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Recent and Subrecent Marine Sediments of the North-Western Weddell Sea and the Bransfield Strait, Antarctica

By Georg Troll†**, Dietmar Matthies*, Alfons Hofstetter** and Wolfgang Skeries***

Summary: The raw material for these investigations are samples from marine (sub)surface sediments around the northern part of the Antarctic Peninsula. They had been sampled in the years 1981 to 1986 during several expeditions of the research vessels *Meteor*, *Polarstern* and *Walther Herwig*.

83 box core, gravity core and dredge samples from the area of the Bransfield Strait, the Powell Basin and the northern Weddell Sea have been examined for their grain-size distribution, their mineralogical and petrographical composition. Silt prevails and its clay proportions exceed 25% wt. in water depths greater than 2000 m. The granulometrical results reveal some typical sedimentation processes within the area of investigation. While turbiditic processes together with sediment input from melting icebergs control the sedimentation in the Weddell Sea, the South Orkney Island Plateau and the Powell Basin, the fine grained material from Bransfield Strait mainly relies on marine currents in the shelf area. In addition, the direct sediment input of coarse shelf sediments from the Bransfield Strait into the Powell Basin through submarine canyons could be proven. Variations in the grain-size composition with sediment depth are small.

The mineral composition of the clay and fine silt fractions is quite uniform in all samples. There are (in decreasing order): illite, montmorillonite, chlorite, smectite, mixed-layers, as well as detrital quartz and feldspars. A petrographically based sediment stratigraphy can be established in using the considerable changes in the chlorite- and Ca-plagioclase portions in samples from Core 224. For this sedimentation area a mean sedimentation rate of 7 cm /1000 a is assumed. Remarkable changes in the portions of amorphous silica components - diatom skeletons and volcanic glass shards - appear all over the area of investigation. They contribute between 4-83 % to the clay and fine silt fraction.

Several provinces according to the heavy mineral assemblages in the fine sand fraction can be distinguished: (i) a province remarkably influenced by minerals of volcanic origin south and north of the South Shetland Islands; (ii) a small strip with sediment dominated by plutonic material along the western coast of the Antarctic Peninsula and (iii) a sediment controlled by metamorphic minerals and rock fragments in the area of the Weddell Sea and Elephant Island.

While taking the whole grain-size spectrum into account a more comprehensive interpretation can be given: the accessoric but distinct appearance of tourmaline, rutile and zircon in the heavy mineral assembly along the northwestern coast of the Antarctic Peninsula is in agreement with the occurrence of acid volcanic rock pieces in the coarse fraction of the ice load detritus in this region. In the vicinity of the South Shetland Islands chlorite appears in remarkable portions in the clay fraction in combination with leucoxene, sphene and olivine, and pumice as well as pyroclastic rocks in the medium and coarse grain fractions, respectively. Amphiboles and amphibole-schists are dominant on the South Orkney Island Plateau. In the sediments of the northwestern Weddell Sea the heavy mineral phases of red spinel, garnet, kyanite and sillimanite in connection with medium to highgrade metamorphic rocks especially granulitic gneisses, are more abundant. A good conformity between the ice rafted rock samples and the rocks in the island outcrops could be proven, especially in the vicinity of offshore islands nearby. On the continent enrichments of rock societies and groups appear in spacious outlines: acid effusive rocks in the west of the ice divide on the Antarctic Peninsula, clastic sedimentites at the tip of the Antarctic Peninsula and granoblastic gneisses in central and eastern Antarctica.

Coarse grain detritus with more than 1 cm of diameter must have been rafted by icebergs. These rock fragments are classified as rock types, groups and societies. The spacial distribution of their statistically determined weight relations evidently shows the paths of the iceberg drift and in nexus with already known iceberg routes also point to the possible areas of provenance, provided that the density of sample locations and the number of rock pieces are sufficient.

Zusammenfassung: Gegenstand dieser Untersuchungen waren marine Oberflächensedimentproben vom nördlichen Teil der Antarktischen Halbinsel. Sie wurden während mehrerer Expeditionen der Forschungsschiffe *Meteor*, *Polarstern* und *Walther Herwig* in den Jahren von 1981 bis 1986 gewonnen.

