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Processes of Modern Sedimentation in the Southern Weddell Sea, Antarctica - Evidence from Surface Sediments

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Abstract: Seventy surface sediment samples from the continental shelf and slope of the southern Weddell Sea have been analysed for grain-size distributions, chemical composition, mineral assemblages in the clay fraction, biogenic and terrigenous components in the coarse fraction, and stable isotope ratios in planktonic foraminifera. New information is presented on modern sedimentary processes and their dependence on the present-day physiographical, glaciological and hydrographical setting. The circulation of the water masses as reflected in the surface sediments differs in detail from that known from *in situ* measurements.

Regional differences in both the biogenic production and the preservation of biogenic components are controlled by the physical and chemical properties of the water masses rather than by differences in the sea-ice coverage or in water depth. The terrigenous sediment supply to the ocean is dominated by ice-rafted debris eroded on the Antarctic continent. The debris from different source areas is characterized by individual petrological and textural compositions. After the release of this debris into the water column, marine currents cause differential lateral transport of grain-size fractions. Resuspension from surface sediments probably plays a major role in sediment redeposition, whilst iceberg ploughing, grounding-line advances, and gravitational transport presently are negligible.

Kurzfassung: An siebzig Oberflächenproben vom Kontinentalschelf und -hang des südlichen Weddellmeeres wurden die Korngrößenverteilung, die chemische Zusammensetzung, die Mineralverteilung in der Tonfraktion, die biogene und terrigene Zusammensetzung der Grobfraktion und die Verhältnisse der stabilen Isotope in planktonischen Foraminiferen bestimmt. Die Verteilungsmuster der Sedimentparameter liefern neue Erkenntnisse zu den heutigen Sedimentationsprozessen und ihre Abhängigkeit von den physiographischen, glaziologischen und hydrographischen Gegebenheiten. Die Zirkulation der Wassermassen, wie sie in den Oberflächensedimenten abgebildet ist, unterscheidet sich im Detail von der aus *in situ* Messungen abgeleiteten Zirkulation.

Regionale Unterschiede in der biogenen Produktion und in der Überlieferung biogener Komponenten werden eher durch die physikalischen und chemischen Eigenschaften der Wassermassen als durch Unterschiede in der Meereisbedekkung oder in der Wassertiefe gesteuert. Der terrigene Sedimenteintrag in den Ozean erfolgt hauptsächlich durch Material, das auf dem antarktischen Kontinent durch Eis erodiert und transportiert wird. Dabei ist das Eisfrachtsediment aus unterschiedlichen Liefergebieten durch individuelle petrologische und texturelle Zusammensetzungen charakterisiert. Nach der Freisetzung des Eisfrachtsedimentes in die Wassersäule führen Meeresströmungen zum lateralen Transport von ausgewählten Korngrößenfraktionen. Bei der Umlagerung von Oberflächensedimenten spielt wahrscheinlich Resuspension eine wesentliche Rolle, wogegen Grundberührungen von Eisbergen, Vorschreiten der Grundlinie des Eises sowie gravitativer Sedimenttransport heute vernachlässigbar sind.

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INTRODUCTION

Sedimentological analyses on undisturbed surface sediments are important techniques for the study of modern sediment formation. In high latitudes they may be used to assess the effects of glaciology, bathymetry, and hydrography on the sedimentary processes.

Because surface sediment samples from the uppermost 0.5 to 1.0 cm in the southern Weddell Sea span up to several centuries (MELLES 1991), they document a long-term mean of the environmental conditions. Hence, they may provide information complementary to *in situ* measurements, which in Antarctica have been carried out for only a few years, have often been restricted to the short austral summer season, and over large areas still have extensive gaps.

The first sampling of bottom sediments was carried out in the southern Weddell Sea during the 1914-1917 drift of „Endurance" (WORDIE 1921). Thereafter, no sediment samples were taken before the Deep-Freeze II expedition in 1957 (REX et al. 1970), followed by the Argentine Antarctic Expedition of 1964/65 (ANGINO & ANDREWS 1968), the International Weddell Sea Oceanographic Expeditions (IWSOE) 1968, 1969, and 1970 (ANDERSON 1975a), and the Norwegian Antarctic Research Expeditions (NARE) in 1976/77, 1978/79, 1984/85, and 1992/93 (ELVERHØI & MAISEY 1983, SOLHEIM & KRISTOFFERSEN 1985). A few samples from the Deep-Freeze II and Argentine expeditions were recovered with grab sampler. Subsequent expeditions used phleger, piston, gravity, or vibro corers to obtain long sediment sequences and dredges to get information on the coarse-grained sediment components from near the surface. Interpretations of grain-size and foraminiferal distributions supplied the first information concerning the general composition of surface sediments and modern sedimentary processes in the southern Weddell Sea (ANDERSON 1975a, ANDERSON et al. 1983).

Comprehensive sampling of undisturbed surface sediments started in the southern Weddell Sea in 1983 during the German Antarctic Expedition ANT-I using large box corers, multi-box corers and van Veen grabs. Until 1988 (ANT-VI), altogether 70 surface samples were obtained between 30° and 47° W, quite regularly distributed and covering wide areas of the continental shelf and slope (Figs. 1 and 2). Based on this material, pre-

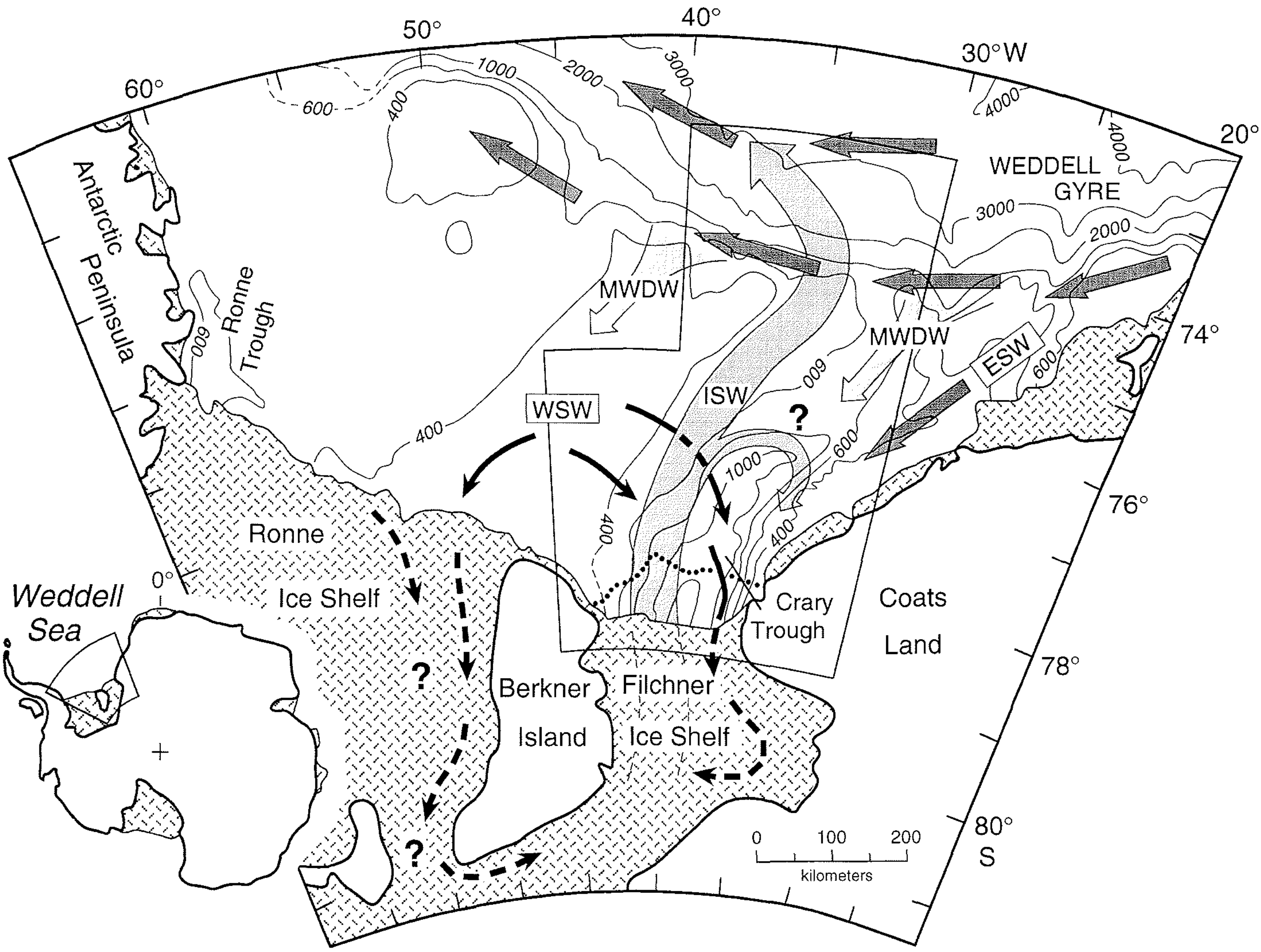

Fig. 1: Physiographic map of the southern Weddell Sea showing the study area and schematically the circulation pattern of the Weddell Gyre and of the major shelf water masses (*MWDW* = Modified Weddell Deep Water, *ESW* = Eastern Shelf Water, *WSW* = Western Shelf Water, *ISW* = Ice Shelf Water). Bathymetric contours (after JOHNSON et al. 1981) are in meters. The dotted line indicates the position of the Filchner Ice Shelf edge prior to a calving event in austral winter 1986.

Abb. 1: Die physiographische Karte des südlichen Weddellmeeres zeigt die Lage des Untersuchungsgebietes und schematisch das Zirkulationsmuster des Weddellwirbels und der wichtigsten Wassermassen auf dem Kontinentalschelf (*MWDW* = Modifiziertes Weddellmeer-Tiefenwasser, *ESW* = Östliches Schelfwasser, *WSW* = Westliches Schelfwasser, *ISW* = Eisschelfwasser). Tiefenlinien (nach JOHNSON et al. 1981) in Meter. Die gepunktete Linie markiert den Verlauf der Filchner-Schelfeiskante bis zu einem Kalbungsereignis im Südwinter 1986.

liminary grain-size analyses (FÜTTERER & MELLES 1990, MELLES & KUHN 1993), the distribution of opal and organic carbon in the bulk sediment (SCHLÜTER 1990), and the distribution of kaolinite and illite in the clay fraction (EHRMANN et al. 1992) were discussed with respect to the Recent glaciological and hydrographical setting.

This study analyses the grain-size distribution and chemical composition of the bulk surface sediment, the mineral assemblage in the clay fraction, the biogenic and terrigenous composition of the coarse fraction, and the stable isotope ratios in planktonic foraminifera with the aims of determining Recent sedimentary processes active in the southern Weddell Sea, and of resolving their dependence on the physiographical, glaciological and hydrographical conditions. For that purpose the distribution patterns of the sediment parameters are compared with the present-day environmental setting.

ENVIRONMENTAL SETTING

Physiographic conditions

The Antarctic continental shelf differs from other continental shelves mainly in having a greater water depth, a general slope towards the continent, and a rough topography. The mean water depth on the continental shelf of the Weddell Sea is about 450 m. The shelf edge corresponds approximately to the 600 m depth contour (Fig. 1).

In the southern Weddell Sea, two northward trending shelf depressions, the Ronne and Crary Troughs, separate relatively shallow (<400 m) shelf areas north of the Berkner Island ice rise from the Antarctic Peninsula in the west and Coats Land in the east (Fig. 1). The Crary Trough shows an asymmetric profile with a gentle western flank (0.3°) opposing a steeper eastern

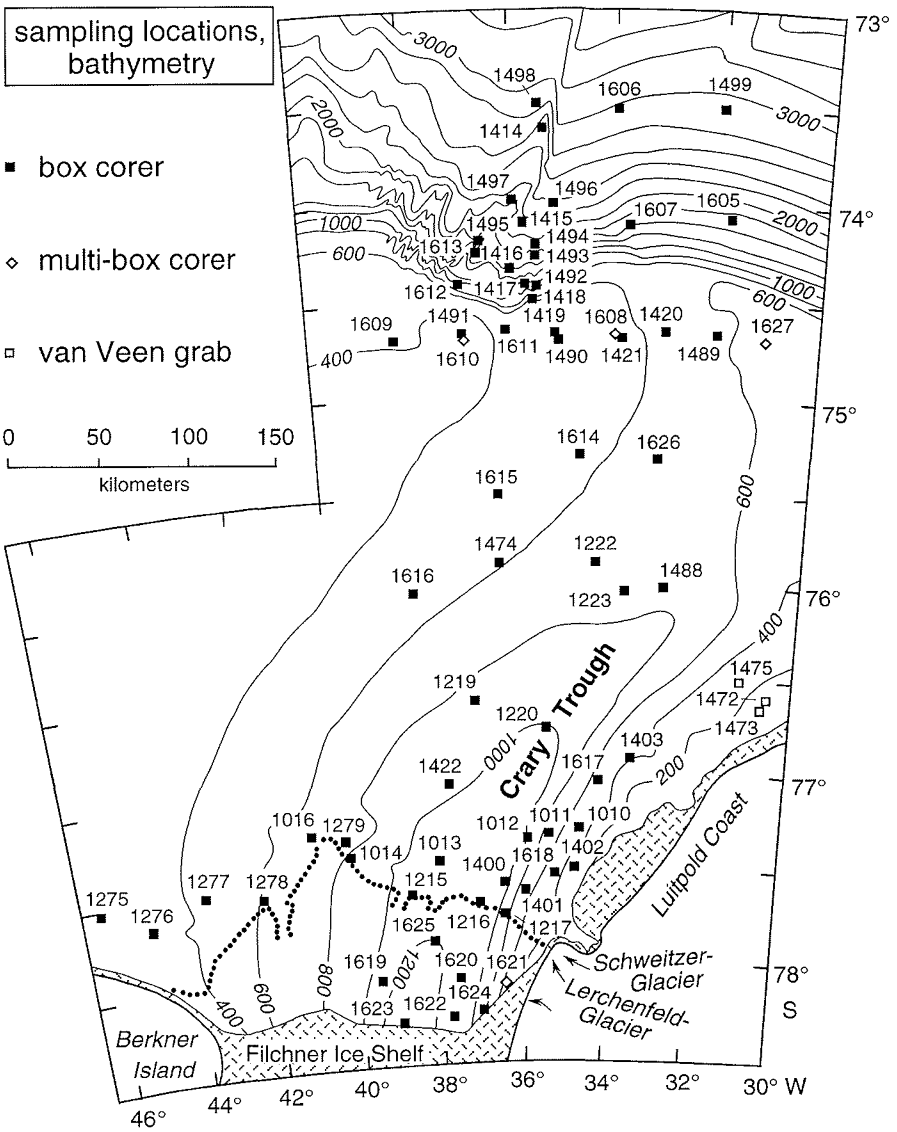

Fig. 2: Sampling locations and bathymetry (depth contours in meters) in the area studied. The bathymetric map is based on echo-sounding data of R.V. „Polarstern" cruises ANT-I to ANT-IV (1983-1988), supplemented on the western continental slope by data of Y. Kristoffersen (Oslo). The dotted line indicates the position of the Filchner Ice Shelf edge prior to a calving event in austral winter 1986.

Abb. 2: Probennahmestationen und Bathymetrie (Tiefenlinien in Meter) im Untersuchungsgebiet. Die bathymetrische Karte basiert auf Echolotdaten der FS „Polarstern"-Fahrten ANT-I bis ANT-IV (1983-1988), am westlichen Kontinentalhang ergänzt durch Daten von Y. Kristoffersen (Oslo). Die gepunktete Linie zeigt den Verlauf der Filchner-Schelfeiskante bis zu einem Kalbungsereignis im Südwinter 1986.

flank (1.1°); maximum water depths are about 1200 m at the actual Filchner Ice Shelf edge (Fig. 1). The trough continues south beneath the ice for more than 600 km reaching water depths of more than 1400 m (Jankowski & Drewry 1981, Robin et al. 1983, Vaughan et al. 1995). The sill at the shelf edge, which forms the transition between the Crary Trough and the Weddell Basin, shows water depths of ca. 600 m and a seaward convex extension in the continuation of the trough axis (Fig. 2).

The upper continental slope down to a water depth of about 2500 m is markedly steeper (1.6°) than the lower slope (0.7°). Between 36° W and 34° W, an asymmetrical channel extends downslope to the north (Fig. 2). Its steep, 200 to 400 m high western flank marks the change between rugged terrain with northward trending ridges and troughs to the west, and smooth topography to the east. The channel can be traced beyond the study area to at least 72°15' S (Melles & Kuhn 1993). A second asymmetrical channel starts on the lower eastern slope, at ca. 31° W (Fig. 2).

Oceanographic conditions

The oceanic circulation in the Weddell Sea is dominated by the clockwise movement of the Weddell Gyre which comprises all water masses down to the sea floor (Carmack & Foster 1975a, Deacon 1979, Gordon et al. 1981, Fig. 1). The upper ca. 200 m of the water column are formed by Winter Water (WW) with specific thermohaline characteristics (Fig. 3). In summer, as a consequence of sea-ice melting, the WW is overlain by a thin low-salinity surface layer (Carmack & Foster 1975a). In depths between ca. 200 m and 1500 m, Weddell Deep Water (WDW, Foldvik et al. 1985a) occurs, which is also called Warm Deep Water (Foster & Carmack 1976). The WDW is underlain by Antarctic Bottom Water (AABW). In the eastern Weddell Basin, the AABW extends to the sea floor, whilst in the southwestern, western, and northern Weddell Basin it is underlain by newly formed, colder Weddell Sea Bottom Water (WSBW, Carmack & Foster 1975a).

