	VOLC	BASALT	
13-E	VOLC	BASALT	
13-F	VOLC	BASALT	COARSE GRN
13-G	VOLC	BASALT	W/OLIVINE
13-H	META	QUARTZITE	
13-I	PLUT	GABBRO	WEATHERED
13-J	META	QUARTZITE	DK. GRAY-GREEN, BANDED
13-K	SED	SILTSTONE	SED CLAST?
13-L	VOLC	BASALT	
13-M	PLUT	GABBRO	
13-N	VOLC	BASALT	
13-O	META	QUARTZITE	
13-P	PLUT	DOLERITE	HYPABYSSAL
13-Q	META	SCHIST	QTZ, FSP, MICA
13-R	PLUT	SYENITE	PORPHYRITIC
13-S	VOLC	BASALT	MED-F. GRN.
13-T	META	QUARTZITE	ORANGE-PINK COLOR
13-U	VOLC	TUFF	RHYOLITIC
13-V	VOLC	BASALT	F. GRN.
13-W	META	SCHIST	MICA, FSP, QTZ; DK GRAY-BLACK
13-X	META	META SUB LITH-ARENITE	MED-DK GRAY
13-Y	PLUT	GABBRO	

85-13-Z	"	10.40	10.20	6.70	0.86	4
85-13-AA	126	18.15	13.20	7.80	0.68	1
85-13-BB	130	14.75	13.45	7.45	0.77	2
85-14-A	0	25.10	21.05	17.00	0.83	5
85-14-B	"	SM	SM	SM		
85-14-C	10	19.80	16.60	13.35	0.83	5
85-14-D	"	11.20	6.00	3.75	0.56	3
85-15-A	0	10.95	9.40	8.20	0.86	3
85-15-B	"	7.40	6.60	6.45	0.92	4
85-17-A	0	61.50	47.95	24.00	0.67	4 BR
85-17-B	"	33.50	25.95	15.05	0.70	5
85-17-C	"	19.10	18.10	10.15	0.80	1
85-17-D	"	18.70	17.70	12.70	0.86	4
85-17-E	"	24.95	16.10	10.40	0.65	4
85-17-F	"	22.50	14.80	7.25	0.60	4
85-17-G	"	17.50	16.65	12.00	0.87	2
85-17-H	"	17.00	12.20	5.10	0.60	4
85-17-I	20	16.00	15.30	12.70	0.91	4
85-17-J	"	16.00	9.00	5.10	0.56	5
85-17-K	51-54	27.90	19.70	12.50	0.68	3 F
85-17-L	"	15.85	11.40	11.20	0.80	4
85-17-M	"	20.45	12.70	11.90	0.71	2
85-17-N	62	24.75	17.00	10.25	0.66	4
85-17-O	103	22.30	18.30	8.05	0.67	3
85-17-P	"	18.50	16.55	10.40	0.80	5
85-17-Q	114	38.00	31.35	18.35	0.74	5
85-17-R	124	62.90	44.50	31.20	0.71	5 F
85-17-S	"	14.60	11.50	6.20	0.69	5
85-17-T	"	11.70	10.25	5.05	0.72	4
85-17-U	142	25.25	24.20	16.00	0.85	3
85-17-V	"	13.85	12.00	7.10	0.76	6 S
85-17-W	204					
85-17-X	205	27.95	12.20	10.00	0.54	3
85-17-Y	220-222	33.00	28.20	17.20	0.76	4
85-17-Z	"	25.05	17.85	8.25	0.62	3
85-17-AA	"	14.60	11.70	11.40	0.86	5
85-17-BB	228	30.00	22.25	9.80	0.62	5
85-17-CC	229	29.65	23.80	17.40	0.78	5
85-17-DD	245	51.00	40.45	16.40	0.63	4
85-17-EE	"	51.00	24.90	13.30	0.50	4
85-17-FF	"	17.50	12.10	7.20	0.66	4
85-17-GG	250	25.50	25.40	16.10	0.86	3
85-17-HH	254	66.75	36.55	17.85	0.53	3
85-18-A	11	41.00	29.60	19.85	0.70	5
85-18-B	1-6	16.80	14.65	4.85	0.63	2
85-18-C	"	13.40	11.90	6.15	0.74	2
85-18-D	121	15.00	12.15	3.70	0.58	3
85-20-A	5	19.30	15.80	7.75	0.69	5
85-20-B	"	13.45	9.40	4.70	0.63	3
85-20-C	10	20.95	17.00	7.30	0.66	4
85-20-D	14	18.80	16.00	11.45	0.80	5
85-20-E	22	25.60	16.70	11.10	0.66	3 S

13-Z	VOLC	BASALT	
13-AA	PLUT	TONALITE	
13-BB	VOLC	BASALT	VESICULAR, PORPHYRITIC
14-A	PLUT	GABBRO	LEUCOCRATIC
14-B	VOLC	BASALT	V. SMALL
14-C	PLUT	GRANITE	ALKALAI
14-D	META	SCHIST	MICA, QTZ.
