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Wilkes Land Continental Margin Physiography, East Antarctica

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Abstract: An updating of the physiography and morphology of the Wilkes Land continental margin is presented. It is postulated that the evolution has been influenced more by depositional effects from the abundant supply of terrigenous material than the erosional effects of bottom currents associated with the opening of Australia and Antarctica.

Zusammenfassung: Es wird eine Auswertung der Physiographie und Morphologie des Kontinentalrandes von Wilkes-Land vorgelegt. Dabei wird angenommen, daß die Entwicklung mehr durch die Folgen der Ablagerung von reichlich angeliefertem terrigenen Material beeinflußt wurde als durch den Erosionseffekt von Bodenströmungen im Gefolge der Trennung von Australien und der Antarktis.

INTRODUCTION

The production of a series of new bathymetric maps of the seas around Antarctica has been in progress since 1974 (VANNEY & JOHNSON, 1976 a, b, c; VANNEY & JOHNSON, 1979, in press; VANNEY, FALCONER & JOHNSON, 1979; JOHNSON, VANNEY & HAYES, 1979). New data obtained on the ELTANIN cruises (34, 36, 37, 38, 46 and 50) and in the DSDP boreholes (HAYES, FRAKES et al., 1975) have enabled us to reinterpret the submarine geomorphology off Wilkes Land (Fig. 1). By convention, Wilkes Land

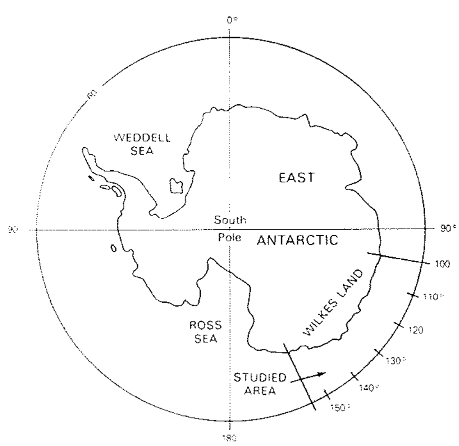

Fig. 1: Index map.
Abb. 1: Lageplan.

refers to the sector of East Antarctica lying directly south of Australia, and extending from the western limit of Ross Sea at 155° E (VANLEY, FALCONER & JOHNSON, 1979) to 100° E. The first map of this area was the Monaco sheet B'III (International Hydrographic Bureau, third edition, 1954). On the basis of the OB cruises between the Mirny Antarctic Observatory and Balleny Islands during the IGY (LISITZIN & ZHIVAGO,

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1959), the Soviets compiled a more accurate map series for the Indian Ocean Atlas (ANONYMOUS, 1975; ZHIVAGO et al., 1975). By incorporating the ELTANIN soundings HAYES & CONOLLY (1972) were able to compile the first accurate chart of the region from 110° to 168°, as a part of their "Bathymetry of the Southeast Indian Ocean" (1971). The new bathymetric and physiographic charts presented and explained in this paper (Fig. 2) have been constructed from all available sounding data; namely, the Soviet data supplied by the Oceanographic Data Center of Washington, the soundings compiled for the General Bathymetric Chart of the Oceans (GEBCO) by the Australian Hydrographic Office, the plotting sheets of the Defense Mapping Agency, and the French hydrographic surveys off Terre Adélie (VANNEY & JOHNSON, 1979). The final contouring in corrected meters varies little from the HAYES & CONOLLY (1972) chart. Fig. 3 presents the major physiographic provinces as deduced from the Fig. 2. We also used the studies of GRINNEL (1971) and VOLOKITINA (1975) for the areas from 125° to 150° E and W of 144° E.