The oceanographic situation on the continental shelf is rather complex and until now not fully understood. At ca. 30° W and

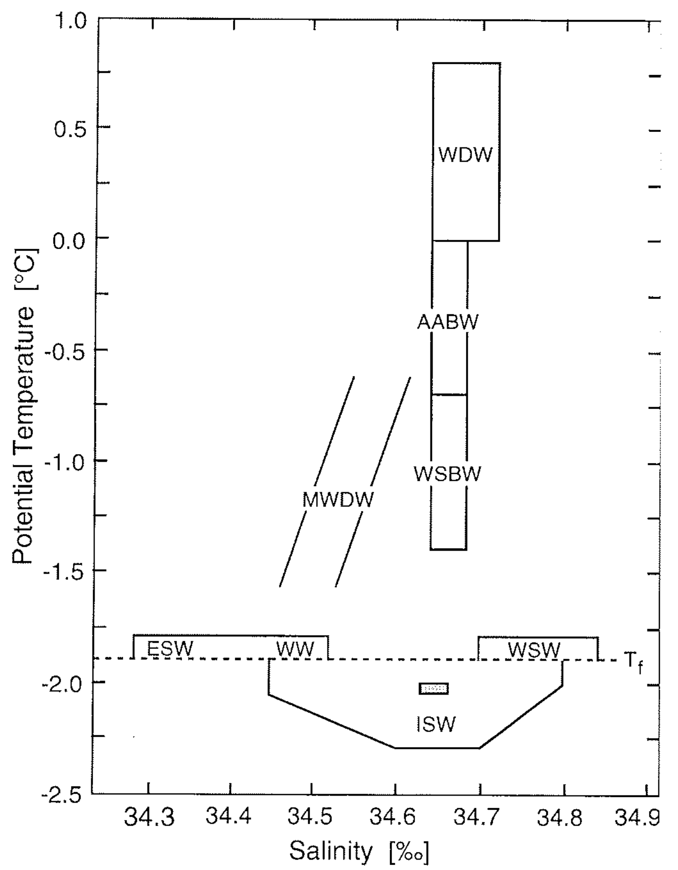

Fig. 3: Potential temperature versus salinity for the major Weddell Sea water masses (after FOLDVIK et al. 1985b). The rectangle within the ISW sector indicates thermohaline characteristics of the ISW at the sill in the north of Crary Trough, the dashed line T_f represents the surface freezing point (*WDW* = Weddell Deep Water, *AABW* = Antarctic Bottom Water, *WSBW* = Weddell Sea Bottom Water, *MWDW* = Modified Weddell Deep Water, *ESW* = Eastern Shelf Water, *WW* = Winter Water, *WSW* = Western Shelf Water, *ISW* = Ice Shelf Water).

Abb. 3: Temperatur/Salzgehalts-Diagramm der wichtigsten Wassermassen im Weddellmeer (nach FOLDVIK et al. 1985b). Das Rechteck im ISW-Feld charakterisiert das ISW am Schelfrand nördlich der Filchner-Rinne, die gestrichelte Linie T_f gibt den Gefrierpunkt für die Meeresoberfläche an (*WDW* = Weddellmeer-Tiefenwasser, *AABW* = Antarktisches Bodenwasser, *WSBW* = Weddellmeer-Bodenwasser, *MWDW* = Modifiziertes Weddellmeer-Tiefenwasser, *ESW* = Östliches Schelfwasser, *WW* = Winterwasser, *WSW* = Westliches Schelfwasser, *ISW* = Eisschelfwasser).

40° W Modified Weddell Deep Water (MWDW, Fig. 3), which results from mixing of WW and WDW, spills over the shelf break and flows to the southwest at water depths of 300 - 500 m (FOSTER & CARMACK 1976, FOLDVIK et al. 1985b, Fig. 1). This flow possibly occurs periodically, because MWDW was found at the Filchner Ice Shelf edge in 1979 but not in 1969 and 1980 (FOLDVIK et al. 1985b).

As part of the Weddell Gyre, the cold and fresh Antarctic Coastal Current flows southwest along the coastline of the eastern Weddell Sea (DEACON 1937, Fig. 1). At ca. 27° W the Antarctic Coastal Current splits (GILL 1973); one branch flows further to the west along the shelf edge, the major part flows to the south along the coastline at the eastern flank of the Crary Trough (CARMACK & FOSTER 1975b). This branch has thermohaline characteristics of the Eastern Shelf Water (ESW, Fig. 3). The major part of the near-surface flowing ESW is believed to be deflected to the west at the Filchner Ice Shelf edge, which extends several hundred meters beneath sea level (FOLDVIK et al. 1985c).

The high salinity Western Shelf Water (WSW, Fig. 3) is formed on the shallow shelf off the Berkner Island ice rise (Fig. 1) by salt rejection due to sea-ice formation (MOSBY 1934). This process is most effective during wintertime, promoted by prevailing katabatic winds (GILL 1973) and strong tidal currents (GAMMELSRØD & SLOTSVIK 1981), which produce open water areas (polynyas). Due to its high density, the WSW flows near the bottom into the Crary Trough and, at its eastern flank, far beneath the Filchner Ice Shelf (CARMACK & FOSTER 1975b, FOLDVIK et al. 1985b). Inferred from the shelf topography, FOLDVIK & GAMMELSRØD (1988) deduced a second WSW branch from the shelf off Berkner Island beneath the Ronne Ice Shelf and further to the Filchner Ice Shelf (Fig. 1). Geophysical data support their suggestion, showing a water column of more than 500 m beneath the ice south of the Berkner Island ice rise (VAUGHAN et al. 1995).

Beneath the Filchner/Ronne Ice Shelf, cooling and freshening transform WSW into Ice Shelf Water (ISW), a water mass characterized by temperatures below the freezing point at the surface (CARMACK & FOSTER 1975b, Fig. 3). The ISW flows from beneath the ice shelf at the western flank of the Crary Trough in water depths of 300 - 800 m and follows the bathymetric contours to the north. It spills over the shelf edge as a bottom current with velocities exceeding 100 cm/s (FOLDVIK 1986). At the continental slope, where the ISW turns to the west due to Coriolis Force, mixing with WDW results in the formation of WSBW (FOLDVIK et al. 1985b). According to CARMACK & FOSTER (1975b), part of the ISW recycles within the Crary Trough and, at its eastern flank, again flows beneath the Filchner Ice Shelf in lower water depth and with slightly higher temperature (Fig. 1). However, this contradicts model calculations of MACAYEAL (1985) and HELLMER & OLBERS (1989), who proposed that the ISW at the eastern flank of the Crary Trough also flows to the north.

Glaciological conditions

In the austral winter, between April and December, almost the entire Weddell Sea, including the study area, is to more than 80 % covered by sea ice (SEA ICE CLIMATIC ATLAS 1985). The sea-ice coverage then decreases rapidly, in the southern Weddell Sea from northeast to southwest above the continental slope and from southeast to northwest above the continental shelf. At the time of minimum ice coverage, in mid-February, the northwestern part of the study area is still to more than 50 % covered by ice, whilst along the ice shelf edges a coastal polynya occurs. Off the Filchner/Ronne Ice Shelf the polynya is ca. 50 km wide, whereas west of Coats Land it is ca. 200 km (ZWALLY et al. 1985).

The Weddell Sea is bordered to the south by the ca. 500 km broad Filchner and Ronne Ice Shelves (Fig. 1). The Ronne Ice

Shelf is supplied predominantly by ice streams from West Antarctica, whereas ice streams flowing into the Filchner Ice Shelf have their source area in East Antarctica, in the Transantarctic Mountains (DREWRY 1983, SWITHINBANK et al. 1987). The <200 km broad ice shelves, ice cliffs, and outlet glaciers of the eastern Weddell Sea are supplied also by ice streams from East Antarctica, in the southern part from the Transantarctic Mountains, and further to the north from Dronning Maud Land.

The position of the ice shelf edge is not constant. Between 1980 and 1984 the Filchner Ice Shelf edge moved to the north with a velocity of ca. 1 km/a. This rate corresponds approximately to the flow rate of the ice, indicating a northward movement over decades, before huge calving events result in a recession of the ice shelf edge (ZAKHAROV & KOTLYAKOV 1980, LANGE & KOHNEN 1985). Such a calving event took place in the southern Weddell Sea in the austral winter of 1986, when three large ice plates and some smaller tabular icebergs broke off from the Filchner Ice Shelf (Figs. 1 and 2).

MATERIAL AND METHODS

Seventy undisturbed sediment surface samples were recovered in the southern Weddell Sea (30°- 47° W) during six cruises of R.V. „Polarstern" between 1983 and 1988 (Fig. 2). Samples were taken using a large box corer, a Van Veen grab, and a multi-box corer. Detailed information on the sampling technique and sampling locations can be obtained from the cruise reports (HEMPEL 1983, 1985, KOHNEN 1984, FÜTTERER 1987, 1988, MILLER & OERTER 1990). Immediately after recovery, surface samples were taken from the uppermost 0.5 to 1.0 cm of the sediment and stored at +4 °C.

In order to register as wide a grain-size spectrum as possible, analyses were determined on two sediment sub-samples. The maximum grain size was limited to 6.3 mm. The larger sub-sample (50-100 ml) was wet-sieved through 2 mm and 63 µm meshes and the gravel/sand ratio determined from the dry weights. Sand and gravel were further subdivided by dry sieving. The smaller sub-sample (3-10 ml) was also wet-sieved through 2 mm and 63 µm meshes. Additionally, the fine fraction was split up into clay (<2 µm) and silt (2-63 µm) using the Atterberg method (settling time based on Stokes´ Law). From the dry weights of sand, silt, and clay of the smaller sub-sample, and the gravel/sand ratio of the larger sub-sample weight percentages of the bulk dry sediment were calculated for each fraction.

The carbonate and organic carbon contents were determined with a Coulomat (Ströhlein, type 702) on freeze-dried and ground bulk sediment samples by the method described by HERMANN & KNAKE (1973). Measurements were conducted on CO_2 generated by combustion (1100 °C) for analysing the total carbon content, and in corresponding samples by treatment with H_3PO_4 (14 %) for the carbonate-bound carbon content. Carbonate was calculated from the contents of carbonate-bound carbon, organic carbon from the difference between total and carbonate-bound carbon.

The mineral composition of the clay fraction was determined by XRD on texturally oriented aggregates with an internal MoS_2 standard. Semiquantitative evaluations of the mineral assemblages were made on the integrated peak areas. The relative percentages of each clay mineral (smectite, illite, chlorite, and kaolinite) were determined using empirically estimated weighting factors (BISCAYE 1964, 1965, BRINDLEY & BROWN 1980). Additionally, the calculated peak areas of all investigated minerals were set in relation to the basal reflection of the MoS_2 standard (at 6.15 Å). More detailed information on the method is given by EHRMANN et al. (1992).

The composition of the coarse fraction (63 - 6300 µm) was determined by grain-counting within isolated sub-fractions similar to the method described by SARNTHEIN (1971). Only major, easily identifiable biogenic and terrigenous groups of components were distinguished. In each sub-fraction at least 400 grains, if available, were identified and counted using a binocular microscope. Of 23 samples, which were sieved into 1.0 Phi° classes, all seven sub-fractions were counted. Of the remaining 47 samples, which were sieved into 0.33 Phi° (0.1 Zeta°) classes, all five gravel fractions and every second of the fifteen sand fractions were counted. In the intermediate sand fractions, grain numbers were calculated by linear interpolation. Check counting on two samples confirmed the admissibility of the interpolation (MELLES 1991).

Different calculations were carried out for biogenic and terrigenous components. For the individual groups of biogenic components the grain percentages were calculated in every grain-size fraction by their grain numbers and multiplied with the corresponding weight percentages in the bulk dry sample. In this way frequency percentages were obtained which were summed up for the coarse fraction. The relative portions of the terrigenous component groups in the bulk terrigenous material within the sand fraction were calculated by multiplying the grain percentages within every sand fraction by the corresponding weight percentages of the sand fractions, summing them up, and setting them in proportion to the bulk terrigenous material.

Stable oxygen and carbon isotopes in planktonic foraminiferal tests were measured on sinistrally coiled *Neogloboquadrina pachyderma*. All measurements were made on a Finnigan MAT 251 mass spectrometer in conjunction with an automatic carbonate preparation device. The amount of carbonate used for one measurement varied between 40 and 60 µg. This corresponds to 2-6 specimens of *N. pachyderma* in the 125-315 µm fraction. Isotope ratios are given in δ notation versus VPDB (Viena Pee Dee Belemnite). Standard deviations of measurements are 0.04 ‰ for carbon and 0.06 ‰ for oxygen (HUBBERTEN & MEYER 1989).

COMPOSITION OF SURFACE SEDIMENT

Surface sediment parameters were plotted in maps of the study area. Isopleths were drawn from those parameters which show significant gradients, with increments dependent upon the total range and the accuracy of the measurement. In order to examine the proportions of three interdependent parameters, the grain-size distribution of the bulk sediment (gravel, sand, mud) and the composition of terrigeneous components in the sand fraction (rock fragments, quartz and feldspar, other minerals) were plotted in triangular diagrams and mapped according to areas defined in the diagrams.

Grain sizes

The grain-size distribution of surface sediments in the southern Weddell Sea is clearly depth-related (Fig. 4). The Crary Trough shows a distinct succession from coarse to fine-grained sediments with increasing water depth, leading from well-sorted sand north of the Berkner Island ice rise, through muddy sand and sandy mud, to mud in the axis of the trough. The eastern flank exhibits similar conditions but, besides well-sorted sand, gravelly sand occurs in shallow water off the Luitpold Coast. High gravel contents (up to 40 %) were also found in deeper water in a zone beneath and in front of that part of the Filchner Ice Shelf which broke off in the austral winter of 1986. In contrast to the upper flank, gravel in this area occurs in a fine-grained, muddy matrix.

On the continental margin north of the Crary Trough two, probably separate, regions of well-sorted sand and gravelly sand occur. With increasing water depth, and towards the northeast on the continental slope, the content of the coarse fraction gradually decreases, resulting in almost pure mud on the lower eastern slope.

Carbonate and organic carbon

High carbonate contents (>2 %) were found along the ice shelf edge of the Luitpold Coast, in deep water of the southern Crary Trough, along the continental margin, and on the western continental slope (Fig. 5). The highest values (up to 55 %) occur on the continental margin beween 600 and 1000 m water depth. Low carbonate values (<0.1 %) were found off the Berkner Island ice rise and in the central Crary Trough.

The total organic carbon content shows maximum values (>0.4 %) in front of the Luitpold Coast, in a wide area of deep water in the Crary Trough, and on the northeastern continental slope (Fig. 6). Minima (<0.2 %) occur off Berkner Island, on two locations on the middle eastern flank of the Crary Trough, and on the western continental margin.

Biogenic components in the bulk sediment

Of the siliceous biogenic components, only sponge spicules and radiolaria occur in significant amounts in the coarse fraction. The sponge spicules are most frequent in the bulk sediment (up to 16.6 %) in a narrow zone off Luitpold Coast (Fig. 7). Except for two regions on the continental margin and slope, where they reach up to 1 %, their percentages are very low in the rest of the study area. The distribution pattern of the radiolaria is rather complicated (Fig. 8). Although in some areas mapping is uncertain, the radiolarian distribution pattern shows some trend opposite to that of the sponge spicules. This is most obvious along the Luitpold Coast, where the radiolaria, in contrast to the sponge spicules, have very low contents or are even absent. The two areas of radiolarian minima on the continental slope also show some relation to those of higher sponge spicule contents. However, in that area of the southern Crary Trough which until 1986 was covered by the Filchner Ice Shelf, both the sponge spicules and radiolaria have distinct minima.

The distribution pattern of the arenaceous foraminifera is characterized by high contents on parts of the upper slope and in the central Crary Trough, with a maximum (>3 %) in front of the ancient Filchner Ice Shelf edge (Fig. 9). Minima (<1 %) occur along the Luitpold Coast, off Berkner Island, and partly on the continental margin and slope.

Both calcareous benthonic and planktonic foraminifera have distinct maxima in narrow zones along the Luitpold Coast and on the continental margin (Figs. 10 and 11). Minima occur in the central Crary Trough, off Berkner Island and on the lower continental slope. A similar pattern is shown by the bryozoa (Fig. 12), whereas the molluscs and the barnacle species *Bathylasma corolliforme* show a slighly different distribution (Figs. 13 and 14). The molluscan maximum on the continental margin is restricted to the western part and, besides the narrow zone along the Luitpold Coast, high contents also occur in the southern Crary Trough. In contrast, *B. corolliforme* was found only on the continental margin and slope; on the southern shelf this species is absent.

A distribution pattern similar to that of the calcareous foraminifera is also indicated by all other calcareous biogenic components, including indeterminable calcareous fragments as well as ostracods, sea-urchin spines, and corals. Because the latter components are very rare, they have not been mapped.

Terrigenous components in the sand fraction

The terrigenous composition of the sand fraction (Fig. 15) is dominated by the quartz and feldspar group, which contributes between 29 and 97 %. Rock fragments show a wide range from 0 to 58 %. Other minerals occur with 3 to 28 %. The highest quartz and feldspar contents were found off Berkner Island, in the northwestern Crary Trough, on the western and eastern continental shelf break and slope, and along the Luitpold Coast. In contrast, relatively high contents of rock fragments occur in deep water of the Crary Trough and in the remaining parts of the shelf break and slope. Other minerals have their lowest values (<10 %) on the continental shelf, in particular along the upper western and eastern flanks of the Crary Trough.