15-A	PLUT	GRANITE	MICRO
15-B	SED	FE-MN NODULE	
17-A	META	QTZ ARENITE CGL	SLIGHTLY META
17-B	META	SUB ARKOSE	MOSTLY QTZ, SOME FSP
17-C	PLUT	GRANODIORITE	
17-D	VOLC	BASALT	THIN MN COAT
17-E	META	QUARTZITE	LT. GRAY; COARSE-GRN
17-F	META	QUARTZITE	LT. GRAY; COARSE-GRN
17-G	VOLC	BASALT	F. GRN (W/ SED CLAST ATTACHED)
17-H	VOLC	BASALT	F. GRN
17-I	VOLC	VOLCANICLASTIC CGL	
17-J	META	META SUB LITH-ARENITE	DK. GRAY; FINE-GRN
17-K	META	META SUB LITH-ARENITE	DK. GRAY; MED-GRN FE-MN COAT
17-L	PLUT	XLN QTZ	PART OF OTHER ROCK? FE-MN COAT
17-M	VOLC	BASALT	SCORIA XTLS OF PLAG, OLIV, PYX
17-N	PLUT	GRANITE	V. WEATHERED; BLK FE-MN COAT
17-O	VOLC	BASALT	V.F. GRN BLK FE-MN COAT
17-P	META	QUARTZITE	DK. GRAY, IMPURE
17-Q	META	META SUB LITH-ARENITE	
17-R	META	QUARTZITE	WHITE
17-S	VOLC	BASALT	
17-T	VOLC	BASALT	FE-MN COAT
17-U	PLUT	GRANITE	FE-MN COAT
17-V	SED	SILTSTONE	SLIGHTLY META?
17-W	META	WEATHERED SCHIST	ABUNDANT MICA, V. FRIABLE
17-X	META	SCHIST	QTZ, FSP, MICA.
17-Y	META	SCHIST	QTZ, FSP, MICA.