WILKES LAND COAST AND CONTINENTAL SHELF

This region which lies between 65 and 67° S corresponds to the area of Antarctica alternatively occupied and vacated by the ice sheet during the Cenozoic glacial pulsations. The shelf width ranges from 35 km near Cape Poinsett to 150 km off Terre Adélie (VANNEY & JOHNSON, 1979) and Knox Coast. East of 145° E (George V Coast) the width is over 300 km and is part of the Ross Sea continental shelf (VANNEY, FALCONER & JOHNSON, 1979). Since the glacial maximum when the ice front was near the shelf edge (VORONOV, 1960), the retreat of the ice has exposed but few rock outcrops in localized areas, such as the low nunataks and many low islands flanking Terre Adélie (VANNEY & JOHNSON, 1979) (Fig. 4). Geology of the coastal areas has been described by STILLWELL (1917), BELLAIR (1961), BELLAIR & DELBOS (1963), HEURTEBIZE (1952), CRADDOCK (1972) for Terre Adélie and Budd Coast (CAMERON, 1963); petrographic data have been summarized by McLEOD & GREGORY (1967) and CRADDOCK (1970). The scattered and resistant rocks have been only very recently exposed as evidence for smoothing or planation by marine agents is absent (ZHIVAGO & EVTEEV, 1970). Locally, these rocks and low islands, which are somewhat similar to the Norwegian strandflat, supply a base for iceberg tongues (Dalton, Dibble ice tongues), minor ice shelves (Voyeykov, Shackleton ice shelves), and the multi-year shore ice defined in this area by KOZLOVSKY (1976) as an intermediate stage of the ice shelves. The narrow rocky coastal belt near the present day sea level is terminated abruptly seaward by a belt having complex, dissected relief in which rocky ridges are interposed between troughs. Along the inner continental shelf depressions form deep basins with depths up to 1,500—2,000 m. The major depressions are, E to W: 1) George V Coast, a composite deep with depths up to 1591 m (ZHIVAGO, 1961; ZHIVAGO & EVTEEV, 1970); 2) seaward of Terre Adélie, the Dumont d'Urville basin (1191 m; VANNEY & JOHNSON, 1979); 3) Clarie and Banzare Coasts, a basin of 1,400 m depth; 4) Budd and Knox coasts, Vincennes Basin (GRINNELL, 1971). These mid-shelf basins over 50 km in width have sheer slopes in places and their bottom is characterized by a fairly rugged topography and partitioning by a series of blocky ridges (as soon showed by LISITZIN & ZHIVAGO, 1959). ZHIVAGO (1961) has suggested that these basins, form a continuous string extending more than 3,000 km from Victoria Land to the Davis Sea. In our opinion the depressions are probably en échelon with a NW—SE orientation, and lie parallel to the shelf edge. HOLTEDAHL (1970) and JOHNSON et al. (1975), interpreted the longitudinal channels in continental margins in the northern hemisphere as the boundary between the crystalline high velocity Paleozoic and Pre-Cambrian rocks and low velocity