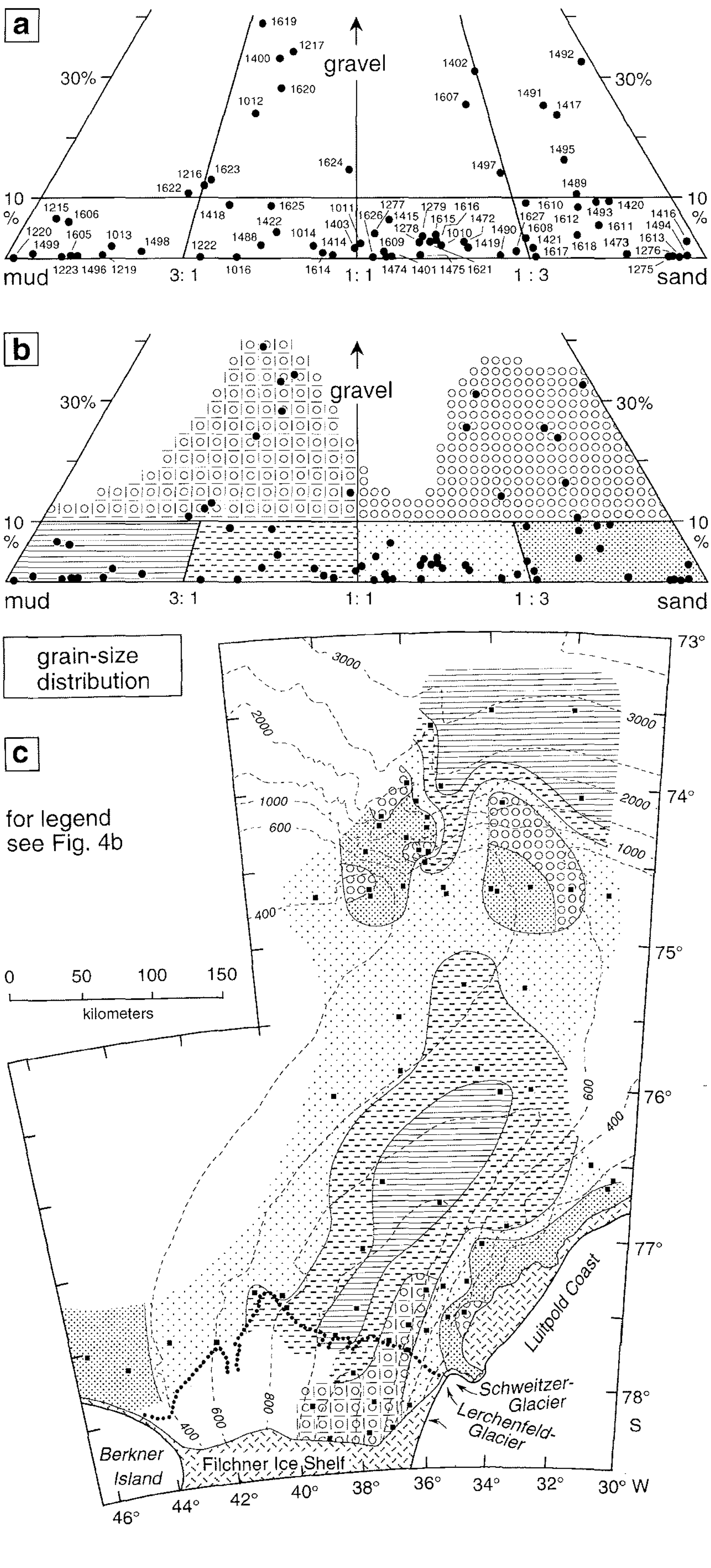

Fig. 4: Grain-size distribution of the bulk dry surface sediment in the southern Weddell Sea: (a) Triangular diagram showing the ratios of mud to sand and the percentage content of gravel (for sample locations see Fig. 2), (b) Triangular diagram equivalent to (a) showing the boundaries and patterns of areas defined for mapping, (c) Map of the grain-size distribution as defined in (b).

Abb. 4: Korngrößenverteilung im Gesamtsediment der Oberflächenproben im südlichen Weddellmeer: (a) Dreiecksdiagramm mit den Verhältnissen von Sand zu Ton plus Silt sowie den prozentualen Gehalten an Kies (Probennahmestationen siehe Abb. 2), (b) Dreiecksdiagramm entsprechend (a), mit den Grenzen und Mustern der kartierten Wertebereiche, (c) Karte der Korngrößenverteilung entsprechend der Einteilung in (b).

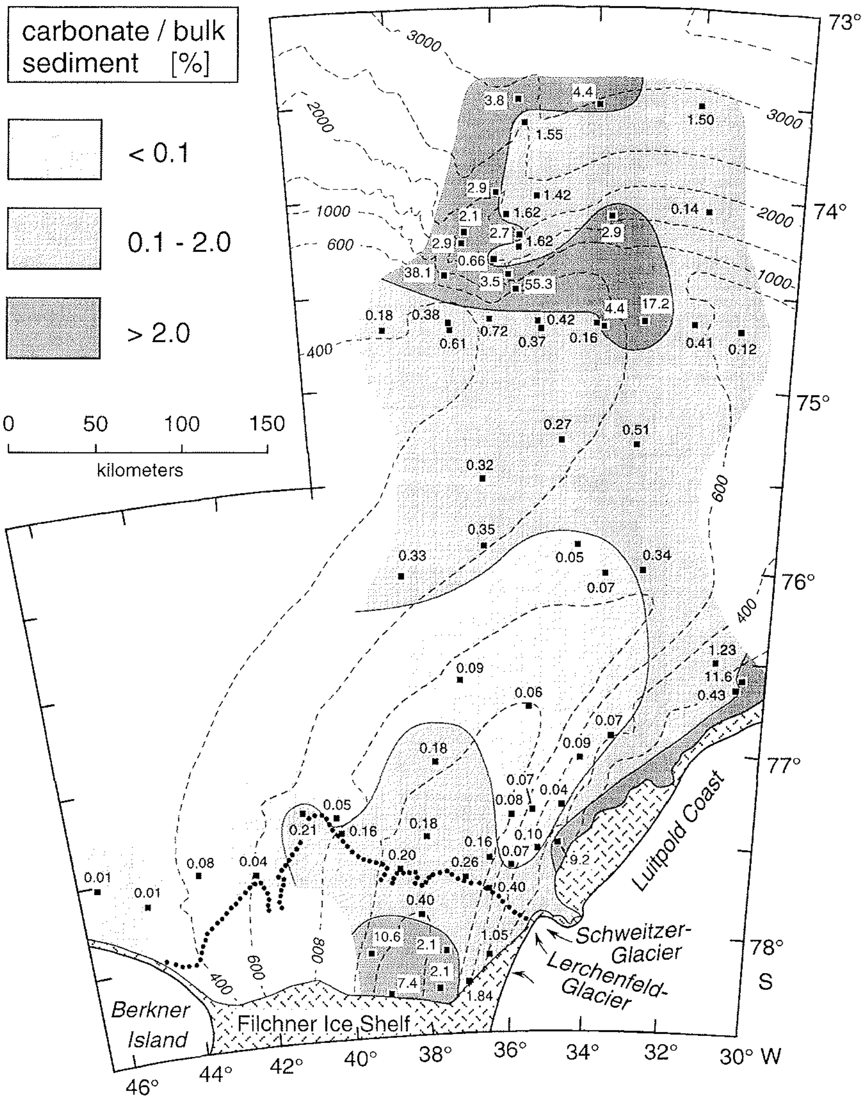

Fig. 5: Distribution of the carbonate content (in % of the bulk dry sediment).

Abb. 5: Verteilung der Karbonatgehalte (in % am Gesamtsediment).

Minerals in the clay fraction

The assemblage of clay minerals in the clay fraction of the surface sediments is dominated by illite, which contributes between 51 and 82 %, followed by chlorite (8-38 %), smectite (2-19 %) and kaolinite (2-16 %). The distribution patterns of the calculated relative percentages of these minerals are very similar to those of their mineral/standard-ratios.

The kaolinite distribution (Fig. 16) is characterized by very low contents (<6 %) on the lower continental slope, off Luitpold Coast, and in front of the actual edge of the western Filchner Ice Shelf. Significantly higher values (>11 %) occur in two regions on the continental margin, in an area in front of the Schweitzer and Lerchenfeld Glaciers, and at one location north of Berkner Island. Compared to kaolinite, smectite shows less clear differences and a rather simple distribution pattern. Relatively high values (>9 %) occur on the entire continental slope and northern shelf, in deep water of the Crary Trough beneath the former Filchner Ice Shelf, and in front of the Berkner Island ice rise. Although chlorite has a wider concentration range than kaolinite and smectite, only indistinct general trends are recognizable. Highest contents (>30 %) occur in the central Crary Trough in front of that part of the Filchner Ice Shelf which broke off in 1986, whereas low values were found mainly below the former ice shelf, and at most locations in front of the Luitpold Coast and on the continental margin and slope. Illite shows maximum values (>70 %) on the northeastern continental slope and in front of the northern part of the Luitpold Coast, with decreasing contents towards the west (Fig. 17). Another maximum occurs in front of the actual edge of the western Filchner Ice Shelf.

Distribution patterns very similar to that of illite are presented by the mineral/standard-ratios of talc (Fig. 18), amphibole (Fig. 19), and feldspar (Fig. 20). These minerals all have maxima on the northeastern continental slope, along the Luitpold Coast, and in the central Crary Trough beneath the former Filchner Ice Shelf. In contrast, the ratio quartz/standard shows distinct maxima (>0.8) in two regions at the shelf break and minima (<0.5) on the northeastern continental slope and in the central and western Crary Trough.

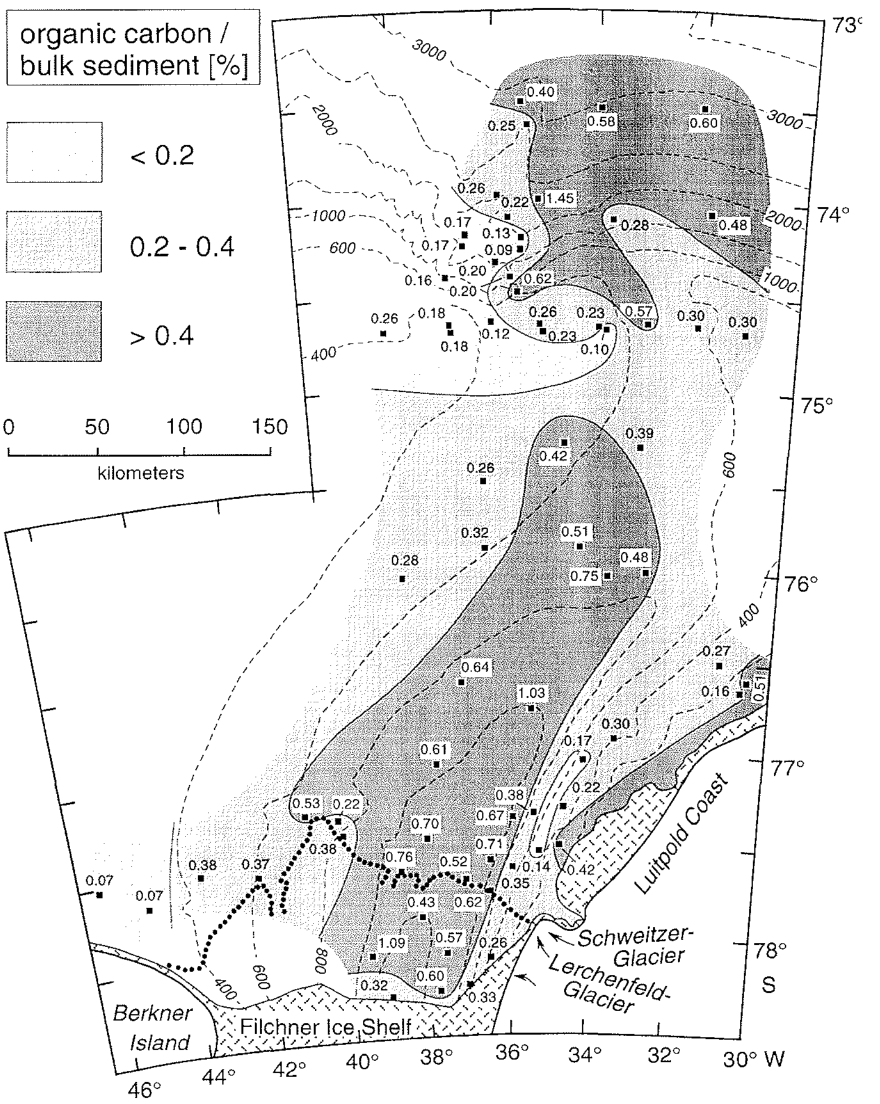

Fig. 6: Distribution of the organic carbon content (in % of the bulk dry sediment).

Abb. 6: Verteilung der Gehalte an organischem Kohlenstoff (in % am Gesamtsediment).

Stable isotopes in planktonic foraminifera

The stable oxygen isotope ratios ($\delta^{18}O$) in foraminiferal tests of the planktonic *N. pachyderma* (Fig. 21) show a very distinct, continuous shift from light values (<3.50 ‰) in front of the Luitpold Coast and the actual Filchner Ice Shelf edge to heavier values towards the north, reaching maxima (>3.80 ‰) on the lower continental slope. Although the carbon isotope ratios ($\delta^{13}C$) vary between 0.79 ‰ and 1.19 ‰, they show a much less clear distribution pattern than the oxygen isotope ratios. Relatively low values of <0.95 ‰ are common in the southwestern and eastern Crary Trough and on the eastern continental slope, whereas relatively high values of >1.10 ‰ were often found on the western continental slope.

GLACIOLOGICAL INFLUENCE ON SEDIMENT FORMATION

The sediment composition on the continental margin of the Weddell Sea is dominated by terrigenous rather than biogenic particles (Anderson et al. 1979, Elverhøi 1984, Fütterer et al. 1988). The distribution of both the biogenic and terrigenous components in the surface sediments is controlled (1) by their quantity produced in or supplied to the ocean, (2) by their biological, chemical and/or mechanical destruction, (3) by their lateral transport in the water column, (4) by their redeposition, and (5) by their dilution with other sediment components. All these processes are controlled by the Recent glaciological, physiographical, and hydrographical conditions.

Biogenic accumulation and ice coverage

The biogenic primary production in the area investigated is limited neither by nutrients nor by oxygen, which are both sufficiently available in the water masses (Foldvik & Gammelsrød 1988, Voss 1988). Hence, the major limiting factor is the scarcity of light (El-Sayed 1971). The light intensity decreases within the upper 25 cm of sea ice by 90 %; at the underside of one-year ice with a snow-coverage of 5 cm, the light intensity amounts to only <0.5 % of the primary radiation (Bartsch 1989). The plankton blooms on the Antarctic continental mar-

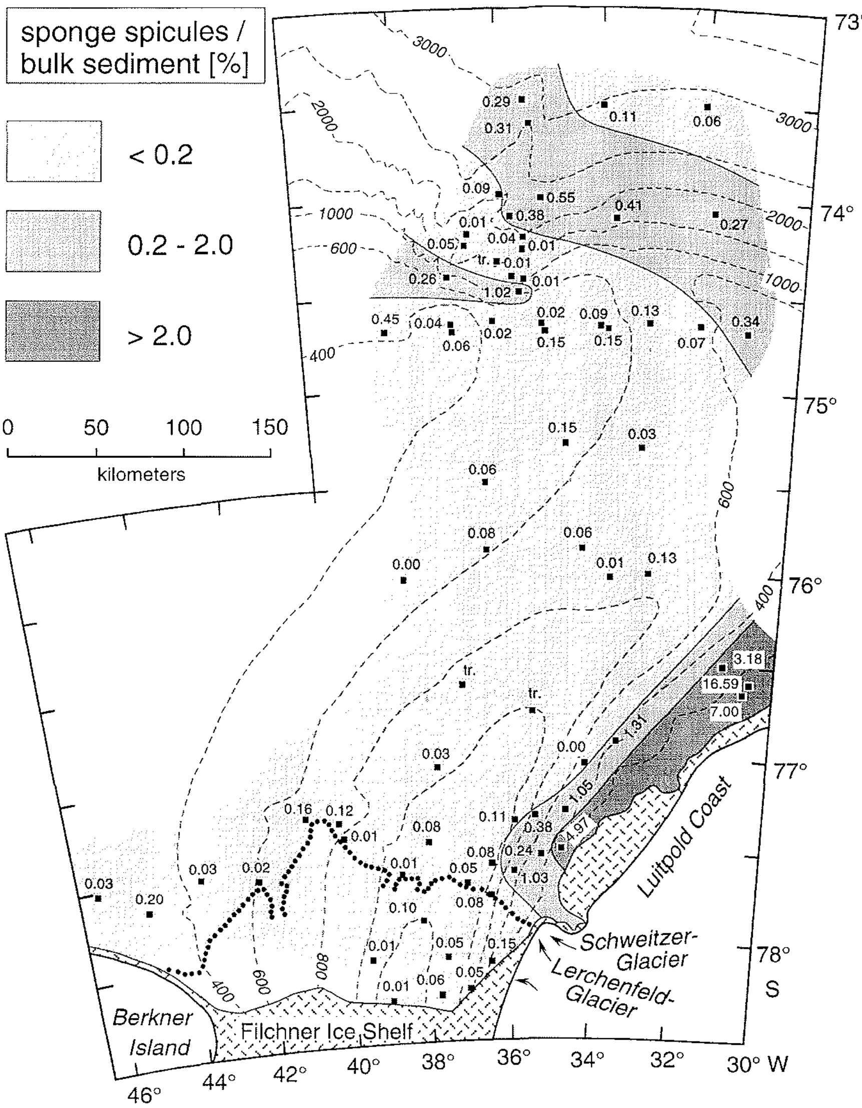

Fig. 7: Distribution of the sponge spicule content in the coarse fraction (in % of the bulk dry sediment).

Abb. 7: Verteilung der Gehalte an Schwammnadeln in der Grobfraktion, bezogen auf das Gesamtsediment.

gin, therefore, are restricted to a few weeks within the austral summer, when the sea-ice coverage partly breaks off. Due to the particle and nutrient flux through the water column, the limiting influence of the sea-ice cover on the planktonic biogenic production may finally result also in a limitation of the benthonic biogenic production.

During the minimum sea-ice coverage in February, polynyas occur along the coastline of the southern Weddell Sea, whilst the northwestern part of the area investigated is still more than 50 % covered by ice (SEA ICE CLIMATIC ATLAS 1985). Based on the oxygen and nitrate profiles in near-surface sediments, SCHLÜTER (1990) calculated a general decrease in organic carbon flux with increasing distance from the ice edge in the southern Weddell Sea. However, this pattern is reflected neither by the organic carbon contents, nor by the contents of radiolaria and planktonic foraminifera, and the $\delta^{13}C$ ratios in planktonic *N. pachyderma*, which all lack an obvious decrease towards the northwest (Figs. 6, 8, 11). This indicates that differences in primary production due to variations of 0-50 % in yearly minimum sea-ice coverage are too small to be resolved by these parameters, or that their distribution patterns are masked by other processes in the water column.

The distributions of sponge spicules, benthonic foraminifera, bryozoa, molluscs, and *B. corolliforme,* being similar to the planktonic organisms and organic carbon, show no distinct decreasing trend towards the area of denser sea-ice cover (Figs. 7, 10, 12-14). The biological production on the sea floor, therefore, is largely independent of differences in primary production in the study area.

In contrast to sea ice, coverage by ice shelves results in a total lack of primary production. In that area of the southern Crary Trough which until 1986 was covered by the Filchner Ice Shelf, seven surface samples were recovered two years after the calving event (Fig. 2). Whilst the radiolarian contents exhibit distinct minima in all these samples (Fig. 8), the organic carbon as well as the planktonic foraminifera have high contents at some locations (Figs. 6 and 11). These frequencies substantiate a lateral supply of both nutrients and planktonic foraminifera beneath the former Filchner Ice Shelf.