17-Z	SED	MUDDY SS	V. FRIABLE
17-AA	META	SCHIST	
17-BB	META	SCHIST	
17-CC	SED	MUDDY SS	
17-DD	META	SCHIST	
17-EE	META	SCHIST	
17-FF	META	SCHIST	
17-GG	META	SCHIST	
17-HH	SED	MUDDY SS	
18-A	PLUT	TONALITE	
18-B	META	PHYLLITE	
18-C	VOLC	BASALT	
18-D	META	META SUB LITH-ARENITE	FINE-GRN; MED. GRAY
20-A	PLUT	GABBRO	ALTERED; CATACLASTIC
20-B	VOLC	BASALT	
20-C	META	SCHIST	
20-D	PLUT	GRANITE	
20-E	META	QUARTZITE	

85-20-F	"	14.70	11.70	5.55	0.67	5 F S
85-20-G	"	13.60	12.40	4.85	0.69	4
85-20-H	"	11.30	10.00	8.70	0.88	6
85-20-I	"	11.55	7.60	5.45	0.68	4
85-20-J	25	15.50	10.15	4.80	0.59	4
85-20-K	32	23.30	17.90	13.80	0.77	3
85-20-L	40	30.75	22.95	20.85	0.80	6 S
85-20-M	"	20.00	14.00	8.35	0.66	5
85-20-N	"	14.45	12.25	6.20	0.71	3
85-20-O	"	12.55	8.90	5.80	0.69	3
85-26-A	0-15	14.15	8.40	8.05	0.70	5
85-26-B	"	GRAV	GRAV	GRAV		
85-26-C	20-30	11.05	8.10	2.50	0.55	5
85-26-D	"	8.50	7.65	5.00	0.81	5
85-26-E	30-40	18.50	9.45	5.45	0.53	3
85-26-F	"	15.05	12.70	6.55	0.72	4
85-26-G	"	11.90	10.40	5.45	0.74	5
85-26-H	"	GRAV	G	G		
85-26-I	32	29.15	20.40	15.35	0.72	5
85-28-A	65-69	10.05	6.10	4.10	0.63	6
85-28-B	"	8.70	8.50	5.15	0.83	4
85-28-C	"	GRAV	G	G		
85-28-D	71	16.70	13.45	8.95	0.76	3
85-29-A	14	GRAV	G	G		
85-29-B	18-20	"	"	"		
85-29-C	49	"	"	"		
85-29-D	60	22.05	21.70	12.95	0.83	1
85-29-E	"	11.10	8.20	7.70	0.80	5
85-30-A	0-3	17.00	9.45	4.70	0.54	5
85-30-B	"	11.90	7.35	4.75	0.63	4
85-30-C	"	9.75	7.55	6.00	0.78	4
85-30-D	"	11.10	9.05	5.10	0.72	3
85-30-E	"	10.35	7.55	5.45	0.73	4
85-30-F	"	GRAV	G	G		
85-30-G	5	21.60	18.25	12.50	0.79	4
85-30-H	"	8.20	5.75	5.25	0.77	5
85-30-I	10-15	15.75	10.55	8.10	0.70	4
85-30-J	"	11.90	10.10	6.40	0.77	4
85-30-K	"	GRAV	G	G		
85-30-L	15-20	10.75	7.70	5.50	0.72	5
85-30-M	"	8.60	7.60	4.40	0.77	5
85-30-N	"	GRAV	G	G		
85-31-A	11	8.95	6.55	2.90	0.62	5
85-31-B	15	13.15	10.30	5.15	0.67	3
85-31-C	45	16.30	7.55	5.10	0.53	4
85-33-A	10-15	16.90	11.30	7.05	0.65	4
85-33-B	"	14.40	12.65	9.30	0.83	2
85-33-C	"	6.25	5.05	4.10	0.81	5
85-33-D	41	11.70	9.80	6.20	0.76	5F
85-33-E	76	20.30	14.95	3.25	0.49	2
85-33-F	"	14.50	12.35	8.85	0.80	5
85-33-G	"	9.55	6.60	2.60	0.57	3

20-F	SED	SILTSTONE	
20-G	META	QUARTZITE	
20-H	VOLC	BASALT	
20-I	VOLC	BASALT	
20-J	VOLC	BASALT	
20-K	PLUT	GRANITE	
20-L	VOLC	BASALT	
20-M	META	SCHIST	
20-N	META	QUARTZITE	DK. GRAY. VEINS-WH. QTZ; F.-GRN
20-O	META	QUARTZITE	COARSE-GRN; PALE GREEN
26-A	META	SCHIST	
26-B			7 SCHIST, 1 - ?