83 Kastengreifer-, Schwerelot- und Dredgeproben aus dem Gebiet der Bransfield-Straße, dem Powell-Becken und dem nördlichen Weddellmeer wurden hinsichtlich ihrer Korngrößenzusammensetzung, ihrer mineralogischen und petrographischen Bestandteile untersucht. Es handelt sich überwiegend um Silte, deren Tonanteile in Wassertiefen größer als 2000 m auf über 25 Gew.-% ansteigen. Anhand der granulometrischen Befunde konnten einige typische Sedimentationsprozesse identifiziert werden. Der Sedimenteintrag in das Weddellmeer, dem South-Orkney-Inselplateau und dem Powell-Becken geschieht überwiegend durch Turbidite und abschmelzende Eisberge. Feinkörniges Material in der Bransfield-Straße wurde durch Meeresströmungen im Schelfgebiet eingetragen. Darüber hinaus konnte der direkte Sedimenteintrag aus der Bransfield-Straße in das Powell-Becken über submarine Canyons nachgewiesen werden.

Die mineralogische Zusammensetzung der Ton- und Feinsiltfraktion aller Proben ist sehr einheitlich. Es handelt sich in abnehmender Reihenfolge um Illit, Montmorillonit, Chlorit, Smektit, Mixed Layers, sowie Quarz und Feldspat. Aufgrund deutlich unterschiedlicher Anteile von Chlorit und Ca-Plagioklas kann eine sedimentstratigraphische Unterteilung des Kernes 224 getroffen werden. Für dieses Sedimentationsgebiet wird eine mittlere Sedimentationsrate von 7 cm/ 1000 Jahre angenommen. Amorphe Kieselsäurekomponenten wie Diatomeenskelette und vulkanische Gesteinsgläser machen zwischen 4 und 83 % der Ton- und Feinsiltfraktion aus.

Aufgrund der Schwermineralvergesellschaftungen in der Feinsandfraktion können mehrere Provinzen ausgeschieden werden: (1) südlich und nördlich der South-Shetland-Inseln eine Vergesellschaftung überwiegend vulkanischen Ursprungs; (2) ein schmaler Streifen plutonisch domierten Materials entlang der westlichen Küste der Antarktischen Halbinsel und schließlich (3) überwiegend metamorphe Minerale im Gebiet der Elephant-Insel und des Weddellmeeres.

Unter Berücksichtigung des gesamten Korngrößenspektrums kann eine umfassende Interpretation erfolgen. Das akzessorische, jedoch deutliche Auftreten von Turmalin, Rutil und Zirkon in der Schwermineralfraktion entlang der nordwestlichen Küste der antarktischen Halbinsel steht im Einklang mit der Präsenz von saueren vulkanischen Gesteinsbruchstücken in der Grobkornfraktion des Eisfrachtdetritus in dieser Region. In der Nähe der South-Shetland-Inseln erscheint in bemerkenswertem Umfange Chlorit in der Tonfraktion in Verbindung mit Leukoxen, Olivin und Bimsstein sowie pyroklastischen Gesteinen in der Mittel- und Grobkornfraktion. Amphibole und Amphibolschiefer herrschen auf dem South-Orkney-Island-Plateau vor. In den Sedimenten des nordwestlichen Weddellmeeres treten häufig die Schwerminerale roter Spinell, Granat, Kyanit und Sillimanit in Verbindung mit mittel- bis hochmetamorphen Gesteinen, insbesondere granulitischen Gneisen, auf. Desweiteren besteht eine gute Übereinstimmung zwischen den Gesteinsaufschlüssen auf den Inseln und den eistransportierten Gesteinsproben.

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Gesteinsfragmente von mehr als 1 cm Größe, die nur in der Sedimentfracht von Eisbergen transportiert sein können, wurden in Gesteinstypen, -gruppen und -gesellschaften unterteilt. Ihre räumliche Verteilung gibt eindeutige Hinweise auf Eisbergdriftwege und erlaubt im Zusammenhang mit bereits bekannten Eisbergstraßen Rückschlüsse auf mögliche Liefergebiete.

INTRODUCTION

In modern geosciences Arctic as well as Antarctic areas serve for the investigation of short and long-term changes in the global meteorological history. This mainly relies on the preserving effect of the polar ice caps and the lack of major anthropogenic impacts. Beside glacial records also limnetic and marine sediments hold important information, which can help to enlight the meteorology of the past. The detailed knowledge of the mineralogical composition of the clay and fine silt fraction in space (lateral) and time (vertical) forms the basis for further interpretations concerning the climatical and sedimentological history of the Antarctic (GROBE 1986).