The nutrient supply is further evidenced by the occurrence of benthonic organisms. High contents at some locations are shown by benthonic foraminifera and bryozoa, and especially by molluscs (Figs. 10, 12, 13). Indication for a living molluscan fauna

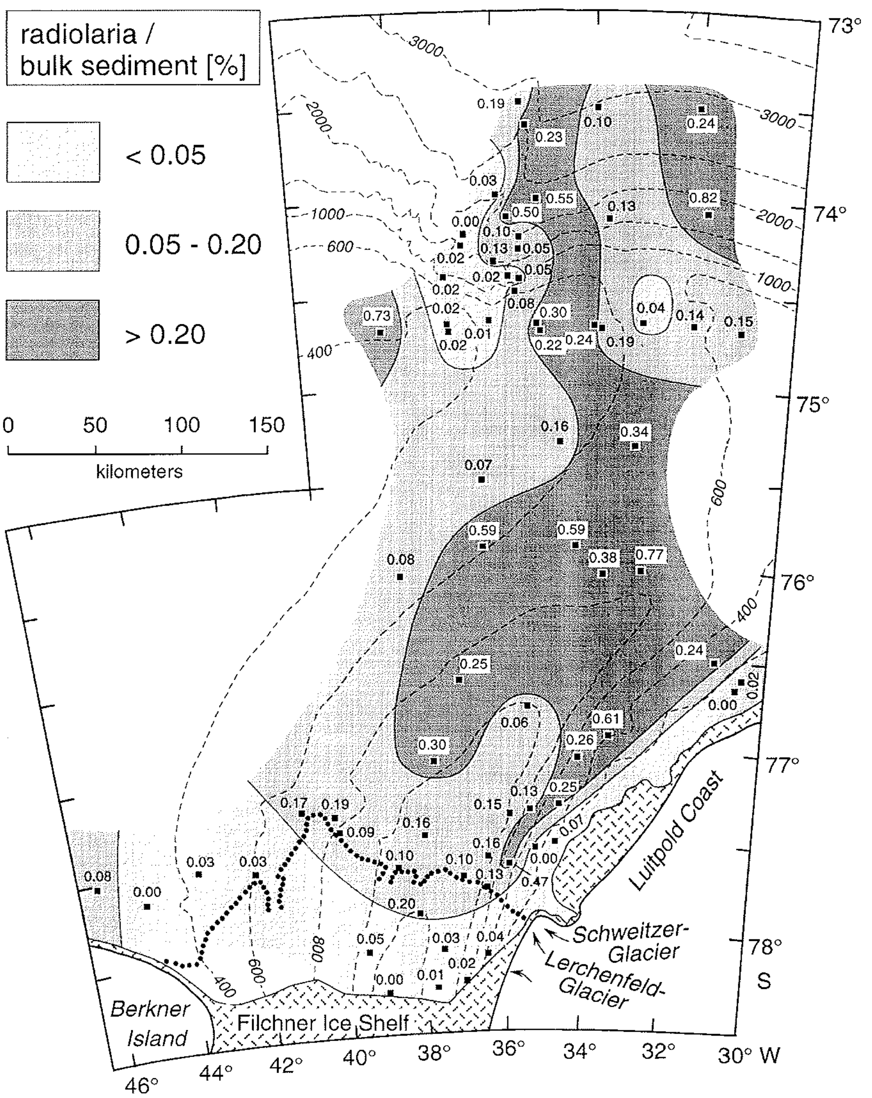

Fig. 8: Distribution of the radiolarian content in the coarse fraction (in % of the bulk dry sediment).

Abb. 8: Verteilung der Gehalte an Radiolarien in der Grobfraktion, bezogen auf das Gesamtsediment.

beneath ice shelves is given also by the species distribution in front of the present-day ice shelf edges in the Weddell and Lazarev Seas (HAIN & MELLES 1994). The absence of *B. corolliforme* at all locations does not necessarily depend on the lack of primary production, because this species is absent on the entire southern shelf (Fig. 14). The sponge spicules, in contrast, exhibit distinct minima, whilst showing high contents in front of the former eastern ice shelf edge (Fig. 7). This similarity to the radiolarian distribution, together with very low opal contents in the bulk surface sediments (SCHLÜTER 1990), may indicate a limitation for all siliceous microfossils due to the former ice shelf cover.

Sediment transport by ice

Due to the scarcity of ice-free areas in the surrounding region, aeolian sediment transport plays a minor role in the terrigenous sediment supply to the ocean. In contrast to temperate glacial regimes, such as Alaska, melt-water transport is also negligible in the present polar glacial regime of Antarctica. Because the sea ice in Antarctica, unlike the Arctic Ocean, is predominantly free of a terrigenous sediment load (PFIRMAN et al. 1990), sea-ice transport is also insignificant. Hence, most of the terrigenous sediment particles are supplied to the ocean by ice shelves, ice cliffs, and outlet glaciers, which form 92 % of the Antarctic coast line (DREWRY & ROBIN 1983). The material is eroded on the continent and incorporated into the ice sheet, where it is transported predominantly in the basal zone (GOW et al. 1968, ANDERSON et al. 1980a). The sediment load is deposited either directly from grounded ice forming lodgement tills or seaward of the grounding line producing glacimarine sedimentation (ANDERSON et al. 1980b).

Huge ice shelves, such as the Filchner and Ronne Ice Shelves, have lost most of the basal debris when reaching the calving line due to basal melting close to the grounding line (ROBIN 1979, ORHEIM & ELVERHØI 1981, HAMBREY et al. 1992, OERTER et al. 1992). In an ice core located 30 km from the edge of the Ronne Ice Shelf, the ice originating from the Antarctic ice sheet amounts to only 17 m (OERTER et al. 1992). This thin layer is covered by ca. 140 m of meteoric ice formed by snow accumula-

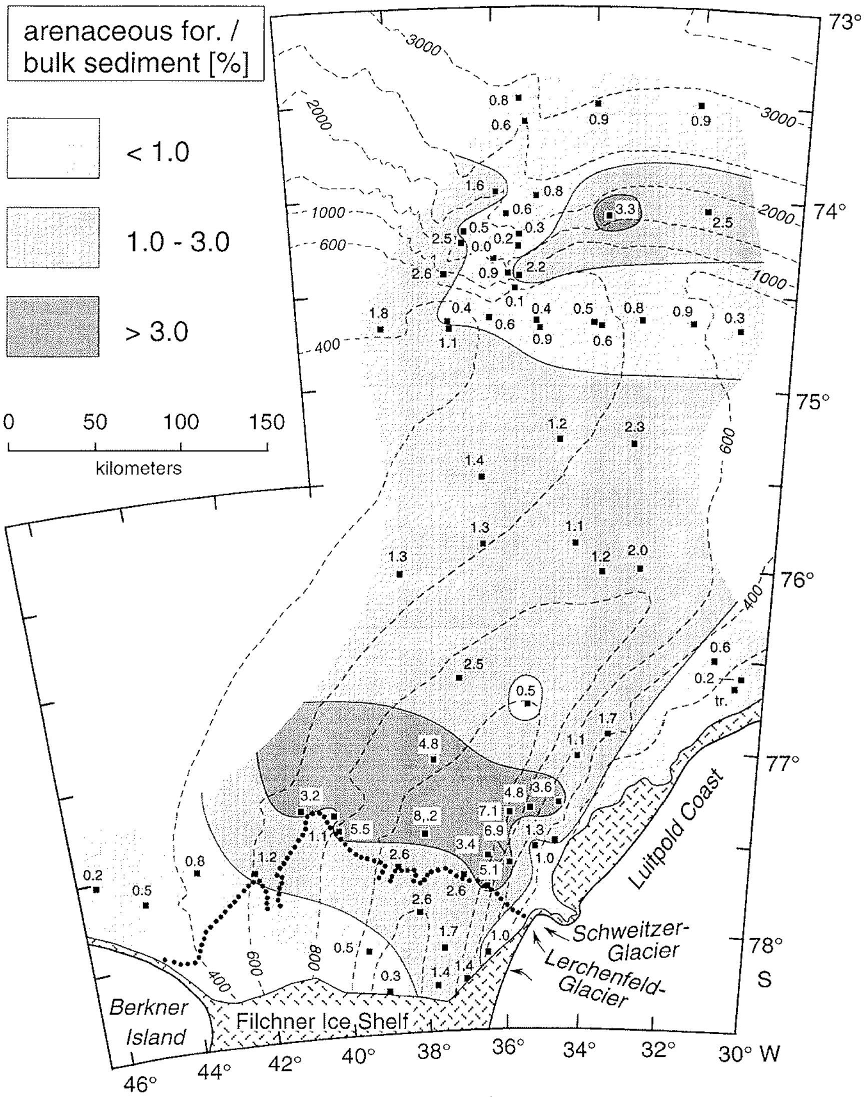

Fig. 9: Distribution of the arenaceous foraminifera content in the coarse fraction (in % of the bulk dry sediment).

Abb. 9: Verteilung der Gehalte an agglutinierenden Foraminiferen in der Grobfraktion, bezogen auf das Gesamtsediment.

tion on the ice shelf, and it is underlain by ca. 85 m of basal marine ice formed in the central and northern parts of the ice shelf by accumulation of ice platelets. The basal marine ice contains fine-grained sediment particles which were scavenged by the ice platelets on their ascent through the water column. However, these particles probably have little influence on the sedimentation in front of the ice shelf because with up to 0.1 g/l (Eicken pers. comm. 1995) their contents are very low compared to 47-78 g/l measured in the debris zones of icebergs (Anderson et al. 1980a). In addition, the particles in the marine ice are concentrated in the central rather than in the basal part of the ice column. Most of them, therefore, are transported over long distances by icebergs, before being released to the water column.

In contrast to huge ice shelves, small ice shelves, ice cliffs, or outlet glaciers may at their ice margins still contain significant amounts of basal debris eroded on the continent (Drewry & Cooper 1981, Kellogg & Kellogg 1988). Most of this debris is deposited from icebergs within short distances from the calving areas (Drewry & Cooper 1981). So far, only a few samples of ice-rafted debris (IRD) were obtained from Antarctic icebergs. They show a wide grain-size spectrum from clay to boulders, poor sorting, and sand contents predominantly between 40 % and 70 % (Anderson et al. 1980a, Petschik pers. comm. 1995). Indirect information on the grain-size distribution of the IRD comes from the lodgement till, which was deposited during the last glacial maximum directly from the grounded ice on the Antarctic continental shelf. Although the lodgement till shows regional and even local variations, it is always characterized by poor sorting (Fig. 22). Because most of the surface sediments in the area investigated are much better sorted than this till, marine sorting processes must have taken place on the ice-rafted particles during and after their settlement through the water column.

Differences in IRD supply due to different melting rates of icebergs are improbable in most of the area investigated, because the Eastern Shelf Water (ESW) and Winter Water (WW) show similar temperature ranges (-1.8 °C to -1.9 °C) and small differences in salinities (<0.2 ‰, Fig. 3). The only exception is the area in front of Berkner Island, where Western Shelf Water (WSW) is formed. This water mass could result in higher melting rates, because it is characterized by much higher salinities at the same temperature range (Fig. 3).

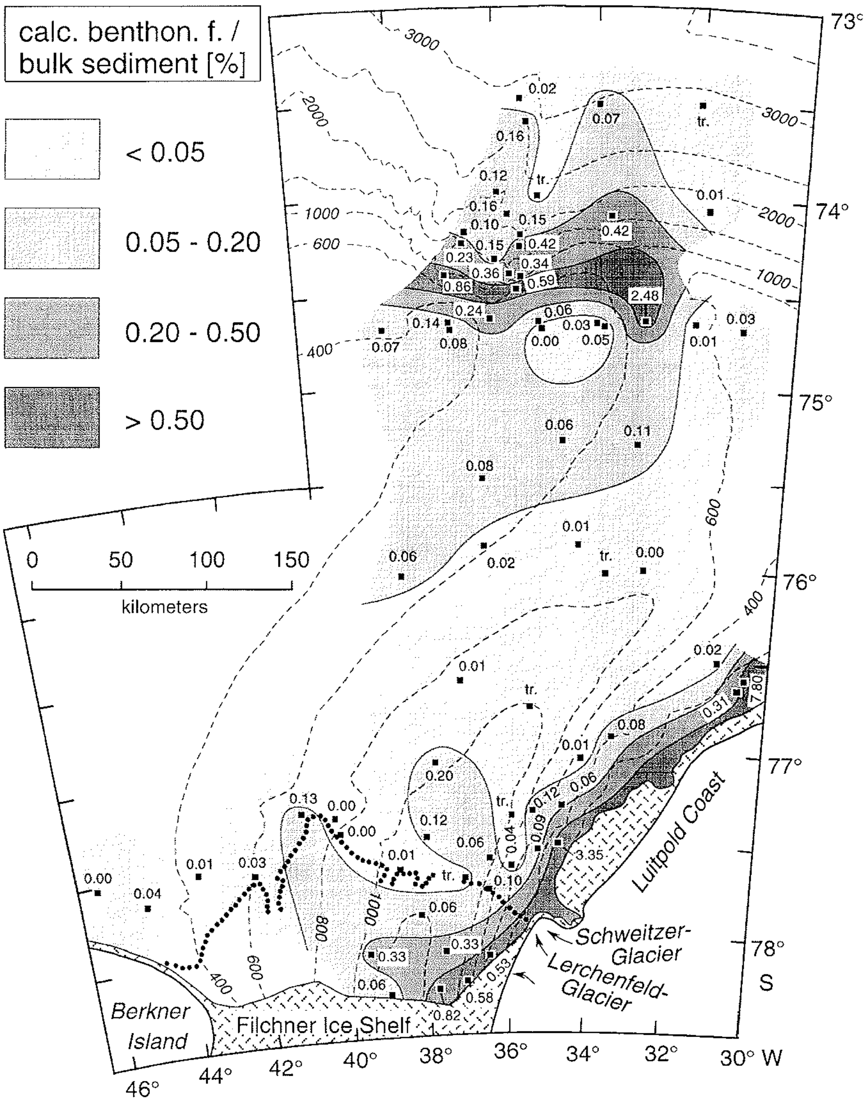

Fig. 10: Distribution of the calcareous benthonic foraminifera content in the coarse fraction (in % of the bulk dry sediment).

Abb. 10: Verteilung der Gehalte an kalkigen benthischen Foraminiferen in der Grobfraktion, bezogen auf das Gesamtsediment.

The IRD composition reflects the petrology of surface rocks in the catchment area of ice streams (Dreimanis 1976). In the southern Weddell Sea, the general movement of icebergs is from east to west due to the East Wind Drift south of ca. 70° S and the Weddell Gyre. Hence, the calving areas of icebergs reaching the outer continental shelf and slope are situated in the northeastern Weddell Sea. In the catchment area of the northeastern Weddell Sea outcrops of predominantly magmatic and especially metamorphic rocks are found (Roots 1969, Juckes 1972, Wolmarans & Kent 1982). Evidence for a similar petrological composition in the presently ice-covered catchment area is deduced from the petrology of ice-rafted pebbles and boulders in adjacent glacimarine sediments (Oskierski 1988, Anderson et al. 1991, Kuhn et al. 1993). An IRD supply of magmatic and metamorphic rocks to the outer continental shelf and slope of the area investigated is confirmed by the composition of the lithic coarse fraction. Due to similar melting rates and a large distance from the calving areas, a more or less constant flux of IRD can be assumed.

In contrast, on the inner continental shelf the surface sediment composition may be influenced by more local IRD sources of individual textural and petrological composition. Oskierski (1988) recognized two petrological provinces by the composition of ice-rafted pebbles in glacimarine sediments. Whilst the province in front of Berkner Island and the Filchner Ice Shelf is dominated by sedimentary pebbles, the province along the Luitpold Coast is characterized by equal contents of magmatic, metamorphic, and sedimentary rocks. Based on pebbles and the coarse sand in lodgement tills and subice shelf deposits, Anderson et al. (1991) distinguished four provinces. They showed a succession from predominantly sedimentary rock fragments off Berkner Island to predominantly magmatic rock fragments off Coats Land. In the latter area, Kuhn et al. (1993) also found high contents of magmatic pebbles in glacimarine sediments.

Although these studies are based on sediments of different ages, the results are similar to the terrigenous composition of the surface sediments. Off Berkner Island and in front of the present-day Filchner Ice Shelf edge, the lithic coarse fraction is characterized by high contents of sedimentary rocks. They include calcareous rocks as well as sandstones with a carbonate matrix. This composition is also reflected in high carbonate contents in

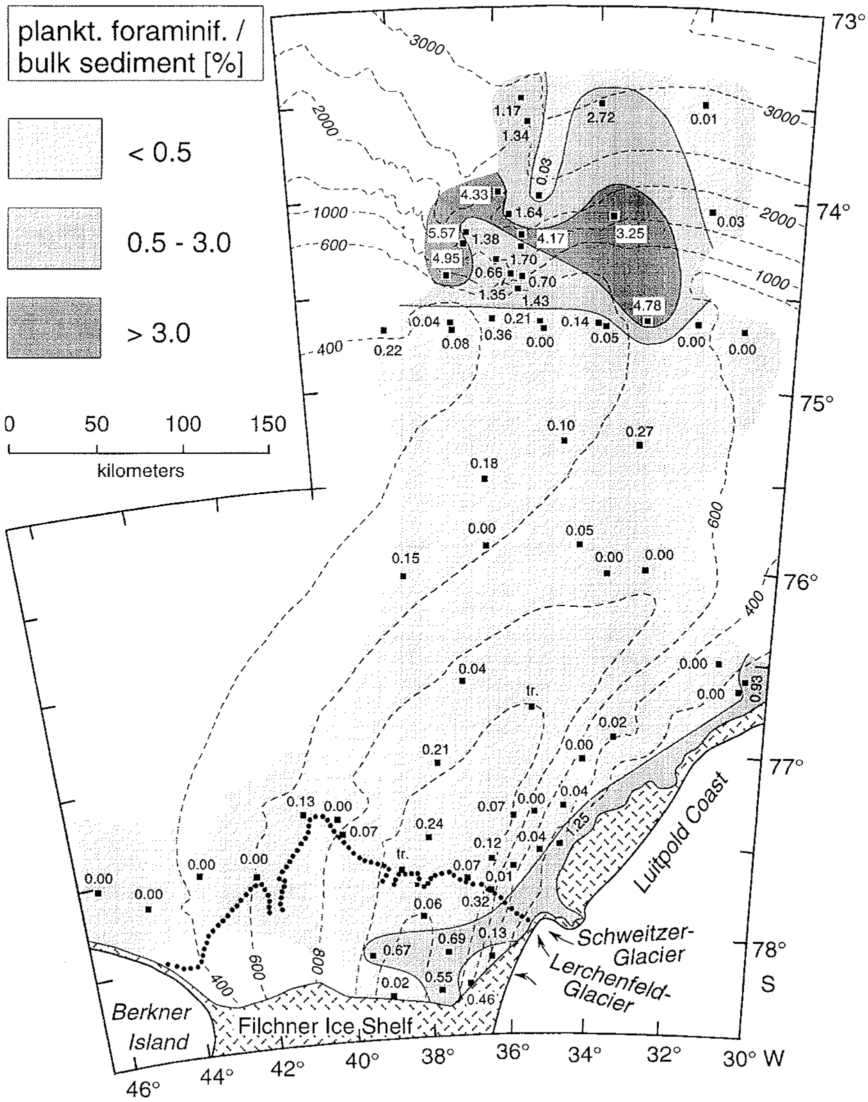

Fig. 11: Distribution of the planktonic foraminifera content in the coarse fraction (in % of the bulk dry sediment).