26-C	META	SCHIST	
26-D	PLUT	DOLERITE	DK. GRAY. VEINS- CALCITE?; F.-GRN
26-E	META	SCHIST	
26-F	META	SCHIST	
26-G	META	SCHIST	
26-H	PLUT	DOLERITE	V. F.-GRN
26-I	PLUT	DOLERITE	
28-A	META	PHYLLITE	
28-B	META	SCHIST	
28-C			
28-D	META	QTZ	
29-A	META	SCHIST	
29-B			
29-C			
29-D	PLUT	DIORITE	
29-E	META	META SUB LITH-ARENITE	DK. GRAY;VEINS-WH. QTZ; M.-GRN
30-A	META	SCHIST	
30-B	META	SCHIST	
30-C	META	SCHIST	
30-D	META	SCHIST	
30-E	VOLC	BASALT	
30-F			
30-G	META	SCHIST	
30-H	META	SCHIST	
30-I	META	QTZ	
30-J	META	SCHIST	
30-K			
30-L	SED	MUDDY SS	
30-M	META	SCHIST	
30-N			
31-A	SED	SILTSTONE	SLIGHTLY META?
31-B	META	PHYLLITE	
31-C	META	SCHIST	
33-A	META	META SUB LITH-ARENITE	F.-GRN; THIN FE-MN COAT
33-B	META	QUARTZITE	
33-C	SED	SED CLAST	KNOBBY BLACK FE-MN COAT
33-D	META	SCHIST	
33-E	META	PHYLLITE	FE-MN COAT
33-F	META	QUARTZITE	W/BIOTITE STREAKS FE-MN COAT
33-G	META	QUARTZITE	FE-MN COAT

85-33-H	92-96	11.30	10.70	6.80	0.83	1
85-33-I	"	11.60	8.75	5.90	0.73	4
85-33-J	"	11.00	9.10	5.90	0.76	4
85-33-K	"	8.20	6.90	4.05	0.75	5
85-33-L	102-108	13.90	8.30	5.15	0.60	3
85-33-M	"	11.85	9.45	6.20	0.75	3
85-33-N	BASE	11.80	7.60	6.25	0.70	3
85-33-O	"	7.40	5.00	4.05	0.72	3
85-33-P	"	6.45	6.10	3.60	0.81	5
85-34-A	12	17.80	12.40	8.25	0.69	3
85-34-B	16	28.30	19.10	18.20	0.76	5
85-34-C	39	13.90	9.40	5.45	0.64	4
85-34-D	61	12.20	7.20	6.60	0.68	4
85-34-E	65	17.65	11.95	9.30	0.71	5
85-34-F	71	28.35	24.90	12.85	0.74	2
85-34-G	95-100	12.90	9.90	6.30	0.72	4
85-34-H	"	13.80	6.45	1.65	0.38	5
85-34-I	"	10.10	8.80	5.30	0.77	4
85-34-J	"	9.90	9.15	3.55	0.69	3
85-34-K	100-105	14.85	11.60	7.85	0.74	6 S
85-34-L	"	10.45	6.10	5.10	0.66	3
85-34-M	117	11.65	8.20	6.00	0.71	3
85-34-N	130	32.60	26.15	12.65	0.68	3
85-34-O	"	30.85	23.65	13.00	0.69	4
85-34-P	"	19.55	13.30	5.50	0.58	2
85-34-Q	"	15.20	13.30	8.15	0.78	3
85-34-R	138	33.90	21.20	7.75	0.52	2
85-34-S	"	10.50	8.35	7.30	0.82	3
85-34-T	169	16.15	9.85	7.25	0.65	5
85-34-U	176	15.25	12.10	5.05	0.64	4
85-34-V	179	21.45	15.60	11.25	0.73	4
85-34-W	"	12.15	11.80	7.00	0.82	5
85-34-X	214	17.75	11.70	10.10	0.72	3