This paper gives a comprehensive petrological description of the marine sediments of the northwestern Weddell Sea, the Powell Basin, South Orkney Island Plateau and the Bransfield Strait, respectively. While looking to the total grain-size spectra and the petrological composition, which are in close relationship to each other, a reconstruction of the sedimentation conditions as well as the stratigraphical position of the sediment samples becomes possible. Moreover, some aspects of the geological setting of the hinterland can be deduced from the coarse grain and heavy mineral fractions. This is of utmost importance because of the lack of outcrops in this region. The discussion about the age of the sediment core samples from the Bransfield Strait should contribute to a better understanding of the most recent climatic and glacial history in this region.

The area of investigation (Fig. 1) extends from 57° to 66° latitude south and 38° to 67° longitude west, and covers an area of about 2,000,000 km². The sea floor topography is quite well known and will, therefore, be described only very briefly. From a geographical point of view the investigated area can be subdivided into three sub-areas, of which the Bransfield Strait forms the southern part, the Powell Basin the middle, and the Weddell Sea the northern part. The Bransfield Strait has an extension of about 1000 km and a width between 100 and 150 km. Several elongated basins subdivide the sea floor. Powell Basin follows to the East and is a structure which opens towards the Weddell Sea, while it is limited in the North by a submarine Andine orogenic belt.

The area of investigation is documented by 83 sampling stations, which cover the shelf as well as the deep-sea area. The samples

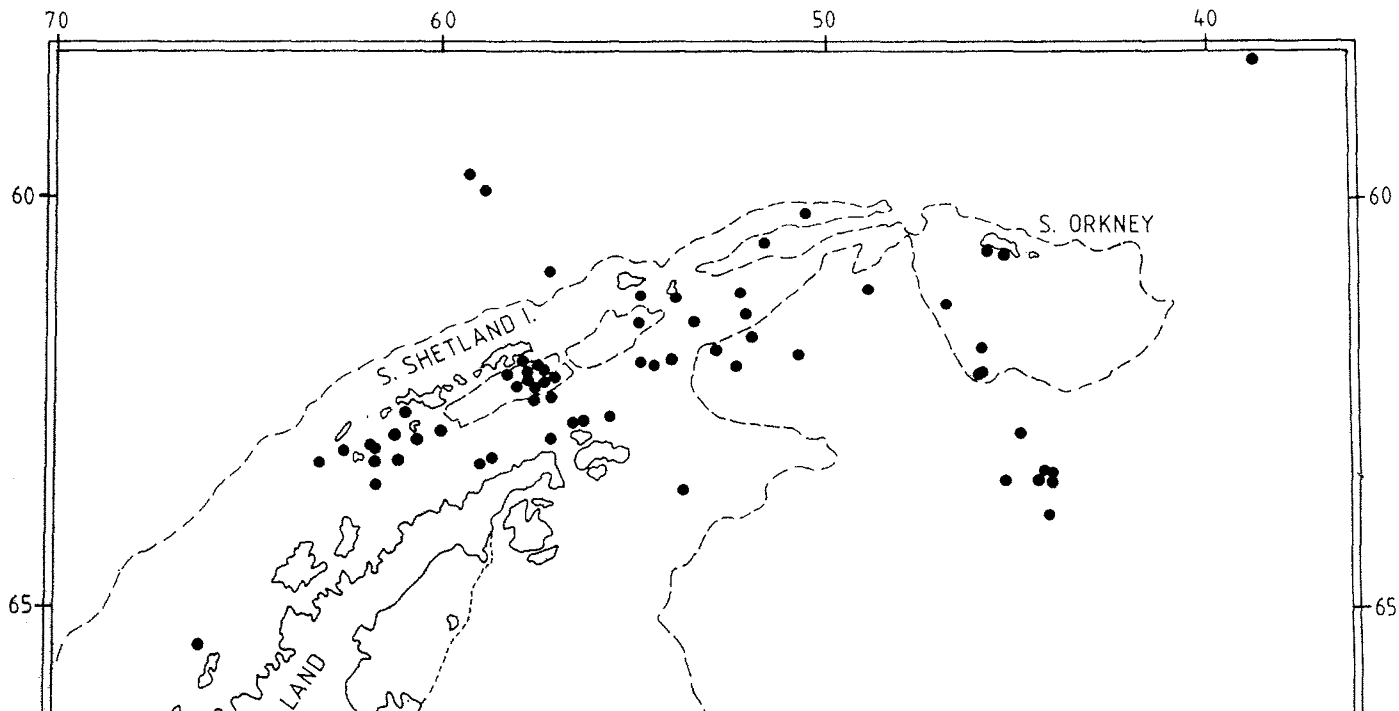

Fig. 1: Geographical distribution of all samples investigated. Dashed line indicates 1000 m bathymetric contourline.