Abb. 11: Verteilung der Gehalte an planktischen Foraminiferen in der Grobfraktion, bezogen auf das Gesamtsediment.

the southern Crary Trough (Fig. 5) which cannot be explained exclusively by the contents of biogenic calcareous components (Figs. 10-14). A sedimentary origin of the IRD is also indicated by the mineral composition of the clay fraction. High contents of kaolinite and minima of illite, talc, amphibole, and feldspar were found off Berkner Island and in front of the Schweitzer and Lerchenfeld Glaciers (Figs. 16-20).

The IRD in these two areas differs from that farther north not only in its petrological composition but also in its grain-size distribution. In front of Berkner Island, the surface sediments are composed of very well-sorted, almost pure quartz and feldspar sands (Figs. 4 and 15). This composition may indicate an IRD with extraordinary high sand contents, which could be formed by erosion of kaolinite bearing, calcareous sandstones exposed on Berkner Island. This interpretation is in agreement with OSKIERSKI (1988) and FÜTTERER & MELLES (1990), who deduced that sedimentary rocks of the Beacon Supergroup are exposed on Berkner Island. Rocks of this type were also found in the Theron Mountains (STEPHENSON 1966), close to the catchment area of the Schweitzer and Lerchenfeld Glaciers (DREWRY 1983). In front of these glaciers, the surface sediments below ca. 800 m water depth are characterized by high gravel contents in a fine-grained, muddy matrix. Their very low sand contents (mostly <25 %; Fig. 4) can only be explained by an extraordinarily high gravel content of the IRD, and its enrichment by fine-grained material due to marine processes. A similar grain-size distribution was found in surface sediments at the western margin of the Ronne Ice Shelf in front of outlet glaciers flowing from the Antarctic Peninsula (HAASE 1983, FÜTTERER & MELLES 1990).

Besides the supply of terrigenous particles, the continental ice could play an important role in the redeposition of glacimarine sediments. Both advances of the ice grounding-line and ploughing of icebergs may result in incorporation and freeze-on of glacimarine sediments, as well as in local debris slides (DOMACK 1982, SOLHEIM & KRISTOFFERSEN 1985, DOWDESWELL 1987, KELLOGG & KELLOGG 1988, LIEN et al. 1989). An influence of these processes on the surface sediment composition, however, is unlikely because none of the samples contained sediment clasts indicative of glacial redeposition. In addition, no evidence was found of a higher degree of consolidation due to iceberg loading.

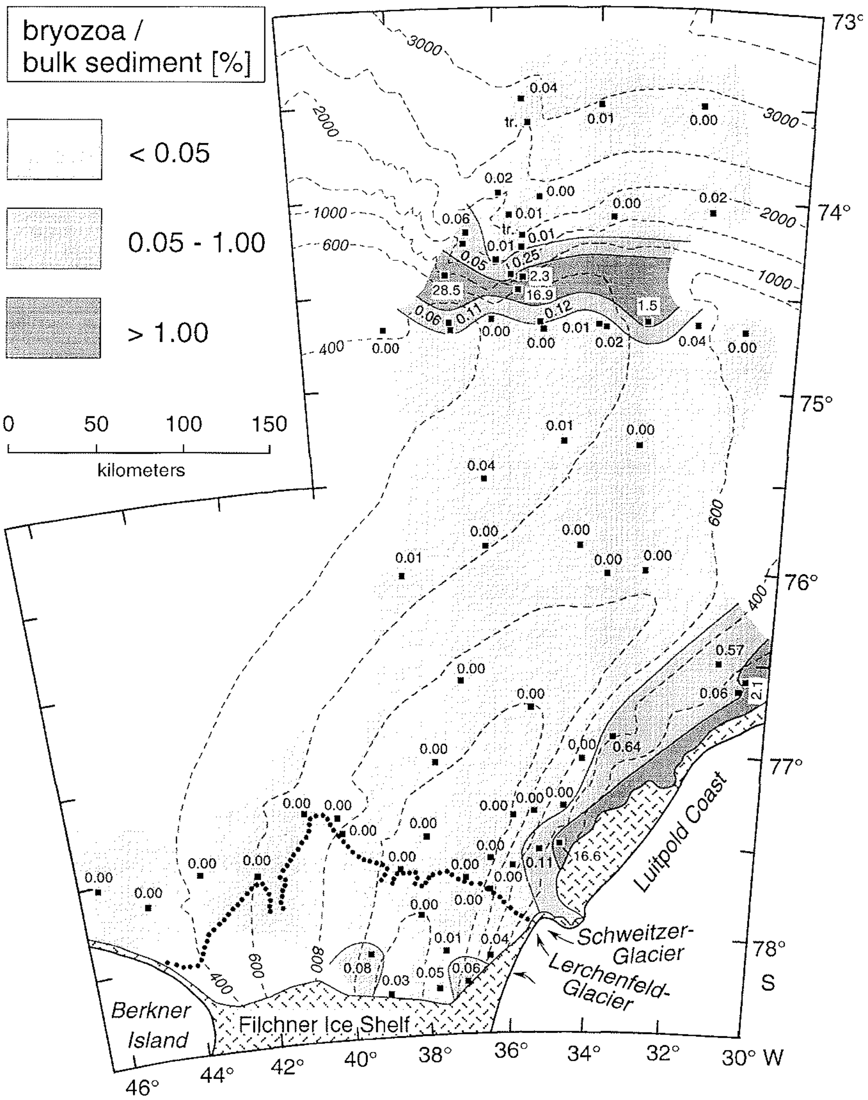

Fig. 12: Distribution of the bryozoan content in the coarse fraction (in % of the bulk dry sediment).

Abb. 12: Verteilung der Gehalte an Bryozoen in der Grobfraktion, bezogen auf das Gesamtsediment.

PHYSIOGRAPHICAL INFLUENCE ON SEDIMENT FORMATION

Water depth and biogenic accumulation

During vertical transport through the water column, unknown quantities of both the skeletons of planktonic organisms and the organic carbon are decomposed. However, the distribution pattern of radiolaria, for example, shows no systematic decrease with increasing water depth (Fig. 8). The planktonic foraminifera have the highest values in shallow water in front of the Luitpold Coast and at the continental margin, whereas on the shallow shelf area off Berkner Island their contents are very low (Fig. 11). Except for high values at two shallow locations in front of the Luitpold Coast, the organic carbon contents tend towards higher rather than lower values with increasing water depth (Fig. 6).

The distribution patterns of all benthonic organisms also argue against a limitation of nutrients in deeper waters of the area investigated, because none of them shows a significant trend towards lower values with increasing water depth (Figs. 7, 9, 10, 12-14). This is also supported by intense bioturbation of the near-surface sediments at all locations investigated. Hence, a simple depth-dependence of the decomposition in the water column can be excluded. The distinct differences in the contents of planktonic and benthonic organisms, and of organic carbon, therefore, must depend mainly on the chemical and physical properties of the water masses.

Gravitational sediment transport

Gravitational sediment transport processes (turbidity currents, slumps, debris flows, etc.) have been frequently described from the Antarctic continental slope and from the flanks of shelf depressions such as the Crary Trough (KURTZ & ANDERSON 1979, WRIGHT et al. 1979, 1983, WRIGHT & ANDERSON 1982, SOLHEIM & KRISTOFFERSEN 1985, FÜTTERER et al. 1988, MELLES & KUHN 1993, KUHN & WEBER 1993). However, there are some indications that these processes have not affected the surface sediments in the study area.

For example, the undisturbed surface sediments of the box cores

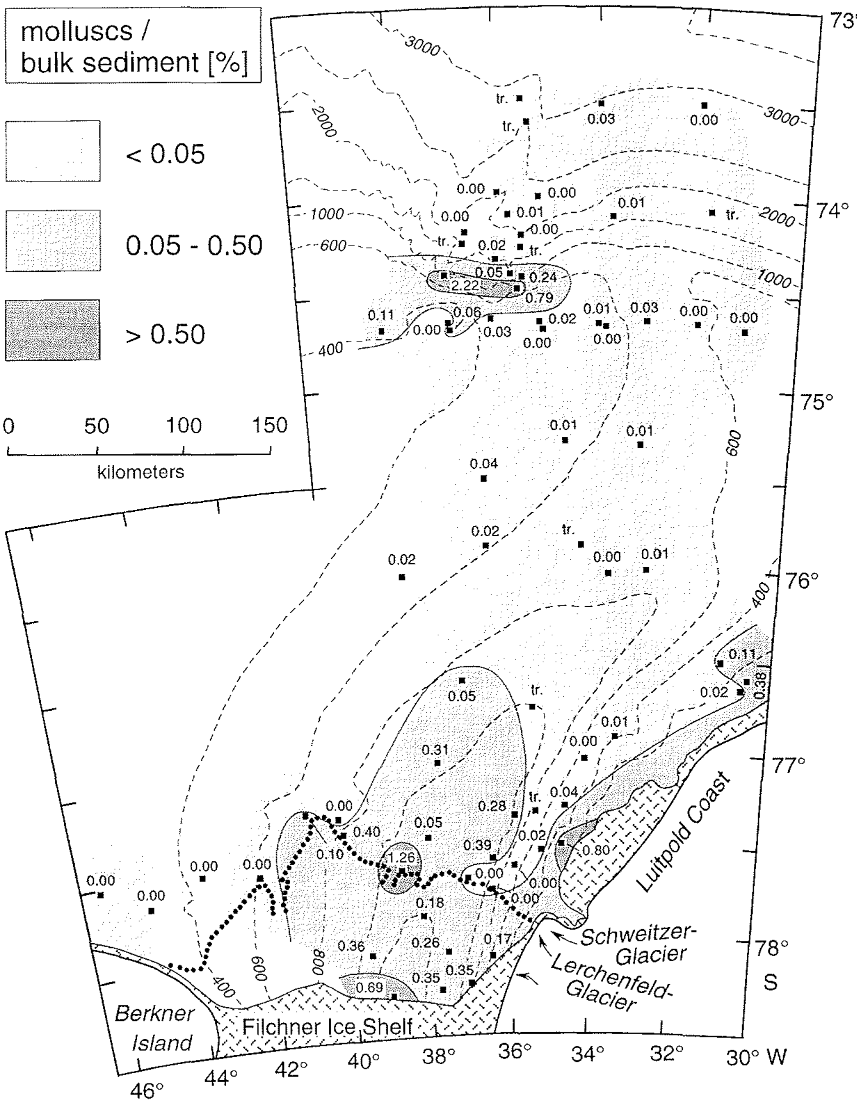

Fig. 13: Distribution of the molluscan content in the coarse fraction (in % of the bulk dry sediment).

Abb. 13: Verteilung der Gehalte an Mollusken in der Grobfraktion, bezogen auf das Gesamtsediment.

contained living macrobenthos at almost all sampling sites. In addition, on the continental margin and on the upper eastern flank of the Crary Trough, continuous zones with high contents of calcareous biogenic components occur along the bathymetric contours (Figs. 10-14), showing bryozoa and *B. corolliforme* in living positions at various locations. Furthermore, gravitational sediment transport to the lower continental slope and deeper Crary Trough seems unlikely, because the mineral compositions in the clay and sand fractions differ significantly from those in the shallower parts (Figs. 15-20). Finally, the coarse-grained sediments at the continental margin cannot be proximal deposits of sediment gravity transport, because they extend upwards onto the very flat continental shelf (Fig. 4).

HYDROGRAPHICAL INFLUENCE ON SEDIMENT FORMATION

Properties of water masses and biogenic accumulation

The above discussion demonstrated that the distinct differences in the contents of planktonic and benthonic organisms, and of organic carbon reflect neither an ice-cover influence on biogenic primary production nor a depth-dependence on decomposition. In addition, an influence of redeposition processes due to glacial sediment reworking or gravitational sediment transport can be excluded. Hence, the biogenic composition of the surface sediment is predominantly controlled by the chemical and physical properties of the different water masses.

The maxima of planktonic foraminifera on the continental margin and in the narrow zone along the Luitpold Coast (Fig. 11) coincide remarkably with the two branches of the Antarctic Coastal Current (Fig. 1). This relation was noticed already by ANDERSON (1975b) and traced back to a high production in the surface water. Very low contents of radiolaria in these areas (Fig. 8) indicate that the production comprises especially planktonic

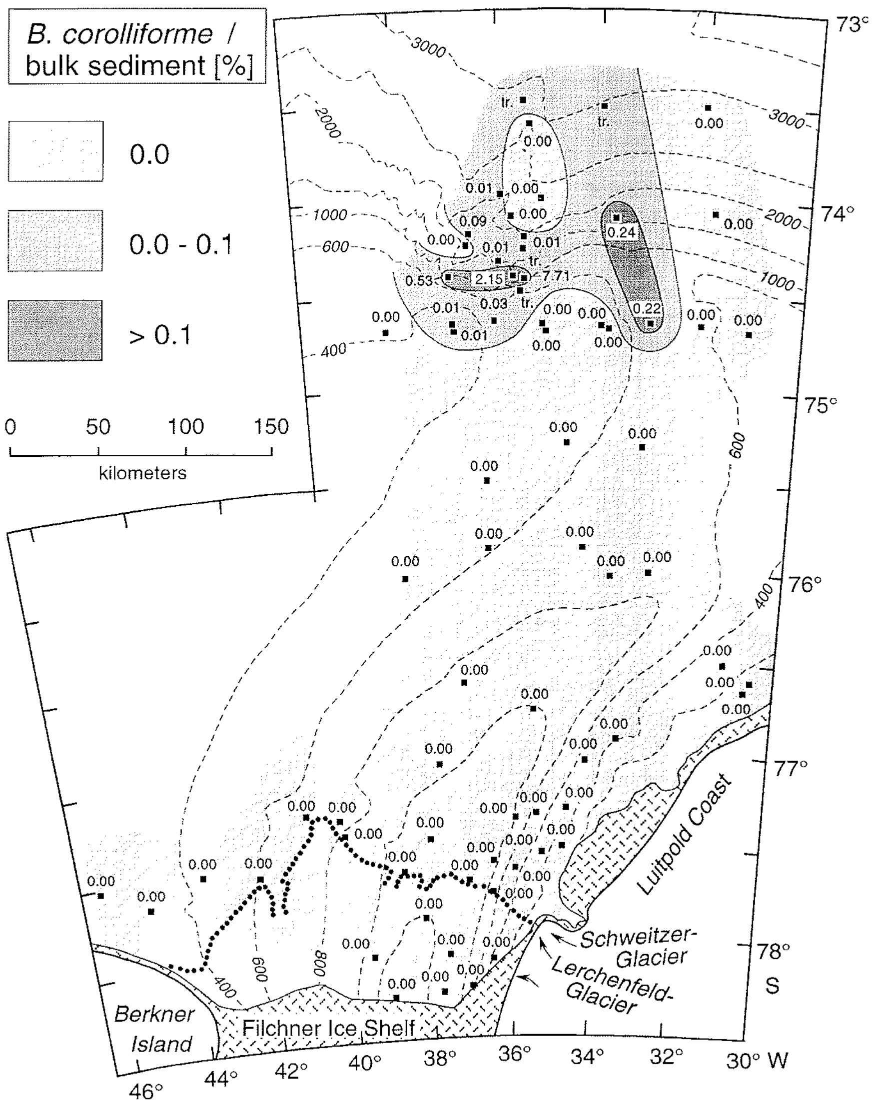

Fig. 14: Distribution of the content of the barnacle species *Bathylasma corolliforme* in the coarse fraction (in % of the bulk dry sediment).

Abb. 14: Verteilung der Gehalte an der Seepockenart *Bathylasma corolliforme* in der Grobfraktion, bezogen auf das Gesamtsediment.

foraminifera, but is reduced with respect to radiolaria. This conforms with the calcite saturation, which reaches more than 280 % in the coastal surface water in the Lazarev Sea (RUTGERS VAN DER LOEFF et al. 1992). The surface water of the Antarctic Coastal Current consists of Eastern Shelf Water (ESW). This water mass is formed by the incorporation of meltwater along the ice margin and, therefore, is characterized by low temperatures and salinities (Fig. 3). The major flow of the Antarctic Coastal Current along the upper eastern flank of the Crary Trough is clearly reflected in light $d^{18}O$ values in planktonic foraminiferal tests (Fig. 21). Continuously increasing values with increasing distance from the ice margin indicate that the second branch of the Antarctic Coastal Current, which flows to the west along the continental margin, is of much smaller intensity.

On the upper eastern flank of the Crary Trough, the ESW reaches the bottom down to 300-400 m water depth (FOLDVIK et al. 1985c). In this area, sponge spicules, calcareous benthonic foraminifera, bryozoa, and, less pronounced, molluscs show distinct maxima (Figs. 7, 10, 12, 13). A dense settlement of sponge and bryozoan faunas has repeatedly been reported from shallow waters of the eastern Weddell Sea shelf (ELVERHØI & ROALDSET 1983, VOSS 1988, HAIN 1990). ANDERSON (1975a, b) found a dominance of calcareous forms in the benthonic foraminiferal assemblage along the eastern Weddell Sea ice margin and concluded that bottom conditions were suitable for both precipitation and preservation of calcium carbonate. The continuation of the narrow zone of high molluscan, planktonic and especially calcareous benthonic foraminifera contents beneath the former Filchner Ice Shelf (Figs. 10, 11, 13) indicates that a significant part of the ESW flowed beneath the ice prior to the calving event of 1986.