85-35-A	0-3	36.10	29.05	19.30	0.75	4
85-35-B	"	17.85	13.70	9.35	0.74	3
85-35-C	"	13.50	10.50	6.55	0.72	3
85-35-D	"	36.20	22.60	15.25	0.64	5
85-35-E	"	16.00	13.25	6.85	0.71	2
85-35-F	"	14.10	10.80	5.65	0.67	3
85-35-G	4-6	41.90	26.05	13.75	0.59	6 S
85-35-H	6-9	15.35	11.50	10.45	0.80	4
85-35-I	"	13.30	7.60	7.45	0.68	4
85-35-J	"	10.50	7.85	7.30	0.80	4
85-35-K	16	44.95	35.05	16.90	0.66	5 S
85-35-L	19	18.05	11.35	7.20	0.63	6 S
85-35-M	"	14.95	9.90	7.15	0.68	4
85-35-N	"	13.65	11.60	6.70	0.75	1

33-H	PLUT	GRANITE	
33-I	META	SCHIST	
33-J	SED	MUDDY SS	V.F.-GRN
33-K	META	META SUB LITH-ARENITE	
33-L	SED	LITH-ARENITE	
33-M	META	META SUB LITH-ARENITE	
33-N	VOLC	BASALT	
33-O	SED	MUDDY SS	FE-MN COAT
33-P	SED	QTZ-ARENITE	
34-A	META	QUARTZITE	FE-MN COAT
34-B	META	META LITH-ARENITE	
34-C	PLUT	GABBRO	POSSIBLY AMPHIBOLITE (V. SMALL)
34-D	META	META SUB ARKOSE	CATACLASTIC TEXT.
34-E	META	QUARTZITE	COARSE-GRN; THIN FE-MN COAT
34-F	VOLC	BASALT	FE-MN COAT
34-G	META	META SUB LITH-ARENITE	F.-GRN; MED. GRAY FE-MN COAT
34-H	META	SLATE	
34-I	VOLC	BASALT	
34-J	SED	QTZ-ARENITE	
34-K	VOLC	BASALT	
34-L	SED	SILTSTONE	FE-MN COAT
34-M	META	META SUB LITH-ARENITE	F.-GRN; DK. GRAY
34-N	PLUT	GABBRO	W/OLIVINE
34-O	PLUT	ANORTHOSITE	
34-P	VOLC	ANDESITE	
34-Q	VOLC	BASALT	
34-R	META	QUARTZITE	
34-S	META	QUARTZITE	
34-T	VOLC	PUMICE	
34-U	VOLC	BASALT	
34-V	VOLC	BASALT	
34-W	META	SCHIST	QTZ, FSP, BIOT.-ABNT. FE-MN COAT
34-X	PLUT	GRANITE	
35-A	SED	SUB LITH-ARENITE	V. WELL INDURATED
35-B	PLUT	ANDESITE	HYDROTHERM. ALTERED
35-C	PLUT	GABBRO	
35-D	META	QUARTZITE	
35-E	META	META ARKOSE	
35-F	META	META SUB ARKOSE	V.F.-GRN
35-G	VOLC	BASALT	
35-H	META	QUARTZITE	ALMOST BLACK
35-I	META	QUARTZITE	
35-J	PLUT	GRANITE	
35-K	VOLC	BASALT	
35-L	SED	MUDDY SS	FE-CEMENT
35-M	VOLC	BASALT	
35-N	PLUT	GABBRO	MELA-GABBRO

Pebble ID	Depth (cm)	a-axis	b-axis	c-axis	sphericity	rnd
85-35-0	59	12.25	9.95	7.65	0.80	4
85-35-P	"	13.65	5.75	3.40	0.47	1
85-35-Q	78	15.55	10.40	6.25	0.65	2
85-35-R	98	31.50	20.75	15.10	0.68	5
85-35-S	114	56.65	31.80	16.80	0.55	2
85-35-T	"	21.90	14.20	10.60	0.68	5
85-35-U	120	21.50	15.05	9.40	0.67	5 F