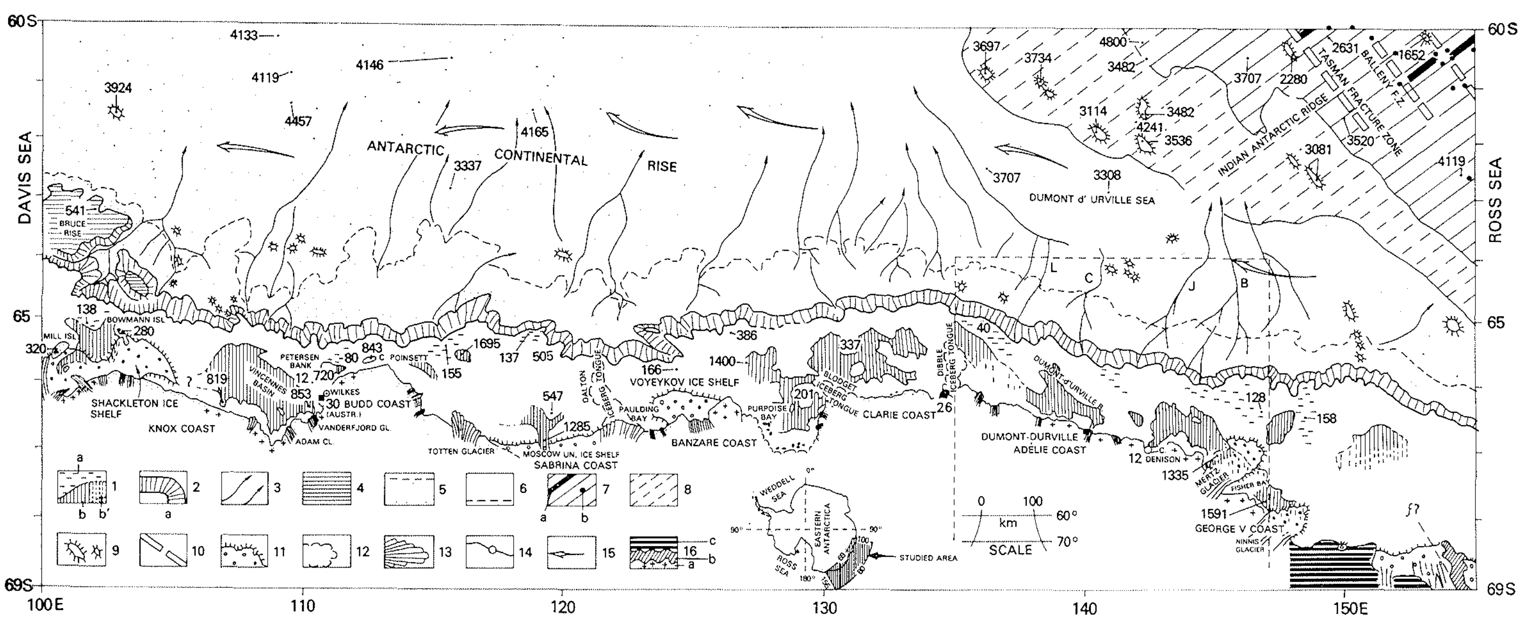

Fig. 3: Physiographic map of Wilkes Land continental margin.
1 = Continental shelf: border bank (a), shelf channel (b), inferred channel (b'). 2 = Upper slope. 3 = Submarine canyon. 4 = Marginal plateau. 5 = Lower slope with benches. 6 = Continental rise. 7 = Oceanic ridge: axis (a) epicenter (b). 8 = Lower flank of oceanic ridge. 9 = Seamount and isolated mountain. 10 = Fracture Zone. 11 = Ice shelf. 12 = Iceberg tongue. 13 = Glacial outlet. 14 = Site of raised beach with elevation in m. 15 = Antarctic bottom current. 16 = Continental geology: Igneous and metamorphic rocks (a) of the basement complex (East Antarctic shield); Upper Precambrian of Transantarctic mountains (Ross orogen) (b); Sedimentary and metamorphic rocks of the Beacon Group (c). From GRADDOCK, 1970.

Abb. 3: Physiographische Karte des Kontinnetalrandes von Wilkes-Land.
1 = Kontinentaler Schelf: Uferwall (a), Schelf-Kanal (b), vermuteter Kanal (b'). 2 = Oberer Hang. 3 = Submarines Canyon. 4 = Rand-Plateau. 5 = Unterer Hang mit Untiefen. 6 = Kontinental-Hang. 7 = Ozean-Rücken: Achse (a), Epizentrum (b) 8 = Untere Flanke des Ozean-Rückens. 9 = Seamount und Einzelberg. 10 = Bruchzone. 11 = Eisschelf. 12 = Eisberg-Zunge. 13 = Gletschertor. 14 = Lage gehobener Strandterrassen mit Höhenangabe in m. 15 = Antarktische Bodenströmung. 16 = Festlands-Geologie: magmatische und metamorphe Gesteine (a) des Grundgebirgs-Komplexes (Ostantarktischer Schild); oberes Präkambrium des Transantarktischen Gebirges (Ross-Orogen) (b); Sedimente und Metamorphite der Beacon-Gruppe (c). Aus CRADDOCK 1970.

Mesozoic rocks deposited in epicontinental basins at the initiation of continental drift. This hypothesis may also apply to Antarctica, where the sea bed seaward of the longitudinal channels consists of Tertiary sequences deposited when this section of Gondwanaland was undergoing initial rifting. The longitudinal channels are thought to be Tertiary antithetic fault traces subsequently scoured, deepened, and enlarged by glacial action. Abundant rectilinear, short, trough-like valleys are present perpendicular to the longitudinal channels. These so-called "transverse channels" are over-deepened. In the Vincennes basin, the Vanderford glacier (Fig. 3) ends abruptly in a basin of over 2,000 m (2287 m) in depth (CAMERON, 1965). Next to Moscow University Ice Barrier a trough at 1,285 m is present. A similar pattern exists off Terre-Adélie with the Géodésie Channel (Fig. 5), Astrolable Basin, Port Martin and Denison Channels (VANNEY & JOHNSON, 1979).