In that branch of the Antarctic Coastal Current which flows to the west along the continental margin, the ESW is underlain by Modified Weddell Deep Water (MWDW) and Ice Shelf Water (ISW, Figs. 1 and 3). High contents of planktonic foraminifera in that area (Fig. 11) again could be due to their high production rate in the ESW. BERGER (1968) has shown that a high calcareous primary production generally results in a depression of the carbonate compensation depth (CCD), the depth at which calcium carbonate supply exceeds dissolution. However, this alone cannot explain the maxima of calcareous benthonic

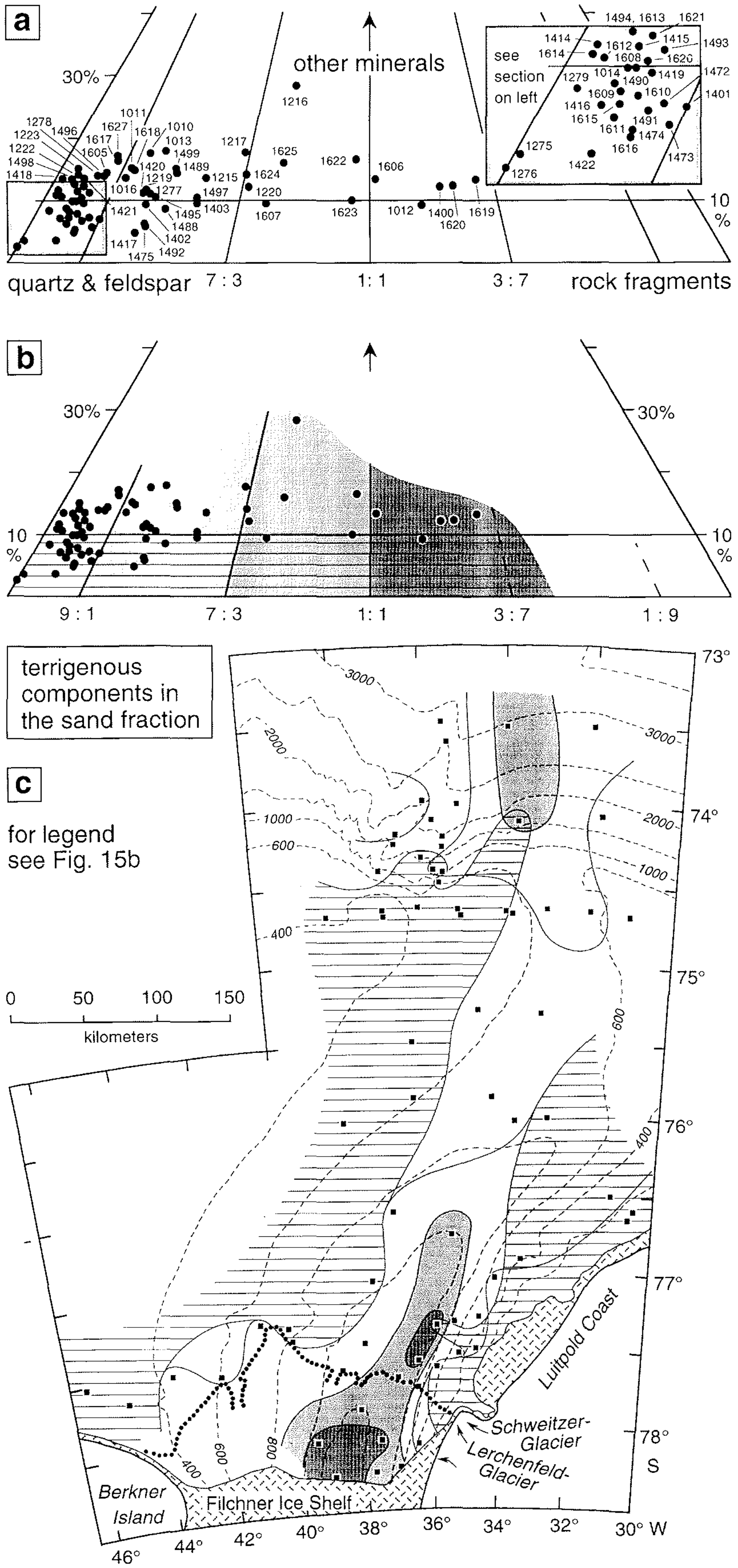

Fig. 15: Distribution of terrigenous components in the sand fraction (in % of the terrigenous sand): (a) Triangular diagram showing the ratios of the quartz and feldspar group to the rock fragments and the percentage content of the other minerals (for sample locations see Fig. 2), (b) Triangular diagram equivalent to (a) showing the boundaries and patterns of areas defined for mapping, (c) Map of the terrigenous component distribution as defined in (b).

Abb. 15: Verteilung der terrigenen Komponenten in der Sandfraktion (in % des terrigenen Sandes): (a) Dreiecksdiagramm mit den Verhältnissen von Quarz plus Feldspat zu Gesteinsbruchstücken und den prozentualen Anteilen an sonstigen Mineralen (Probennahmestationen siehe Abb. 2), (b) Dreiecksdiagramm entsprechend (a) mit den Grenzen und Mustern der kartierten Wertebereiche, (c) Karte der terrigenen Komponentenverteilung entsprechend der Einteilung in (b).

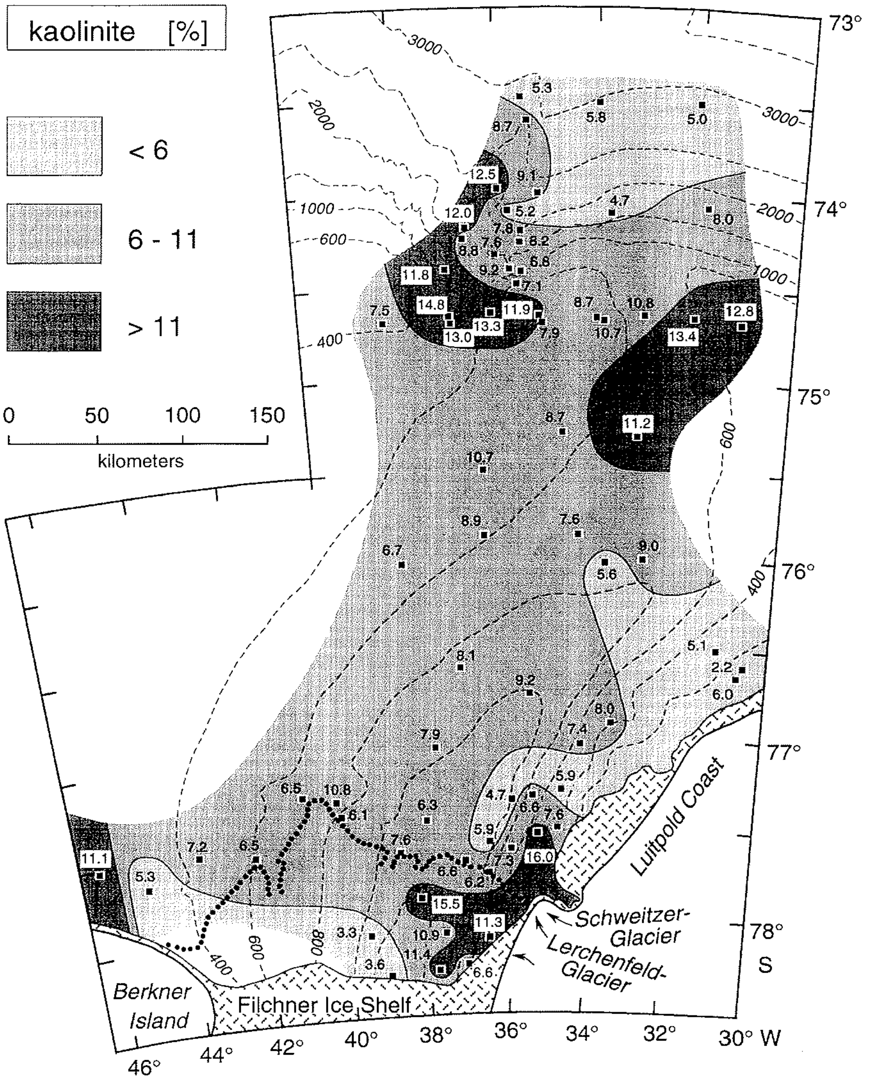

Fig. 16: Distribution of the content of kaolinite in the clay fraction (in % of the clay minerals).

Abb. 16: Verteilung der Gehalte an Kaolinit in der Tonfraktion (in % an den Tonmineralen).

foraminifera, bryozoa, molluscs, and the barnacle *B. corolliforme,* which at some locations reach values much higher than in front of the Luitpold Coast (Figs. 10, 12-14). Hence, additional factors have to support the high benthonic calcareous production and/or reduced dissolution on the continental margin.

ANDERSON (1975b) noticed a coincidence of high calcareous foraminiferal contents with very coarse-grained surface sediments, and traced this relation back to reduced dissolution due to a high clastic accumulation with associated rapid burial. This process could be of significant influence on the continental margin, where high postglacial accumulation rates are indicated by sediment coring and sub-bottom profiling (MELLES 1991, MELLES & KUHN 1993). In front of the Luitpold Coast, in contrast, high accumulation rates are unlikely despite the proximity to the narrow ice shelf, because in that area a very thin or no cover of glacimarine sediments was found above the basement (ELVERHØI & MAISEY 1983, SOLHEIM & KRISTOFFERSEN 1985, KUHN et al. 1993).

The continental margin as well as the area in front of the Luitpold Coast are associated with high bottom current velocities. CARMACK & FOSTER (1977) calculated velocities of up to 40 cm/s for the Antarctic Coastal Current to the east of its point of divergence (ca. 27° W). Because the main portion of this current follows the coastline to the south, only slightly lower current velocities can be expected for the ESW off the Luitpold Coast. In the ISW on the continental margin, current meter moorings have registered even higher mean velocities of >50 cm/s in the ISW close to the bottom (FOLDVIK 1986). The flow of ISW across the shelf edge is probably traced by the coarse-grained surface sediments (Fig. 4, FÜTTERER & MELLES 1990, MELLES & KUHN 1993).

On the one hand, high current velocities may favour the settlement of sessile organisms with filtering feeding habitats, such as bryozoa, sponges, and barnacles. This suggestion is supported by the occurrence of bryozoa in front of the Ronne Ice Shelf, where tidal current velocities perpendicular to the ice edge exceed 40 cm/s (VOSS 1988, ROBIN et al. 1983). The barnacle species *B. corolliforme* also settles in a high-energy current environment, for example at the shelf edge of the Ross Sea (BULLIVANT 1967). The absence of *B. corolliforme* at the

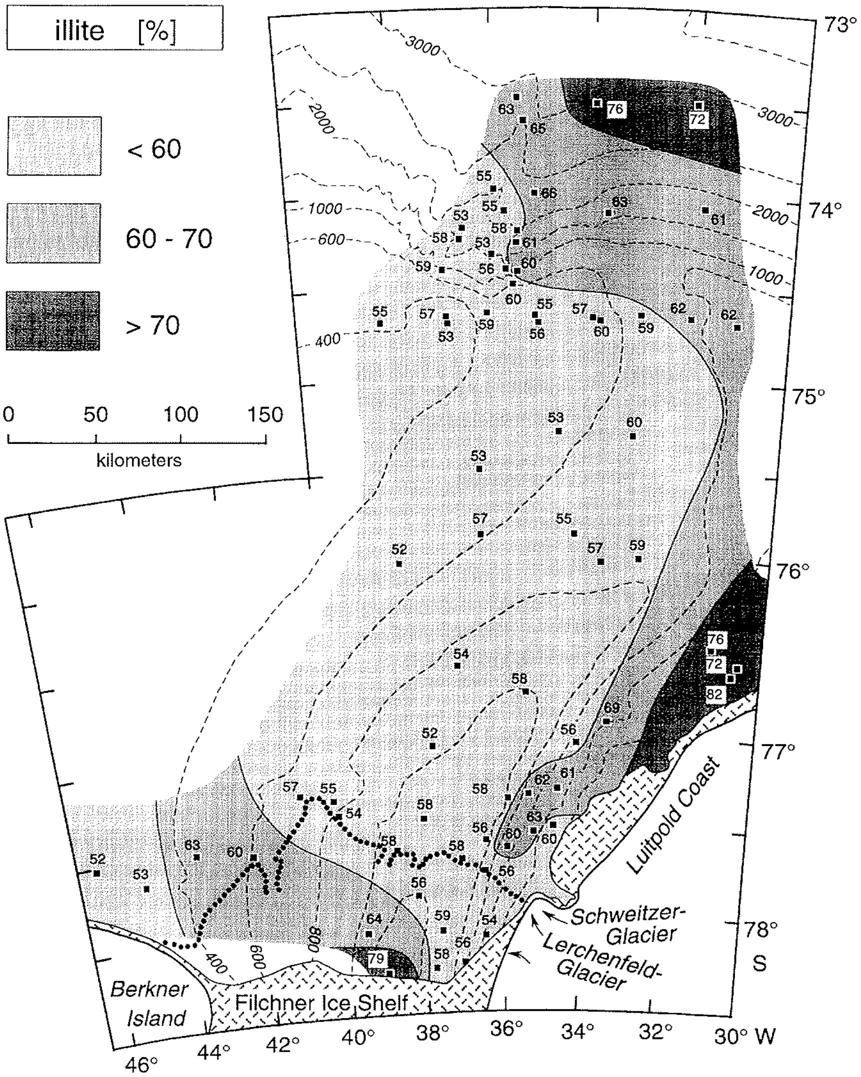

Fig. 17: Distribution of the content of illite in the clay fraction (in % of the clay minerals).

Abb. 17: Verteilung der Gehalte an Illit in der Tonfraktion (in % an den Tonmineralen).

Luitpold Coast (Fig. 14) may indicate that the current velocities of the ESW are too low for this species, whereas low sponge spicule contents on the continental margin (Fig. 7) could be limited by the stronger currents of the ISW.

On the other hand, high current velocities of the bottom water may cause a restriction of organic carbon accumulation or its erosion, resulting in a well oxygenated, non-corrosive interstitial water in the uppermost sediment, favouring the preservation of calcareous components (ANDERSON 1975b, MACKENSEN et al. 1990). In front of the Luitpold Coast, high organic carbon contents argue against the importance of this process, whereas on the continental margin low contents at some locations indicate a significant influence (Fig. 6). In addition, the ISW is formed beneath the ice shelf and flows north at intermediate depths until it makes contact with the bottom at the shelf edge. The ESW, in contrast, is exposed to organic carbon-rich sediments over a long distance in the eastern Weddell Sea (MACKENSEN et al. 1990), which in addition is an area of high primary production. The ESW, therefore, should have incorporated more CO_2 by oxidation of organic carbon than the ISW.

Whilst the high-energy flows of ISW and ESW obviously favour calcareous production and preservation, they seem to retard accumulation of radiolaria and arenaceous foraminifera (Figs. 8 and 9). In front of the Luitpold Coast, high contents of sponge spicules (Fig. 7) argue against silicate dissolution in the ESW. Hence, the perforate, generally small (<315 µm) radiolarian skeletons are more likely swept farther westward during settling through the water column. On the continental margin, in contrast, dissolution in the MWDW or ISW cannot be excluded. The minima of arenaceous foraminifera in both areas could be the result of their vulnerability against strong bottom currents.

Maximum contents of arenaceous foraminifera occur in the central Crary Trough in front of the former Filchner Ice Shelf (Fig. 9). High mud contents in this area (Fig. 4) indicate a low current velocity of the Western Shelf Water (WSW), which is flowing into the trough and further south beneath the ice shelf. Besides this faunal group, only molluscs show relatively high concentrations (Fig. 13). All other benthonic calcareous organisms have very low contents on the entire western shelf (Figs. 10, 12, 14), the area of both WSW formation and flow. This indicates

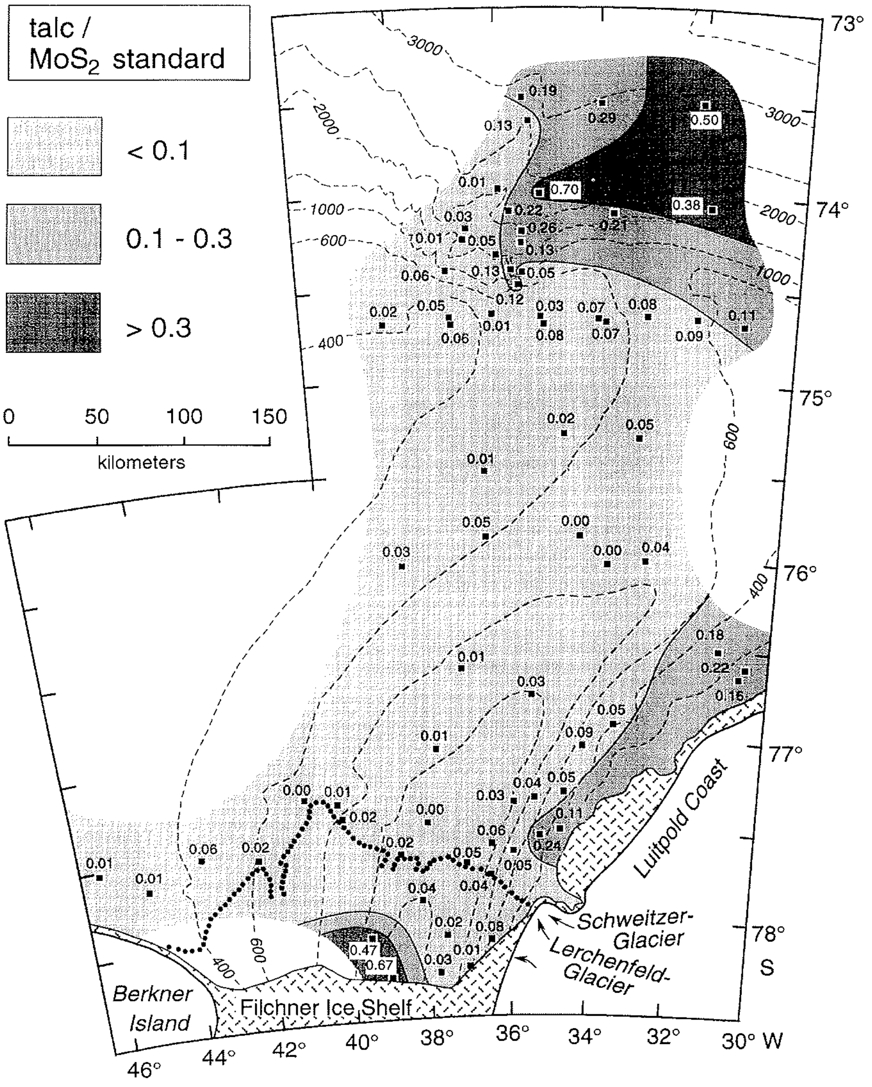

Fig. 18: Distribution of the content of talc in the clay fraction (as ratio to an internal MoS_2 standard).