Abb. 1: Verteilung der Probenstationen. Gestrichelte Linie beschreibt die 1000 m Tiefenlinie.

were delivered during the cruises of the research vessels *Meteor, Polarstern* and *Walther Herwig*. The geographical positions of the stations, the water depths and the sampling techniques are reported elsewhere. Fig. 1 shows the geographical distribution of the stations.

Fig. 2 depicts the drift of larger icebergs (>60 km^2) within this area. Data from satellite images (Naval Polar Oceanographic Center) of the years from 1977 to 1986 form its basis. It is assumed that the marine catchment area for the icebergs and their ice rafted detritus lies within 102° W and 0°. The terrestrial catchment area for the ice rafted detritus which envelopes the Weddell Sea, has an areal extension of about 3,500,000 km^2. The knowledge of these drift paths is of great significance for the discussion of sedimentation processes and transport paths in marine Antarctic regions. Information on the drift paths are given by HOEBER et al. (1987) and LAXON et al. (1992).

MATERIAL AND METHODS

All samples were taken during several cruises of RV *Meteor* (M 56/3, 1981), RV *Polarstern* (ANT-II/3, 1983; ANT III/2,1984; ANT III/3,1985; ANT IV/2, 1985), and RV *Walter Herwig* (Cruise 68/2,1985). Fine and medium grained material derived from gravity and box cores, while the coarse detritus was sampled by means of dredges and box cores. The samples were transported and stored in a cold store.

Grain-size analysis

In order to separate the grain-size fractions greater than 0.063 mm the samples were wet sieved and fractionated into the grain-size fractions 0.063-0.2 mm (fine sand), 0.2-0.63 mm (sand), 0.63-2 mm (coarse sand), and 2-6.3 mm (fine gravel). The ATTERBERG sedimentation method was used for the fractions smaller than 0.063 mm. Koagulation phenomena were eliminated by the use of H_2O dist. A comparative study with a sedigraph (GROBE 1986) revealed a good agreement with our results obtained by the sedimentation method.

Heavy mineral analysis

For the heavy mineral analysis the samples were wet sieved through a 0.1 mm screen to separate the fine sand (0.-0.2 mm) and very fine sand (0.63-0.1 mm) fractions present in each sample.

The very fine sand fraction and the fine sand fraction were chosen as the size intervals to be investigated because they commonly contained the highest percentage of heavy minerals, and they do not cause any optical problems. The two fractions were split into heavy and light mineral assemblages by the use of an aqueous sodium poly-tungstenate solution (3 Na_2WO_4 x 9 WO_3 x H_2O, density 2.95 g/cm^3). The heavy fractions of all samples

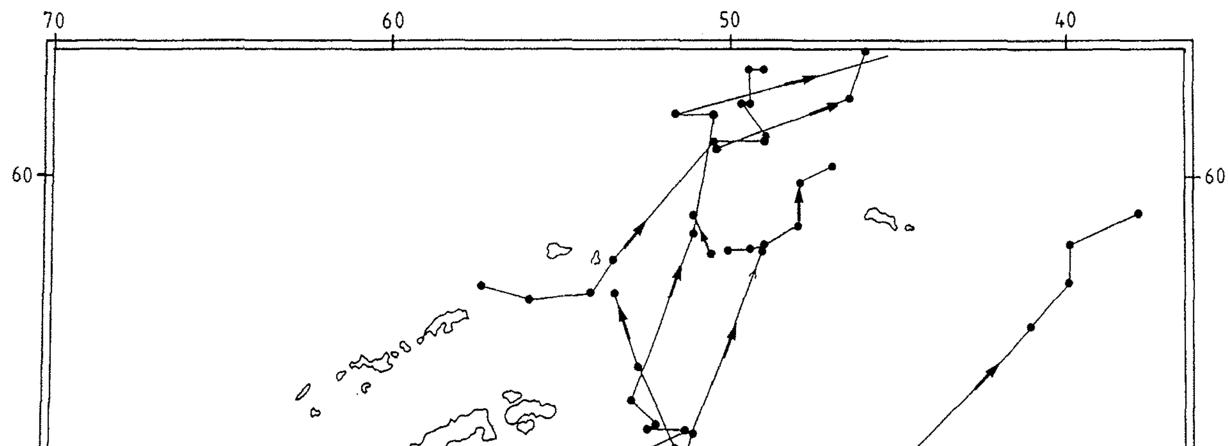

Fig. 2: Drift paths of larger icebergs (>60 km^2) in the years between 1977 and 1986 based on satellite data from Naval Polar Oceanographic Center.