It is logical to think that the basins and channels extend under the ice shelves and ice sheets. Because the traverse sounding tracks are too greatly separated to permit positive interpolation, one does not know the subglacial topography with sufficient accuracy to determine the exact relations between preglacial and submarine relief. However, we can note that the moderately rugged subglacial floor lies just above sea level (IMBERT, 1953, 1959; BENTLEY, 1964; STEED & DREWRY, 1977) and that two basins lie at the eastern (Wilkes basin between 135—150° E) and western regions (95—120°), with very rugged relief and steep sided blocks bordering the coastal belt. Thus, the Vincennes basin seems to be a probable continuation of the deep valleys found in the Wilkes subglacial basin which apparently is connected to the George V Basin by the Ninnis and Mertz glacier system (WEINHAUPT, 1961).

Outside of the rocky zone, the remnant part of the shelf is occupied by a series of banks similar to the undulating plains described in the Soviet literature (ZHIVAGO, 1961; LISITZIN & ZHIVAGO, 1958, 1960; ZHIVAGO & EVTEEV, 1970). The depth of these border banks ranges from 200 to 500 m, but small shallower areas are known (Fig. 3): 128 and 158 m off George V Basin, the Adélie Knolls 78 m, 40 m at the NW termination of Dumont d'Urville Basin (VANNEY & JOHNSON, 1979); West of 130° E, a number of banks are present: 166 m (Banzare Coast), 137 and 155 m (Sabrina Coast), 80 m (Budd Coast), 138 m (Knox Coast). Seaward of Wilkes Station is the Petersen Bank (12 m), and along the edge of the Shackleton Ice shelf the Mill and Bowmann Islands, which are entirely formed of ice and are respectively 320 and 280 m high.

Sediment cores from these banks between 95° and 135° E reveal the presence of a thick glacial marine cover containing coarser debris (more than 100 gr/m^3 of 1 mm and larger diameter; LISITZIN, 1958, 1960). Seismic and echo-sounding data suggest a depositional origin of the banks. They are apparently morainal ridges accumulated along the border of the icesheet, or under the base of the ice shelves, augmented by recent "iceberg sediments" poorly sorted in size. The ELTANIN cores for example from the outer banks (core 37—6 at 199 m) contain a high percentage of rock fragments (PAYNE & CONOLLY, 1972). The fact that the unusually deep basins and channels lie seaward of the ice tongue and glaciers is indicative of their glacial origin. Undoubtedly, all the median and inner shelf depressions were heavily carved by the main outlet glaciers and melt water erosion. However, their straight and sharp contours, their longitudinal trend, and their relation with the subglacial relief suggest block faulting. ZHIVAGO (1961) ascribes their formation to a peripheral faulting caused by changing in ice load on the continent. In this respect, the outer shelf could represent the true constructive shelf developed during the phases of ice sheet maximum, and the rocky and hill rocky zone would be interpreted as the erosional shelf repeatedly dislocated and denuded during the retreat and advance phases. If the recent vertical movements are accepted, as evidenced by the upheaval of