Abb. 18: Verteilung der Gehalte an Talk in der Tonfraktion (als Verhältnis zu einem internen MoS_2-Standard).

an undersaturation of the WSW at the water/sediment interface in respect to calcium carbonate. However, the occurrence of the CCD in the water column on the continental shelf, as assumed by ANDERSON (1975a), can be excluded due to the molluscan distribution and the presence of calcareous foraminifera at almost all locations (Figs. 10 and 11).

Low contents but a presence of calcareous organisms also occur on the lower continental slope and on that part of the outer shelf and upper slope where the ISW is absent (Figs. 10-14). Hence, besides the WSW also the Antarctic Bottom Water (AABW), Weddell Deep Water (WDW), and Modified Weddell Deep Water (MWDW) probably cause carbonate dissolution in the surface sediment as assumed earlier by ANDERSON (1975a) and MACKENSEN et al. (1990). This interpretation is consistent with the calcite saturation in the water column and pore water in the Lazarev Sea, which show oversaturation of calcite in the water masses above ca. 3200 m, whereas the pore water in 4 cm sediment depth is clearly undersaturated below 1000 m (RUTGERS VAN DER LOEFF et al. 1992). In contrast to the areas of ESW and ISW flows, calcite undersaturation in the surface sediments of the remaining study area could be the result of different ages, formation processes and flow paths of the AABW, WDW, and MWDW. In addition, it could be due to lower calcareous primary production or accumulation rates in this area or to lower current velocities retarding winnowing of organic carbon and settlement of bryozoa and *B. corolliforme*. The latter process could also be responsible for the low contents of sponge spicules (Fig. 7).

Sediment transport in the water column

The composition of the ice-rafted debris (IRD) can be altered by marine processes after its release into the water column (CHRISS & FRAKES 1972, ANDERSON et al. 1980b). Whilst strong currents may cause a depletion of fine fractions, a decrease in current velocity may result in accumulation of the suspended load and, by this, dilution of the IRD by fine fractions. The same processes could influence the accumulation of planktonic organisms. High current velocities on the sea floor may additionally cause resuspension and redeposition of both terrigenous and biogenic sediment components. In the Weddell Sea, the energy level in the water column is controlled predominantly by

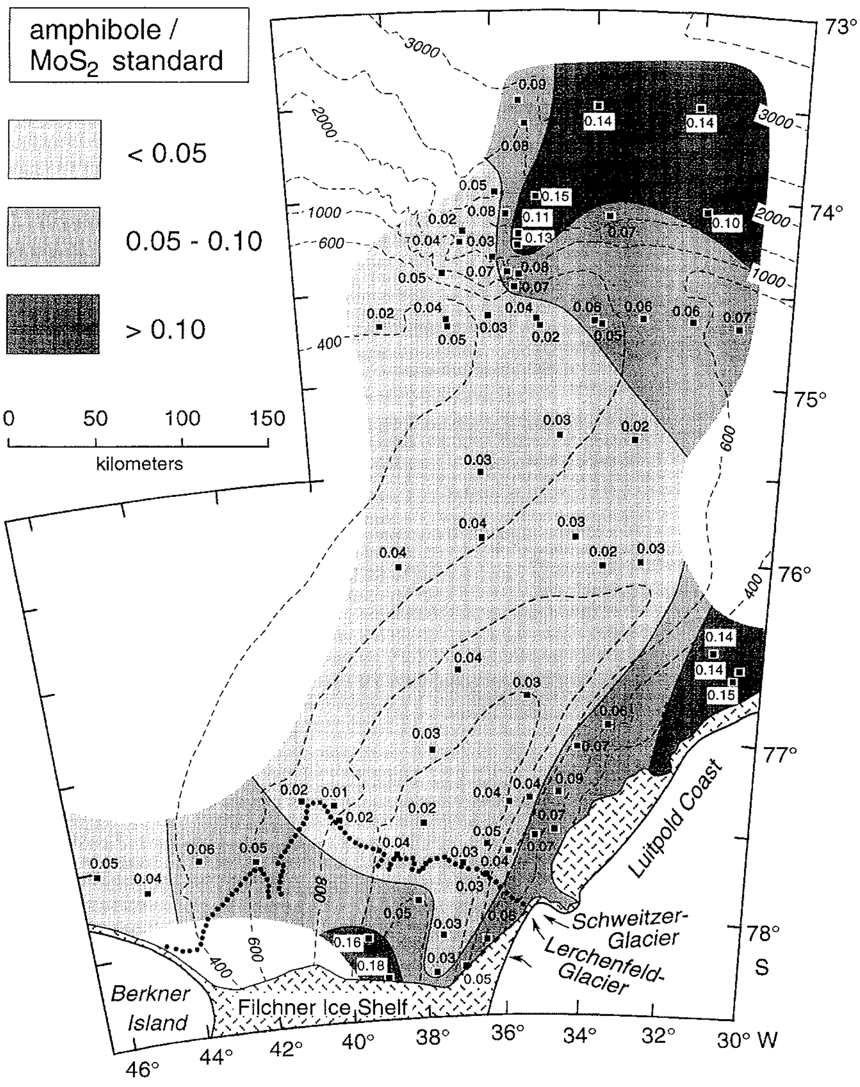

Fig. 19: Distribution of the content of amphibole in the clay fraction (as ratio to an internal MoS_2 standard).

Abb. 19: Verteilung der Gehalte an Amphibolen in der Tonfraktion (als Verhältnis zu einem internen MoS_2-Standard).

thermohaline currents. In coastal areas tidal currents could also be influential. Melt-water streams and wind-induced waves, in contrast, are negligible due to the climatic situation, the dense sea-ice coverage, and the deep continental shelf.

On the continental margin, well-sorted sands and gravelly sands occur in two apparently isolated regions, surrounded by poorly sorted muddy sands (Fig. 4). For this area, the discussion of sediment transport by ice has demonstrated a more or less constant flux of poorly sorted IRD. The flow of the Antarctic Coastal Current along the continental margin cannot be responsible for the coarse-grained surface sediments, because it has current velocities of only 6 to 7 cm/s, measured at the shelf edge close to the bottom at ca. 40° W (FOLDVIK et al. 1985a). Hence, the sands and gravelly sands have to be formed under the influence of the Ice Shelf Water (ISW).

The ISW flows from beneath the Filchner Ice Shelf (Fig. 1), follows the isobaths along the western flank of the Crary Trough in intermediate water depth, and spills out over the shelf break as a bottom current with mean velocities exceeding 50 cm/s (FOLDVIK 1986). At this velocity, the ISW is able not only to erode particles of medium-sand size from the bottom, but also to transport gravel-sized IRD particles (HEEZEN & HOLLISTER 1964). Whilst the gravelly sands on the continental margin could be due to winnowing of the finer fractions during and after settling of the IRD, the well-sorted sands must be the result of sand supply by the ISW itself. Hence, the coarse-grained surface sediments on the continental margin are probably both compound and residual glacimarine sediments as defined by ANDERSON et al. (1980b).

The flow of ISW over the shelf edge takes place without seasonal variations in a ca. 150 km wide, 150 - 250 m thick layer (FOLDVIK et al. 1985d). On the continental slope at least three separate, meandering plumes were identified; the major plume can be followed from ca. 33°30′ W at the shelf edge to ca. 35°50′ W in 1800 m water depth (FOLDVIK & GAMMELSRØD 1985, 1988). This coincides remarkably with the eastern area of coarse-grained surface sediments. The occurrence of two apparently isolated areas could be due to a step-wise shift of the main flow from the western to the eastern area within the time interval presented in the surface sediments. However, there is some evidence for two separate ISW branches from individual sources.

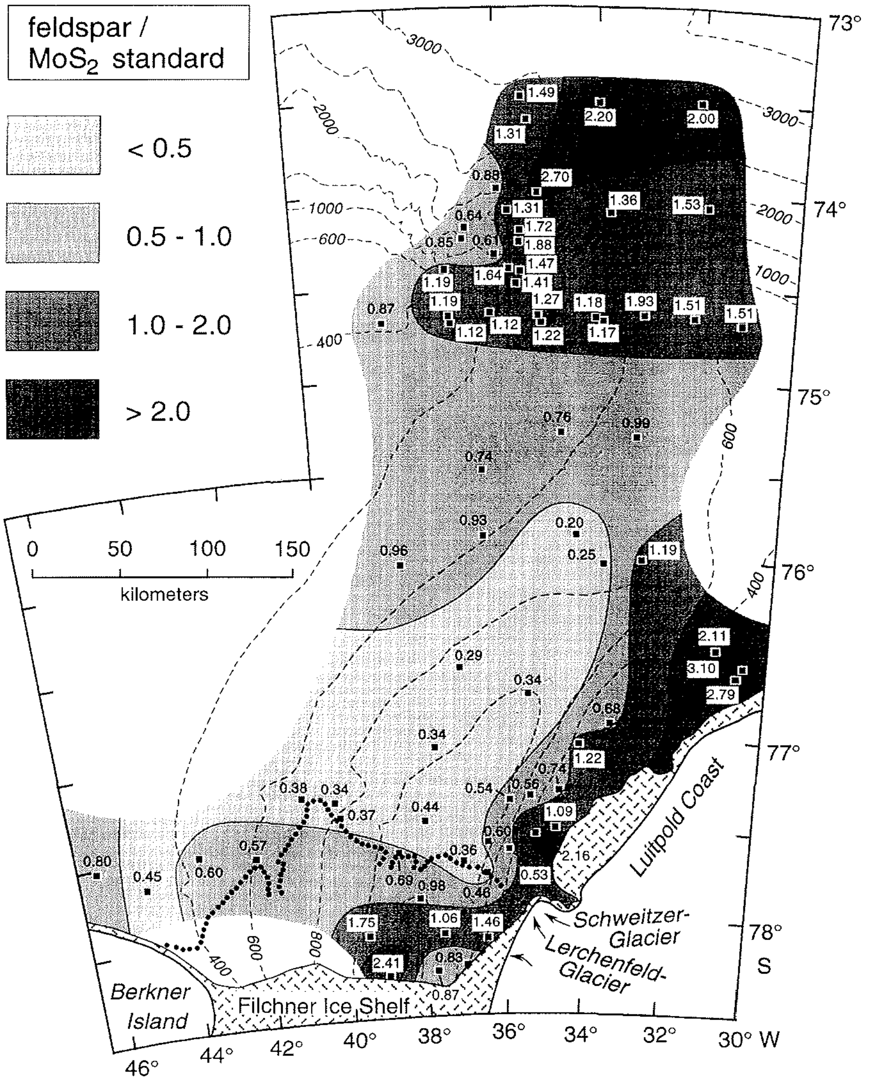

Fig. 20: Distribution of the content of feldspar in the clay fraction (as ratio to an internal MoS_2 standard).

Abb. 20: Verteilung der Gehalte an Feldspäten in der Tonfraktion (als Verhältnis zu einem internen MoS_2-Standard).

For example, the loss of three current meter moorings, deployed on the upper continental slope in the western coarse-grained area, could be due to a very strong ISW flow exceeding 150 cm/s (Foldvik 1986, Fütterer & Melles 1990). In addition, hydrographic sections across the Crary Trough show two ISW plumes on its western flank and a third, slightly warmer plume flowing in the opposite direction on its eastern flank (Foldvik et al. 1985b, Dieckmann et al. 1986). All of them occur in water depths similar to those of the shelf edge (Fütterer & Melles 1990). Different sources of the ISW flows are indicated also by the carbon isotopes in the benthonic foraminifera *Cassidulina biora*. On two locations in the eastern coarse-grained area they are more than 0.2 ‰ lower than in the western area. Possible explanations for two individual ISW flows could be the existence of a second circulation cell beneath the Filchner Ice Shelf as assumed by Hellmer & Olbers (1989) or an additional circulation of WSW beneath the Ronne Ice Shelf and around Berkner Island to the Filchner Ice Shelf (Fig. 1) as concluded by Foldvik & Gammelsrød (1988).

On the continental margin, the suspended load close to the bottom is much lower than in some other glacimarine environments (Elverhøi & Roaldset 1983). This indicates considerable stability of the ISW flow paths in those areas, where it extends to the sea floor. In this manner the ISW could stream predominantly above coarse-grained sediments already winnowed of most of the fine-grained material. The little-remaining clay fraction shows a mineral composition similar to the southern shelf. High contents of kaolinite (Fig. 16) and low contents of illite, talc, amphibole, and feldspar (Figs. 17-20) point to a significant impact of the IRD from Berkner Island, and the Schweitzer and Lerchenfeld Glaciers on the suspended load in the ISW.

Redeposition of biogenic components by the ISW is indicated by the occurrence of up to 8 cm long, always empty shells of the barnacle *B. corolliforme* at sites PS1417 and PS1492 (Fig. 2). Both sites are situated on the upper continental slope, ca. 20 km in ISW flow direction from site PS1611, where the box corer contained living species of *B. corolliforme* .

The extension of the western coarse-grained area (Fig. 4) indicates that the major part of the inferred western ISW plume on

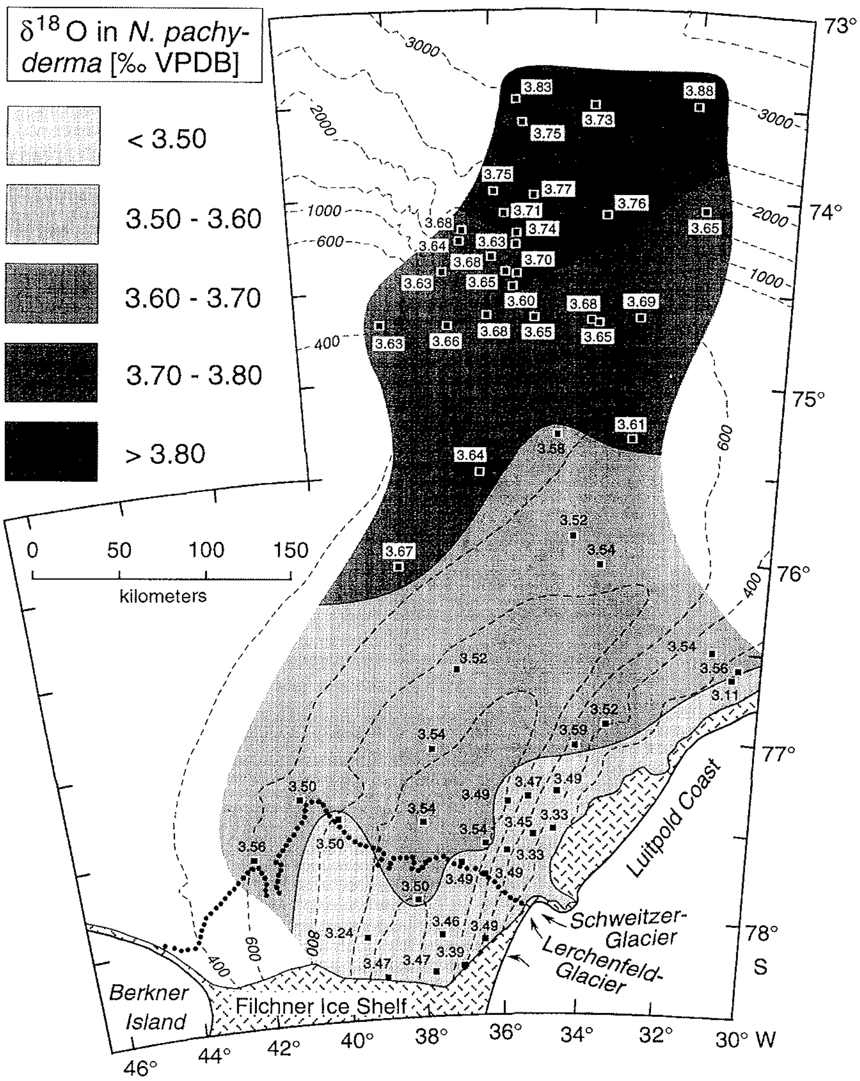

Fig. 21: Distribution of the stable oxygen isotope ratio in the planktonic foraminifera *Neogloboquadrina pachyderma* (in ‰ VPDB).

Abb. 21: Verteilung der stabilen Sauerstoff-Isotopenverhältnisse in den planktonischen Foraminiferen *Neogloboquadrina pachyderma* (in ‰ VPDB).

the upper continental slope crosses a striking, 200 - 400 m high western flank of an asymmetrical channel, which trends northwards into the deep sea (Fig. 2). The eastern ISW plume, and that part of the western ISW plume deflected at the channel flank and conducted along it to the north, extend to about 2000 - 2200 m water depth, as indicated by low temperatures and salinities of bottom water in this area (MELLES & KUHN 1993). Even for the bottom water in 3500 m depth, an ISW source is assumed from temperatures as low as -0.7 °C, measured directly east of the flank (BAYER et al. 1990). However, the current velocities of this bottom water can only be weak, as evidenced by very fine-grained surface sediments (Fig. 4).

The mineral composition in the clay fraction of the fine-grained sediments on the continental slope differs considerably from that on the continental shelf. High contents of illite, talc, amphibole, and feldspar, and low contents of kaolinite (Figs. 16-20) indicate a source area dominated by magmatic and metamorphic, rather than sedimentary rocks. Such a petrological composition is found in ice-free areas of the eastern Weddell Sea (ROOTS 1969, JUCKES, 1972), and is believed to be similar to the terrigenous sediment transported by icebergs from this region. The IRD supply, however, must be enriched in fine material by marine currents, because the surface sediments on the lower slope show mud contents of more than 80 %, much higher than assumed for the IRD in the Weddell Sea (Fig. 22).