85-35-V	"	14.35	13.50	8.50	0.82	1
85-35-W	140-141	29.20	18.85	13.80	0.67	4
85-35-X	"	18.05	15.10	9.35	0.76	2
85-35-Y	150	22.50	13.00	6.65	0.56	1
85-35-Z	180-184	17.60	15.65	10.55	0.81	5
85-35-AA	"	13.20	9.00	6.00	0.68	3
85-35-BB	"	14.75	12.45	8.50	0.79	5
85-35-CC	"	17.80	11.50	2.95	0.48	1
85-35-DD	188	23.20	16.25	9.80	0.67	1
85-35-EE	"	14.40	11.65	3.75	0.60	2
85-35-FF	192	48.70	21.85	11.65	0.48	2
85-35-GG	196	18.50	15.65	10.65	0.79	4
85-35-HH	217	17.30	9.70	4.15	0.51	1
85-35-II	219	21.50	12.45	8.75	0.62	5
85-35-JJ	225	17.45	14.20	7.95	0.72	4
85-35-KK	245	13.85	11.25	8.20	0.78	3 BR
85-35-LL	252	35.45	24.25	12.05	0.62	4
85-35-MM	281	22.30	9.20	5.85	0.48	3
85-36-A	1-2	29.10	19.40	7.90	0.57	4
85-36-B	23-24	24.85	13.20	7.20	0.54	4
85-36-C	"	19.00	15.85	9.65	0.75	2
85-36-D	30	16.80	12.35	8.90	0.73	3
85-36-E	32	21.00	18.30	8.15	0.70	4 F
85-36-F	36	43.60	33.00	23.75	0.74	5
85-36-G	43	9.80	8.05	6.20	0.80	4
85-36-H	57	15.50	15.15	7.35	0.77	4
85-36-I	71	28.55	22.70	19.25	0.81	5
85-36-J	73	50.75	39.00	34.65	0.81	3
85-36-K	79	28.10	25.70	7.90	0.64	2
85-36-L	81	24.75	16.65	12.00	0.69	4
85-36-M	87	35.80	26.65	25.30	0.81	5
85-36-N	90-100	13.10	9.30	6.30	0.70	3
85-36-O	"	13.45	8.05	5.40	0.62	4
85-36-P	"	12.05	10.20	4.70	0.69	2
85-36-Q	100-110	13.60	12.70	5.45	0.72	3
85-36-R	"	11.35	8.90	4.55	0.68	2
85-36-S	122	31.90	23.70	9.15	0.60	3
85-36-T	160-164	25.85	20.80	9.55	0.67	2
85-36-U	"	8.80	7.40	5.05	0.78	4
85-36-V	"	17.60	16.65	9.20	0.79	6 F
85-36-W	"	9.30	8.60	5.30	0.81	4
85-36-X	208	21.85	20.65	12.75	0.82	5 F
85-3-1	CC-1	25.70	16.70	11.40	0.66	5

ID	rock type	specific lithology	comments
35-O	VOLC	BASALT	
35-P	META	PHYLLITE	
35-Q	PLUT	GRANODIORITE	
35-R	META	QUARTZITE	
35-S	META	PHYLLITE	
35-T	VOLC	BASALT	
35-U	VOLC	BASALT	
35-V	VOLC	BASALT	SCORIA
35-W	META	QUARTZITE	GREEN : COARSE-GRN
35-X	PLUT	GABBRO	F.-GRN
35-Y	META	QUARTZITE	(ONLY SLIGHTLY META)
35-Z	VOLC	BASALT	
35-AA	PLUT	GRANITE	
35-BB	META	META LITH-ARENITE	
35-CC	PLUT	GABBRO	F.-GRN
35-DD	PLUT	GABBRO	
35-EE	META	PHYLLITE	
35-FF	META	SLATE	
35-GG	META	SCHIST	QTZ, FSP, BIOT, HB.