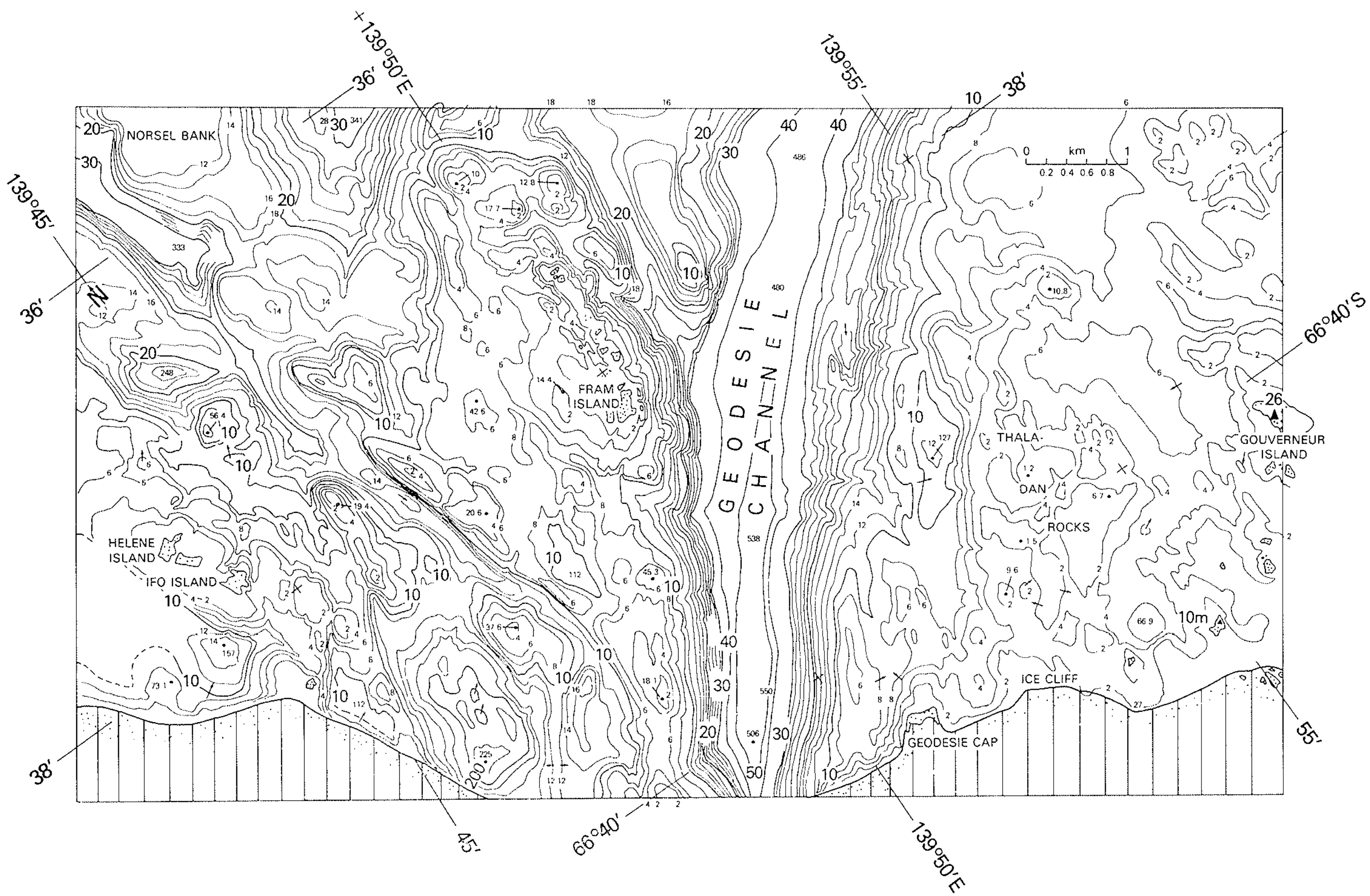

Fig. 4: Bathymetry of the Geodesie Channel sector of the Terre Adélie. Vertical lines: glaciated mainland and ice cliff. Drawn from French hydrographic survey at 1/20,000. From VANNEY & JOHNSON, 1978, in press.

Abb. 4: Bathymetrie des Geodesie-Kanal-Sektors des Adelie-Landes. Senkrechtschraffur: vergletschertes Festland und Eis-Kliff. Gezeichnet nach der französischen hydrographischen Kartierung 1:20.000. Aus VANNEY & JOHNSON 1978, im Druck.

coastal blocks as indicated on the Budd Coast (VORONOV & KOROTKEVITCH, 1962) and the raised beaches (NICHOLS, 1970) (Fig. 3), it is also evident that the subglacial and submarine relief are related to extensional stresses of the margin during the Australian-Antarctica rifting.