In the southern Weddell Sea, the Weddell Deep Water (WDW) and the Antarctic Bottom Water (AABW) flow westward along the continental slope as part of the Weddell Gyre. Current velocity measurements within these water masses are scarce; whilst in the northwestern Weddell Sea they show up to 10 cm/s (BARBER & CRANE 1995), in the eastern and northern Weddell Sea all of them show velocities of less than 6 cm/s (CARMACK & FOSTER 1975a, FOSTER & MIDDLETON 1979), enabling a maximum grain-size of coarse silt to be transported (SINGER & ANDERSON 1984). Hence, accumulation of mud suspended in the WDW and AABW can be expected. Accumulation in fact is indicated by similarities between the fine-fraction compositions in the study area (Figs. 16-20) and in the eastern Weddell Sea. For example, ELVERHØI & ROALDSET (1983) found high illite and amphibole contents in the clay and mud fractions in front of the Fimbul Ice Shelf. Sediments from a submarine terrace on the slope show a combination of high illite and very low kaolinite

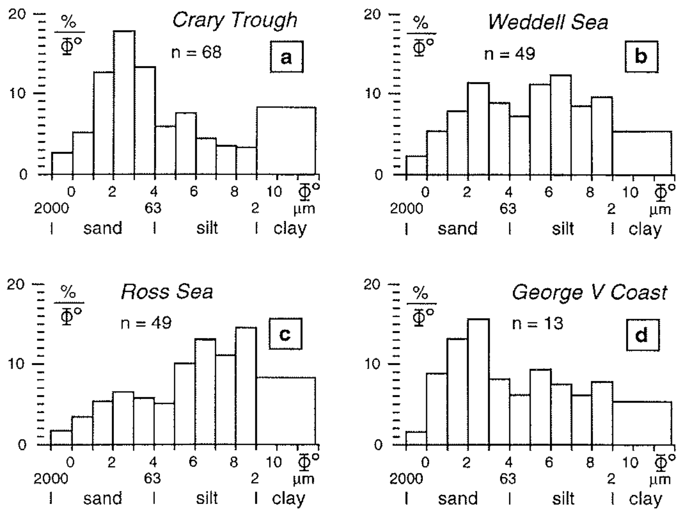

Fig. 22: Mean grain-size distributions (<2 mm; n = number of samples) of the lodgement till from different continental shelf areas of Antarctica showing regional differences but similarly poor sorting in all areas. Data from the Crary Trough (a) after MELLES (1987), data from the entire Weddell Sea (b), Ross Sea (c) and George V Coast (d) after ANDERSON et al. (1980b).

Abb. 22: Die mittleren Korngrößenverteilungen (<2 mm; n = Probenzahl) von glazialen Diamiktiten aus unterschiedlichen Schelfgebieten der Antarktis zeigen regionale Unterschiede aber ähnlich schlechte Sortierungen in allen Gebieten. Daten von der Filchner-Rinne (a) nach MELLES (1987), von den Kontinentalschelfen des gesamten Weddellmeeres (b), des Rossmeeres (c) und der George V-Küste (d) nach ANDERSON et al. (1980b).

contents in the clay fraction (GROBE 1986, GROBE & MACKENSEN 1992). The same composition with additional high amphibole contents occurs on the continental slope and shelf between 25° and 29° W, adjacent to the area studied (WEBER 1992).

The influence of sediment accumulation by that part of the Antarctic Coastal Current, which flows along the continental margin to the west, is less clear. FOLDVIK et al. (1985a) measured current velocities of 6 to 7 cm/s close to the bottom at ca. 40° W. GILL (1973) calculated a decrease of 40 % in velocity west of 24° W. Although accumulation of fine material may, therefore, be expected, this is demonstrated neither by the clay composition nor by the grain-size distribution. This indicates that sedimentation on the entire continental margin of the area studied is more or less dominated by the ISW flows, masking any other marine influence.

In contrast, on the upper eastern flank of the Crary Trough, where the major branch of the Antarctic Coastal Current flows to the south, a marine sediment supply is evident from the mineral composition in the clay fraction. The similarity to the lower continental slope, namely low kaolinite and high illite, talc, amphibole, and feldspar contents (Figs. 16-20), again indicates a source area situated in the eastern Weddell Sea. The narrow zone in front of the Luitpold Coast which shows this characteristic clay composition extends below the former Filchner Ice Shelf, indicating a lateral sediment supply by the Eastern Shelf Water (ESW), as assumed also for planktonic foraminifera and nutrients. In front of the Schweitzer and Lerchenfeld Glaciers, the ESW-signal is overprinted by enhanced IRD supply rich in sedimentary rocks.

The Western Shelf Water (WSW) is formed on the shallow shelf in front of Berkner Island and descends towards deeper areas. It probably occurs on the bottom of the remaining western continental shelf in those regions not influenced by the Antarctic Coastal Current. There, the composition of the clay fraction is relatively homogeneous, characterized predominantly by high kaolinite and low illite, talc, amphibole, and feldspar contents (Figs. 16-20). The grain-size distribution, in contrast, shows a continuous increase in mud content with increasing water depth (Fig. 4).

The well-sorted sands in front of Berkner Island are composed almost exclusively of quartz and feldspar (Fig. 15). An early interpretation as interglacial dune and beach deposits (REX et al. 1970), was first disproved by ANDERSON (1971), who assumed a marine origin from the grain-size distribution and the presence of a marine microfauna. FÜTTERER & MELLES (1990), in contrast, deduced a glacimarine accumulation with a dominance of glacial sediment supply of Beacon Group sedimentary rocks from Berkner Island. This interpretation is in conformity with the discussion of terrigenous sediment transport by ice (see above). In addition, a marine sand supply is unlikely, because there is some evidence for only sluggish bottom water circulation in front of Berkner Island. For example, tidal currents, which reach up to 40 cm/s perpendicular to the edge of the Ronne Ice Shelf (ROBIN et al. 1983), are probably of minor importance, because no large floating ice shelf occurs at the coastline off Berkner Island, and because the sands cover a much wider area, extending ca. 300 km farther to the north (ANDERSON et al. 1983). The strong flow of ISW, on the other hand, is located further east of the well-sorted sands (FOLDVIK et al. 1985b, DIECKMANN et al. 1986). Finally, the distinct minima in sponge spicules and bryozoa (Figs. 7 and 12) and the absence of the barnacle *B. corolliforme* (Fig. 14) are probably due to low current velocities.

In contrast to the well-sorted sands off Berkner Island, the muddy sands on the upper western flank of the Crary Trough (Fig. 4) could be influenced by the ISW flow. Because the ISW overlies the WSW, it could only winnow the fine fractions from the IRD as it settles through the water column. The sandy muds, gravelly muds and muds in the central Crary Trough, in contrast, are probably caused by enrichment of the IRD with fine-grained material, which is supplied by both the ESW and ISW flows. Hence, the Crary Trough acts as a sediment trap. This is also evident from the thickness of postglacial sediments recovered, which ranges from about a metre in the axis of the trough to only a few centimetres along the flanks (FÜTTERER & MELLES 1990). IRD-enrichment with fine-grained sediments was found also in other depressions on the Antarctic continental shelf, e.g., in the region of the Antarctic Peninsula, in front of the Adelie-George V Coast, and in the Ronne Trough in the western Weddell Sea (ANDERSON et al. 1983, FÜTTERER & MELLES 1990).

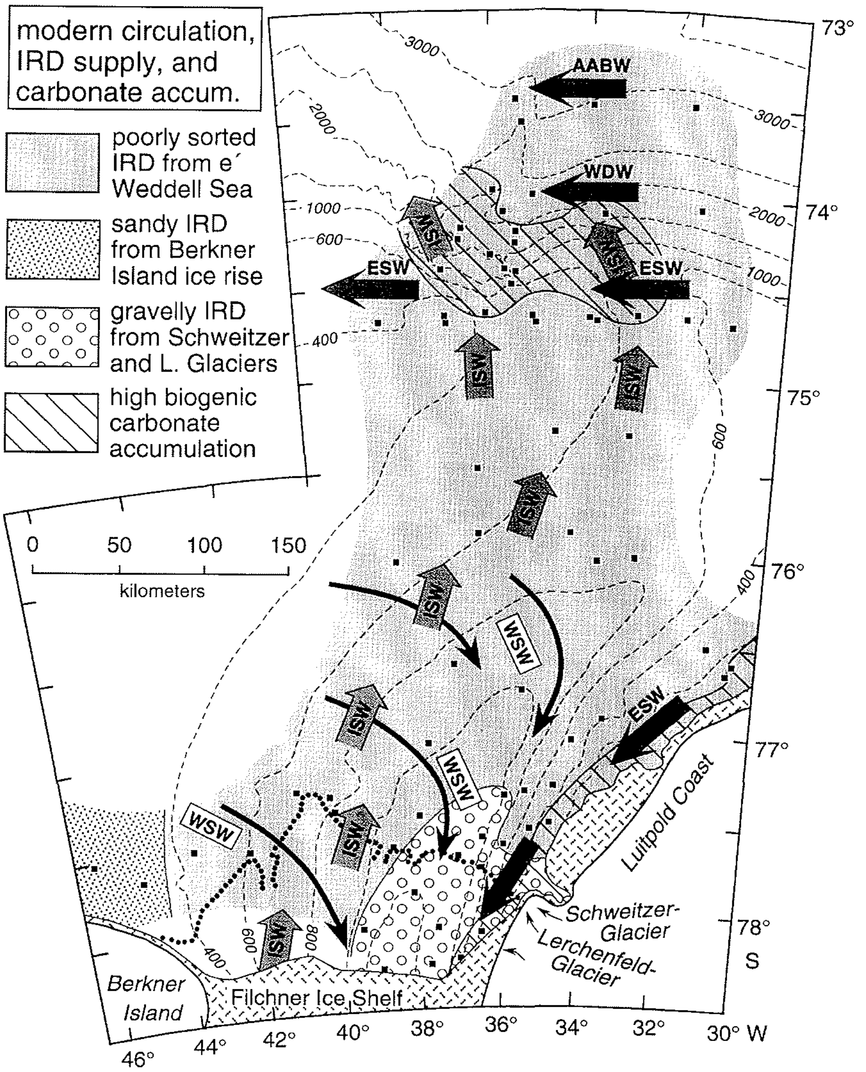

Fig. 23: Map showing the modern ice-rafted debris (IRD) supply, areas of highest biogenic carbonate accumulation, and water mass circulation in the southern Weddell Sea (*AABW* = Antarctic Bottom Water, *WDW* = Weddell Deep Water, *ESW* = Eastern Shelf Water, *WSW* = Western Shelf Water, *ISW* = Ice Shelf Water).

Abb. 23: Karte mit dem rezenten Eintrag an Eisfrachtsedimenten (IRD), den Gebieten höchster biogener Karbonatakkumulation und der Zirkulation der Wassermassen im südlichen Weddellmeer (*AABW* = Antarktisches Bodenwasser, *WDW* = Weddellmeer-Tiefenwasser, *ESW* = Östliches Schelfwasser, *WSW* = Westliches Schelfwasser, *ISW* = Eisschelfwasser).

SUMMARY AND CONCLUSIONS

The composition of surface sediments yields important information on the modern processes of sedimentation in the southern Weddell Sea and their dependence on the present-day glaciological, physiographical, and hydrographical setting. In addition, some new conclusions may be drawn concerning the controversially discussed present-day oceanographic circulation, and the stability of the environmental conditions within the time period represented in the surface sediments.

Most of the terrigenous material is delivered to the ocean by glacial transport. In the northern part of the area studied the ice-rafted debris (IRD) is probably supplied from the eastern Weddell Sea (Fig. 23). This IRD is characterized by poor sorting and a dominance of crystalline source rocks (Fig. 24). On the southern continental shelf, in contrast, the IRD contains significant portions of sedimentary rocks. Whilst the IRD from the Schweitzer and Lerchenfeld Glaciers is abnormally rich in gravel, that from Berkner Island probably consists of almost pure sand.

Biogenic production and preservation are controlled by the physical and chemical properties of the water masses rather than by differences in the sea-ice cover or in water depth. The strong bottom water flows of the ISW at the continental margin and of the ESW off the Luitpold Coast favour the settlement of sessile organisms with filtering feeding habitats such as bryozoa, barnacles, and sponges (Figs. 23 and 24). In addition, they reduce carbonate dissolution at the water/sediment interface. Carbonate dissolution on the other hand takes place in the areas of the slow WSW, WDW, and AABW flows. These areas are characterized by very low contents of most calcareous biogenic components, with the exception only of molluscs, which reach relatively high values beneath and in front of the former Filchner Ice Shelf. In contrast to the calcareous organisms, the radiolaria and in some parts the arenaceous foraminifera have their maximum contents in the areas of the WSW, WDW, and AABW flows.

No evidence was found for sediment redeposition by grounded ice or gravitational transport. Resuspension by flowing water, in contrast, is believed to play a significant role in sediment formation. However, incorporation of fine-grained material, which

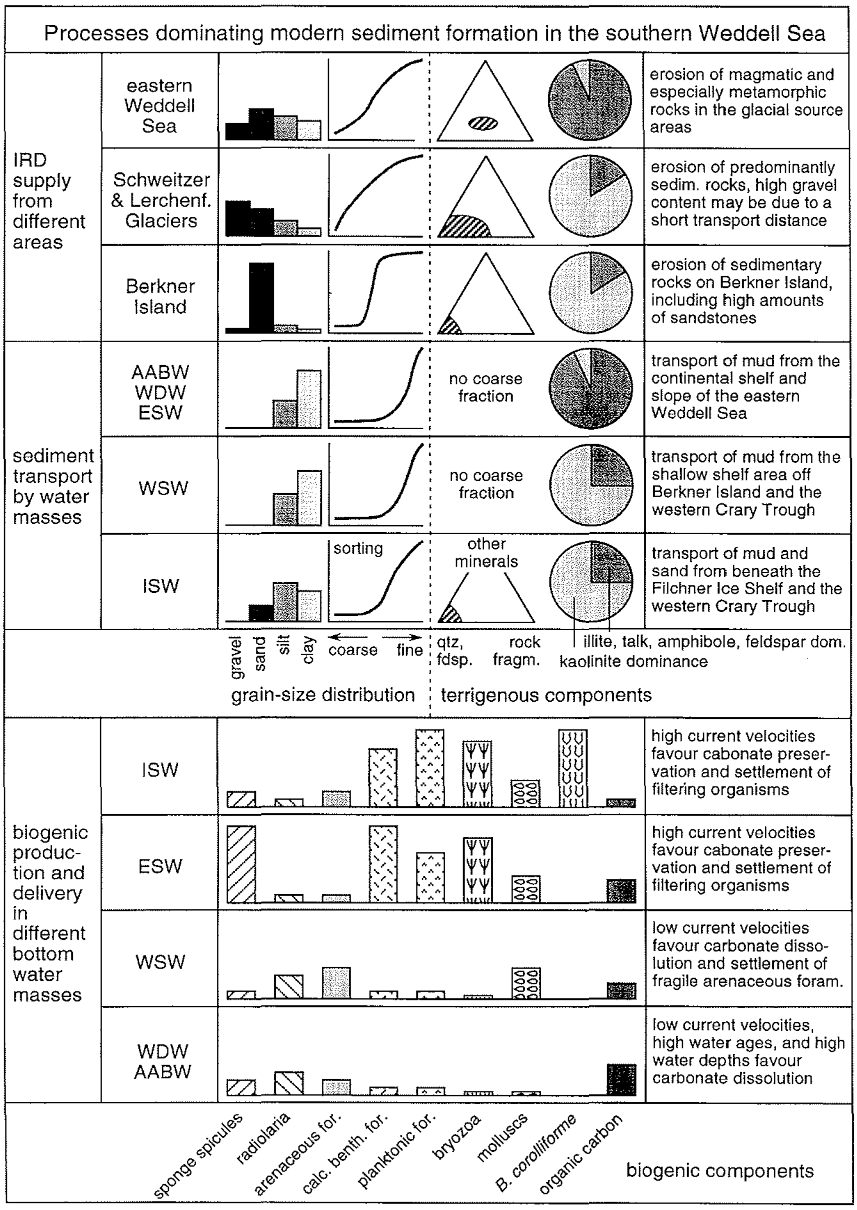

Fig. 24: Schematic presentation of the processes dominating modern sediment formation in the southern Weddell Sea. Of major importance are differences in the ice-rafted debris (IRD) supply, and in sediment transport and biogenic accumulation in dependence from the water mass properties (*AABW* = Antarctic Bottom Water, *WDW* = Weddell Deep Water, *ESW* = Eastern Shelf Water, *WSW* = Western Shelf Water, *ISW* = Ice Shelf Water).

Abb. 24: Schematische Darstellung der dominierenden Prozesse für die rezente Sedimentbildung im südlichen Weddellmeer. Von besonderer Bedeutung sind Unterschiede im Eintrag der Eisfrachtsedimente (IRD) sowie im Sedimenttransport und in der biogenen Akkumulation in Abhängigkeit von den Eigenschaften der Wassermassen (*AABW* = Antarktisches Bodenwasser, *WDW* = Weddellmeer-Tiefenwasser , *ESW* = Östliches Schelfwasser, *WSW* = Westliches Schelfwasser, *ISW* = Eisschelfwasser).

is released to the water column as part of the IRD, probably dominates the lateral transport. The water masses of the Weddell Gyre (AABW, WDW, and ESW) supply mud from the eastern Weddell Sea to the lower continental slope and to the eastern flank of the Crary Trough (Figs. 23 and 24). Some fine-grained material is also transported from the shelf area off Berkner Island to the central Crary Trough by the WSW flow. The ISW, in contrast, transports up to sand-sized particles from the southern shelf area to the continental margin.

Most of the sedimentary parameters show significant regional differences within the area investigated. This indicates that the environmental conditions were more or less stable during the time period of a few decades to several centuries as represented by the surface sediments. The oceanographic circulation during this time period, reflected by the sediment composition, differs in detail from that deduced from *in situ* measurements available so far. For example, there is strong evidence from the sediment composition that significant parts of the ESW in front of the Luitpold Coast have flowed beneath the former Filchner Ice Shelf prior to the calving event in 1986 (Fig. 23). In addition, the sediments indicate the occurrence of two individual ISW plumes at the continental margin. Their probable source area is the Filchner Ice Shelf; however, it is uncertain, whether both plumes originate from those ISW cores measured on the western ice shelf edge, or whether the eastern plume represents the ISW core on its eastern edge. In contrast, no evidence was found of branches of MWDW regularly spilling over the shelf break and flowing as far south as the ice shelves of the southern Weddell Sea.

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