35-HH	META	SLATE	
35-II	VOLC	BASALT	
35-JJ	SED	MUDDY-SS	
35-KK	META	QUARTZITE	DK. GRAY
35-LL	META	QUARTZITE	WHITE: COARSE-GRAINED
35-MM	META	PHYLLITE	
36-A	VOLC	BASALT	
36-B	VOLC	BASALT	FE-MN COATED
36-C	PLUT	GRANODIORITE	
36-D	VOLC	BASALT	
36-E	META	META LITH-ARENITE	FE-MN COATED
36-F	META	META SUB LITH-ARENITE	
36-G	META	SCHIST	
36-H	VOLC	BASALT	FE-MN COATED
36-I	VOLC	BASALT	
36-J	VOLC	BASALT	PORPHYRITIC
36-K	META	META-SS	
36-L	META	QUARTZITE	DK. GRAY: PARTLY FE-MN COATED
36-M	SED	SUB LITH ARENITE	
36-N	META	QUARTZITE	THIN FE-MN COAT
36-O	SED	SILTSTONE	
36-P	PLUT	GRANITE	V. WEATHERED FE-MN COAT
36-Q	META	QUARTZITE	WHITE: BLACK FE-MN COAT
36-R	META		FE-MN COAT
36-S	META	SLATE	FE-MN COAT
36-T	VOLC	BASALT	
36-U	META	QUARTZITE	WHITE: COARSE-GRAIN
36-V	SED	MUDDY-SS	
36-W	META		FE-MN COATING
36-X	META	QUARTZITE	APPROX. 5% MAFICS
3-1	META	QUARTZITE	BLACK - LOTS OF BIOTITE XTLS

85-4-1	CN-1	29.20	29.05	15.40	0.81	3 BR
85-5-1	CC-1	16.70	12.80	7.30	0.69	5
85-6-1	BG-1	52.45	35.60	19.50	0.63	5 F S
85-6-2	BG-2	16.25	14.20	9.25	0.79	3
85-6-3	BG-3	23.45	16.30	10.40	0.68	2
85-6-4	BG-4	18.70	11.15	8.40	0.64	5
85-6-5	BG-5	19.35	11.30	6.80	0.59	4
85-6-6	BG-6	15.35	13.10	12.85	0.89	5
85-6-7	BG-7	16.15	15.95	10.60	0.87	4
85-6-8	BG-8	13.80	9.85	7.35	0.72	5
*	BG-8(2)	10.40	8.60	3.50	0.65	4
85-6-9	BG-9	17.20	12.60	7.20	0.67	3
85-6-10	BG-10	15.60	12.35	9.80	0.79	5
85-7-1	BG-1	31.90	23.95	20.90	0.79	4 F S
85-7-2	BG-2	23.00	21.85	11.30	0.78	1
85-8-1	BG-1	30.90	18.90	14.65	0.66	5
85-8-2	BG-2	28.80	23.90	6.70	0.58	5
85-12-1	CC-1	38.15	29.60	21.60	0.76	4
85-12-2	CC-2	27.05	21.90	19.65	0.84	4
85-13-1	CC-1	29.55	15.30	9.55	0.55	5 F S
85-13-2	CC-2	11.20	6.80	6.20	0.70	6
85-13-3	CC-3	26.00	19.80	11.60	0.70	4
85-17-1 T	TOP-1	32.50	22.40	17.70	0.72	5 F
85-17-2 T	TOP-2	36.60	30.30	17.80	0.74	3
85-17-1 B	BOTTOM-1	28.65	20.55	13.30	0.69	5
85-17-2 B	BOTTOM-2	14.80	12.10	9.30	0.80	5
85-17-3 B	BOTTOM-3	14.60	13.80	9.40	0.85	4
85-17-4 B	BOTTOM-4	13.50	9.00	7.85	0.73	5
85-17-1 CC	CC-1	27.00	24.70	13.75	0.78	5
85-18-1	CC-1	33.30	30.60	25.40	0.89	5
85-21-1 CC	CC-1	46.80	34.80	19.40	0.68	4