WILKES SLOPE, RISE AND ADJACENT PROVINCE

The continental slope is very steep, especially landward (where the average gradient is about 70 m/km) a feature characteristic of other parts of Antarctica. The lower slope has a gentler gradient averaging 15 m/km, with minor irregularities and breaks in slope (ZHIVAGO & LISITZIN, 1957; LISITZIN & ZHIVAGO, 1959). In the west, seaward of Shackleton ice shelf is a massive marginal plateau, the Bruce Rise. This plateau is located on the continental rise (at 4,000 m depth) and is separated from the Antarctic continental shelf by a steep scarp cut by numerous channels. The surface of the rise, which lies at a depth of 600 to 1200 m, is gently undulating. Elsewhere on the shelf off Wilkes Land, there are benches of minor dimensions, in form of elongated plateaus stretched out between the canyons, i. e. off Banzare Coast and Terre Adélie (VANNEY & JOHNSON, 1979). These tabular like features do not form prominent banks as the old erroneous records suggested. For example, the Umitaka Maru sounding lines in 1964—1965 (OZAWA, 1965) disproved the existence of Verik (65 m) and other postulated nearby shoals. The origin of the plateau and benches is very intriguing. Perhaps they are the bathymetric expression of slippage and tilting of continental blocks or lava outcrops. However their relation with the extensional movements related to the Antarctic-Australian breakup is considered as highly probable. The submarine canyons are relatively numerous and the best characterized are present off Terre Adélie where they were labelled Buffon, Jussieu, Cuvier and Lamarck Canyons (VANNEY & JOHNSON, 1979, Fig. 4). The thinning of the recent sediment cover and the rugged topography shown by the seismic profiles published by HOUTZ & MARKL (1972) is evidence for recent active erosion in the submarine canyons. The "nickpoint" between the lower slope and continental rise is often difficult to discern and appears to be masked by recent deposits or mass movements. The boundary selected on Fig. 3 corresponds to a general smoothing of the topography below 4,000 m. The average gradient is less than 2.5 m/km off Clarie Coast and 1.3 m/km farther west. The continental rise is not smooth, on the contrary it is characterized by little "mesas". Because of these irregularities and low general gradient it is difficult to define abyssal plain boundaries. The contact with the Wilkes (South Indian) abyssal plain is therefore only approximate as suggested by the maps of HAYES & CONOLLY (1972) and HEEZEN et al. (1973). The rise north Dumont d'Urville Sea is more irregular and punctuated by seamounts which range from 3,500 m to 3,700 m in depth (Fig. 3). It is likely that the peaks correspond to the unburied summits of the Indian-Antarctic Ridge flank province. They seem clustered along the southern termination of the topographic lineaments known farther north and associated with the set of fracture zones named George V, St. Vincent and Gambier by HAYES & CONOLLY (1972).

The oceanic ridge occupies the NE corner of the studied area. Ship tracks are few in this area. The oceanic ridge appears to be a broad arch (culminating at 1,652 m), with short and roughly parallel topography trending NNW (Fig. 3). This elongate relief is the normal prolongation of the ridge trends described in the Indian-Australian Basin (HAYES & CONOLLY, 1972) and N of Ross Sea (VANNEY, FALCONER & JOHNSON, 1979). In this sector, large rocky sectors were observed, and the sea bottom photographs taken during the ELTANIN cruises reveal that manganese nodules are common.