Abb. 2: Driftwege größerer Eisberge (>60 km^2) nach Satellitenaufnahmen des Naval Polar Oceanographic Center aus den Jahren 1977 bis 1986.

were mounted on slides using Lakeside (n = 1.54). A polarisation microscope was used to identify and count 200 heavy minerals in each of the two fine sand-size fractions of each sample.

According to Boenigk (1983) the reliability of mineral percentages based on a count of 400 grains/sample should vary from 1.7-5.0 %, depending on the percentage of a given mineral constituent in the sample.

Dropstone analysis

The qualitative determination of most of the dropstone specimen is ensured by their megascopic features. Carbonatic rocks were separated into calcitic and dolomitic types by means of diluted acid (2-5 %). Some magmatic specimens were stained selectively for potassium-feldspar. The relative amount of minerals from some magmatic rocks was determined by point counting under the microscope.

All quantitative data reported on rock groups and societies are given in weigth percentages. Sampling locations in close vicinity to each other (offshore <50 km, in the open sea <150 km) are treated as one sample.

Petrology

The mineralogical composition of the clay fraction was determined by an X-ray diffractometer (PHILIPS, Cu ka, 40 kV and 20 mA). The detrital minerals in the coarser fraction were microscopically examined.

In order to analyse the amount of amorphous silica in the fine grain fractions, mainly biogenic opal, a selective solubility procedure was used. This wet chemical method relies on the different solubility resistances of amorphous silica and crystalline components in highly concentrated sodium solutions (Matthies & Troll 1987).

RESULTS

Granulometry

The investigated marine surface sediments are mostly silts with varying amounts of clay and sand (Fig. 3). Samples from water depths deeper than 2000 m contain more than 25 % clay.

Beside 34 surface samples from box core two additional gravity cores with 13 (Core 224) and 12 samples (Core 278) were examined for grain-size composition (Tab. 1). The grain-size