85-21-2 CC	CC-2	24.05	19.70	10.50	0.71	3
85-21-3 CC	CC-3	24.50	20.30	14.50	0.79	3
85-21-4 CC	CC-4	23.40	15.65	11.40	0.69	3
85-21-5 CC	CC-5	21.20	18.20	14.30	0.83	3
85-21-6 CC	CC-6	19.40	16.85	9.00	0.74	3
85-21-7 CC	CC-7	17.55	14.30	7.30	0.70	3
85-21-1 CN	CN-1	28.00	19.30	10.90	0.65	3
85-21-2 CN	CN-2	31.20	17.30	16.20	0.66	2
85-21-3 CN	CN-3	26.40	17.70	14.90	0.72	3
85-21-4 CN	CN-4	16.00	14.65	11.00	0.86	3
85-21-5 CN	CN-5	23.70	21.75	16.00	0.85	2
85-21-1 BC	BC-1	32.45	19.80	11.10	0.59	3
85-21-2 BC	BC-2	25.40	20.15	9.10	0.66	3
85-21-3 BC	BC-3	23.35	17.00	12.70	0.73	4
85-24-1	BG-1	33.00	21.00	19.40	0.72	6
85-26-1	BG-1	29.10	22.60	8.90	0.62	2
85-26-2	BG-2	35.80	20.25	14.30	0.61	5

4-1	META	SCHIST	BIOTITE
5-1	META	PHYLLITE	WEATHERED
6-1	META	QUARTZITE	BANDED PARTLY FE-MN COATED
6-2	SED	GRAYWACKE	(SLIGHTLY META?) FE-MN COAT
6-3	META	GRANITE	V. ALTER./WEATH. FE-MN COAT
6-4	META	QTZ-SS	FINE-GRN. WELL INDURATED
6-5	SED	SLATE	FE-MN COAT
6-6	META	QUARTZITE	COARSE-GRN. WHITE FE-MN COAT
6-7	META	SCHIST	MOSTLY QTZ. SOME BIOTITE
6-8	VOLC	BASALT	FE-MN COAT
6-8(2)	META	QUARTZITE	FE-MN COAT
6-9	META	SLATE	FE-MN COAT
6-10	SED	GRAYWACKE	
7-1	VOLC	BASALT	
7-2	META	QUARTZITE	BANDED
8-1	META	QUARTZITE	LIGHT GRAY
8-2	META	QUARTZITE	LIGHT GRAY
12-1	PLUT	GRANITE	
12-2	VOLC	PUMICE	FLOW TEXTURE
13-1	META	PHYLLITE	
13-2	META	PHYLLITE	
13-3	SED	GRAYWACKE	(SLIGHTLY META?)
17-1T	PLUT	GABBRO	
17-2T	PLUT	GRANITE	ENCRUSTED W/ BRYOZOA?
17-1B	META	SCHIST	QTZ. FSP. BIOTITE
17-2B	META	SCHIST	"
17-3B	META	SCHIST	"
17-4B	META	SCHIST	"
17-1CC	SED	SED CLAST	LT. COLORED. SANDY MUDSTONE
18-1	PLUT	GRANODIORITE	
21-1CC	META	SCHIST	NOTE: ALL SCHISTS FROM CORE 21
21-2CC	META	SCHIST	ARE LITHOLOGICALLY IDENTICAL
21-3CC	META	SCHIST	
21-4CC	META	SCHIST	
21-5CC	META	SCHIST	
21-6CC	META	SCHIST	
21-7CC	META	SCHIST	
21-1CN	META	SCHIST	
21-2CN	META	SCHIST	
21-3CN	META	SCHIST	
21-4CN	META	SCHIST	
21-5CN	META	SCHIST	
21-1BC	META	SCHIST	
21-2BC	META	SCHIST	
21-3BC	META	SCHIST	
24-1	META	QUARTZITE	COARSE-GRN. WHITE
26-1	VOLC	VOLCANICLASTIC CGL	
26-2	PLUT	DOLERITE	W/ BANDS OF CALCITE