The Wilkes slope exhibits the transition from the detrital glacial marine deposits to calcareous clay and sandy silt, then the siliceous (diatomeous) ooze, which is dominant on the rise. Finally, the glacial stone percentage decreases to several kg/m^3 in the surficial sediments (ZHIVAGO & LISITZIN, 1957; LISITZIN & ZHIVAGO, 1958). Several piston cores sampled during the ELTANIN cruises were investigated by PAYNE & CONOLLY (1972) and KENNETT & WATKINS (1975, 1976), WATKINS & KENNETT (1972, 1977). The cores taken on the slope show clay with laminated silt and sand overlying on poorly sorted muddy sand with many erratic pebbles. A few cores show evidence of scouring action in the canyons. The deeper cores of the rise contain graded sandy and silty clay turbidites with sand layers and silt laminae. For the recent sedimentary events, a conspicuous difference exists between the Indian-Australian Ridge which underwent erosion (absence of Brunhes period sediments) and the Wilkes Land continental margin where the bottom current effects have been absent. Similar observations can be made for the geologic evolution (Fig. 5). The sedimentary body of the continental rise, which is up to 2 km thick in places as revealed by seismic profiles made by HOUTZ & MARK (1972), was drilled during the Leg 28 of DSDP at the sites 267 (slightly north of 60° S), 268 (upper limit of the western rise) and 269 (contact rise and Ridge). Detailed analysis of the drilling and interpretation were given by HAYES & FRAKES (1975), PIPER & BRISCO (1975), BARRETT (1975), and only a brief summary is given here. Underlying a widespread Plio-Pleistocene cover about 100 m thick, the main sedimentary sequence consists of 180 m (267 B), 200 m (268), and over 800 m (269) of Miocene deposits. The Late Obligocene, reached at 268 and 269 sites, is absent at 267 because of the intervention of the only important disconformity of the region owing to a local erosion phase. Thus, the Oligocene unconformity known in the Ross Sea (example: site 274, HAYES, FRAKES et al., 1975) and Kerguelen area seems absent for the main part of the Wilkes Land continental margin, except the local occurrence at site 267. Most of the deposits since the Miocene are silty clay turbidites with laminae produced by contour currents.

The oceanic basalt basement, recovered under the thin pelagic Eocene at 267 B, was too weathered to be dated by radiometric methods. However, after the geophysical interpretation of WEISSEL & HAYES (1972), WEISSEL et al. (1977), the oceanic basement would be between 50 and 40 m. y. in age. These data suggest that the tectonic structure of the margin is contemporaneous with the Antarctic-Australian breakup. But the development of the margin was not only controlled by the structural evolution. Proportionally as the Southeast Indian Ridge axis spread the continents apart the margin was also influenced by the climatic deterioration. This assertion is substantiated by the fact that the early temperate water sediments of the continental rise were buried under a bulky upbuilding when the Antarctic inland ice passed over the coastal blocks and reached the sea level during Early-Middle Miocene (22—10 m. y.) to Pliocene (HAYES & FRAKES, 1975). The evidence for cold water deposition and terrigenous input conditions is evidenced by the northward progression of ice-rafted debris first appearing in the Early Miocene at site (268) and Middle Miocene at site (267) (PIPER & BRISCO, 1975; HAYES & FRAKES, 1975) (Fig. 5). Because of the role of the Antarctic-Australian separation in the eastward spreading of circum-Antarctic current, and the sudden introduction of a glacial environment the lack of unconformities created by the influx bottom Antarctic water seems peculiar. This suggests that the substantial increase in deep water adjacent to the ice sheet and shelf minimized the effect of bottom currents on the Wilkes Land margin morphology. This is not necessarily because of currents were not sufficient in velocity, but rather due to large supply of sedimentary detritus. It seems therefore that the turbidity currents and sedimentary transfer northward have been more important.

We suggest the following explanations: (1) the narrowness of the passage between the

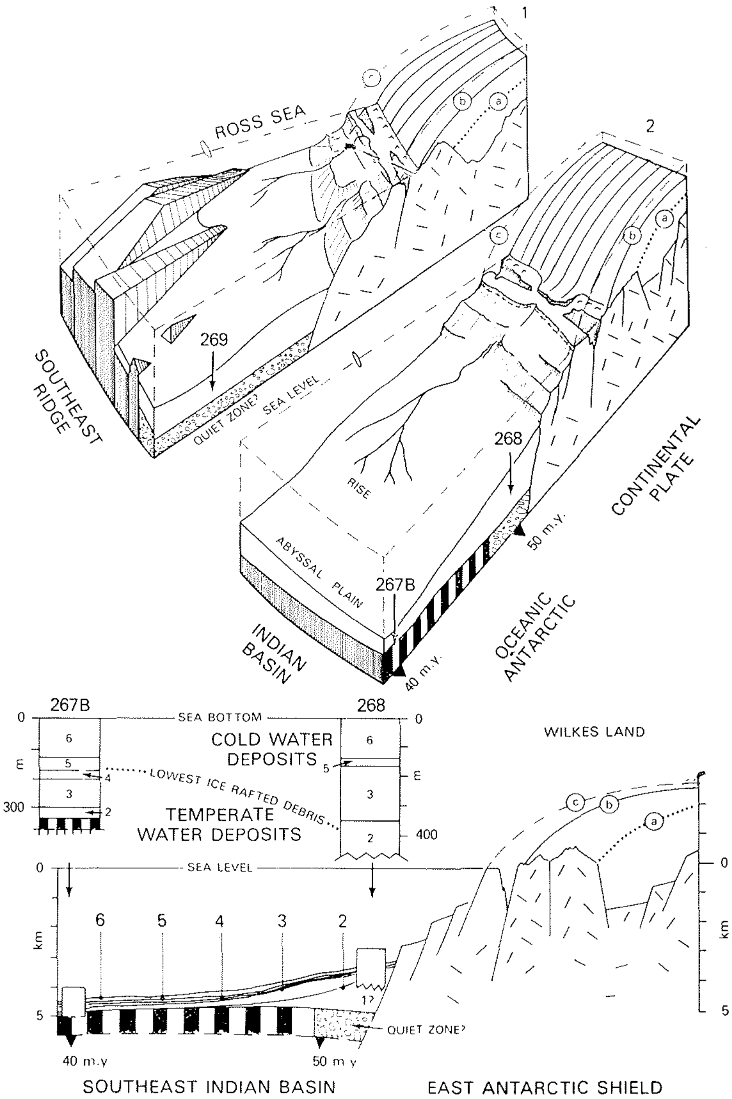

Fig. 5: Structural schematic interpretation — Dashed lines: detailed map in VANNEY & JOHNSON, 1978 (in press) of Wilkes continental margin.

Upper: Diagrammatic perspective view. Glaciated systems of Terre Adélie (1) and Wilkes Land (2). Inland ice progression: glacial inception in Pre-Miocene period (a); Miocene to present advance (b); Supposed maximal extension (c).

Lower: Interpretative section from Leg 28 data. Stratigraphic record: Late Eocene (1), Late Oligocene (2), Early Miocene (3), Middle Miocene (4), Late Miocene (5), Plio-Pleistocene (6). Interpretation from HAYES & FRAKES (1975), PIPER & BRISCO (1975), BARRETT (1975).

Abb. 5: Schematische Deutung der Strukturen. Gestrichelt: Detail-Karte des Kontinentalrandes von Wilkes-Land (in VANNEY & JOHNSON 1978, im Druck).

Oben: Perspektivisches Diagramm. Vergletscherung von Adelie-Land (1) und Wilkes-Land (2). Vorrükken des Inland-Eises: Beginn der Vergletscherung in vormiozäner Zeit (a); Vorrücken vom Miozän bis heute (b); vermutete maximale Ausdehnung (c).

Unten: Mutmaßliches Schichtprofil nach Daten von Leg 28. Stratigraphische Folge: Ober-Eozän (1), Ober-Oligozän (2), Unter-Miozän (3), Mittel-Miozän (4), Ober-Miozän (5), Plio-Pleistozän (6). Interpretation nach HAYES & FRAKES (1975), PIPER & BRISCO (1975), BARRETT (1975).

Oceanic Ridge and the margin north of Victoria Land was an obstacle to the westward expansion of the Pacific and Ross Sea bottom water; (2) the deep depressions of the Wilkes shelf were, as now, sites propitious for the formation and trapping of dense water (GORDON & TCHERNIA, 1972). This water apparently escaped on occasion by overflow over the border banks, and thus, was able to carry away a great load of debris and to trigger mass movements, slides and turbidity currents.

Specifically of the Wilkes Land continental margin evolution is very similar to those of the floor of Amazon, where the bottom currents have been unimportant in shaping the rise (DAMUTH, 1975). The contrasting geomorphic processes of the circum-Antarctic sea floor demonstrate that the current contour model is operative only for a portion of a continental margin poorly supplied by gravity-controlled and mass movement processes.

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