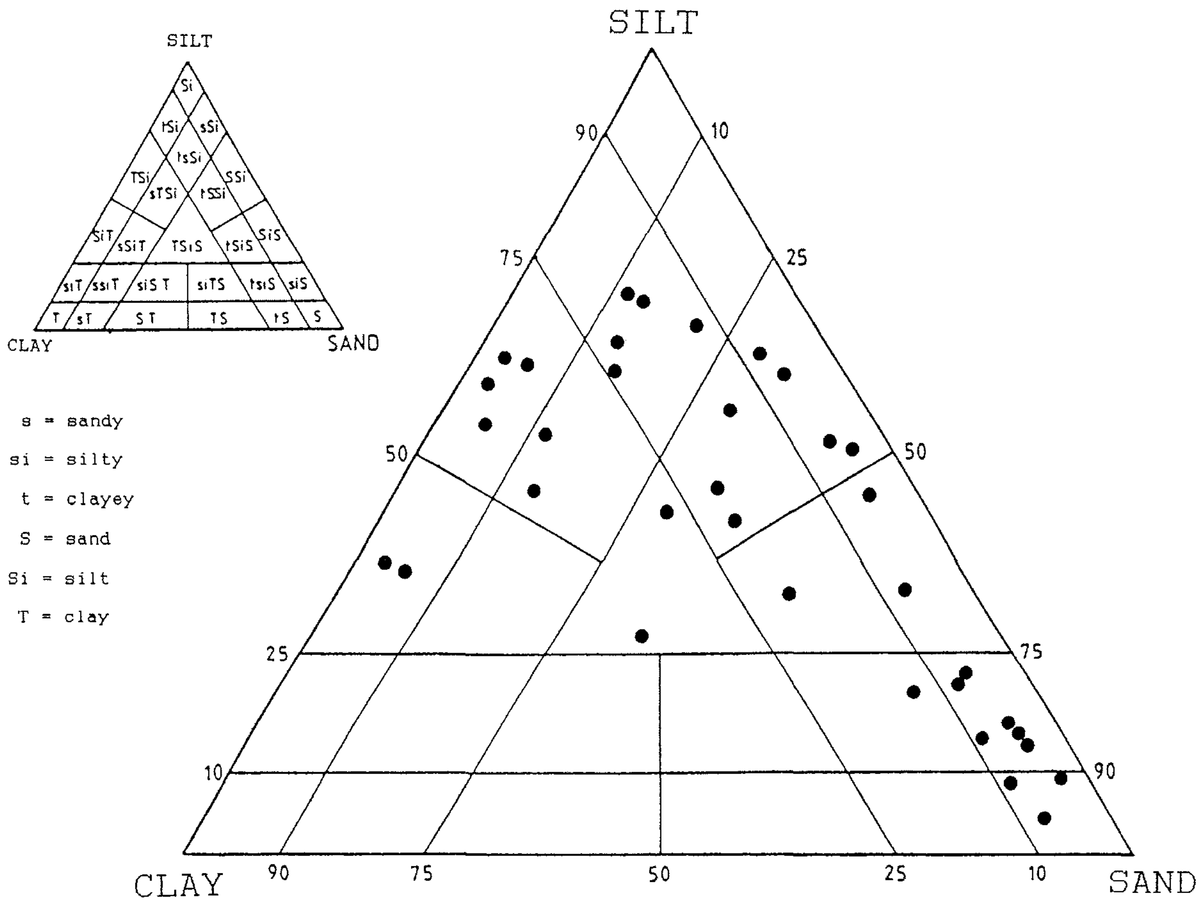

Fig. 3: Grain-size classification system according to Füchtbauer & Müller (1970).

Abb. 3: Korngrößenklassifikationsschema nach Füchtbauer & Müller (1970).

sample	clay	silt	sand
Core 224			
17 cm	42	43	15
35 cm	46	45	9
62 cm	48	38	14
90 cm	50	33	17
193 cm	55	41	4
255 cm	52	44	4
301 cm	50	42	8
334 cm	37	48	15
432 cm	47	39	14
485 cm	54	34	12
540 cm	42	38	20
582 cm	49	34	17
648 cm	48	40	12
mean:	48±5	40±4	12±5
Core 278			
66 cm	45	49	5
121 cm	48	51	1
183 cm	46	51	3
275 cm	37	62	1
465 cm	30	67	3
523 cm	45	54	1
624 cm	43	52	5
700 cm	30	66	4
775 cm	45	51	4
875 cm	49	50	1
982 cm	48	51	1
1103 cm	40	59	1
mean:	42±6	55±6	3±2

Tab. 1: Weight proportions of the clay, silt and sand fractions in samples from gravity cores 224 and 278 (in wt.-%).

Tab. 1: Gewichtsanteile der Ton-, Silt- und Sandfraktion in Sedimentproben der Schwerelotkerne 224 und 278 (in Gew.%).

distributions remain quite constant with depth, which leads to a relatively small standard deviation. This is also confirmed by the excellent agreement between the mean grain-size distribution of the gravity cores (6-11 m) and the corresponding box core samples (approx. 0.5 m) representing the youngest sediment, only. They vary within the single standard deviation of the gravity core samples (Tab. 2).

Granulometrical characteristics of the four geographic areas are described as follows (Fig. 4):

Weddell Sea
Of all investigated samples the Weddell Sea group (1167-5, 1168-2, 1169-1,1171-1,1173-6,1174-2) contains the highest average amount of clay (40 %). Five samples are poorly sorted clay and silt and represent pelagic sedimentation, whereas sample 1168-2 exhibits a moderately sorted sediment assemblage from clay to gravel (Fig. 4e). According to its textural parameters sample 1168-2 represents a turbiditic layer.

	Station 224			Station 278		
	clay	silt	sand	clay	silt	sand
A	48±5	40±4	12±5	42±6	55±6	3±2
B	45	43	12	42	56	2

Tab. 2: Comparison of the grain-size composition (wt.%) of gravity core (A) and box core (B) samples.

Tab. 2: Vergleich der Korngrößenzusammensetzungen (Gew.%) von Schwerelot- (A) und Kastenlotproben (B).

South Orkney Island Plateau
Samples of the South Orkney Island Plateau (1176-3,1176-4, 1177-3,1178-4) show similar grain size distribution characteristics as the Weddell Sea sediments. Only a higher average amount of the fine sand fraction (26 %) has been observed (Fig. 4d). This can be explained by the presence of glacial sediments, both from the Weddell Sea pack-ice and from the South Orkney Island Plateau. Sample 1176-4 represents a turbiditic layer.

Powell Basin
Powell Basin pelagic sediments (samples 1180-4, 210, 225) consist of clay, silt, and sand (Fig. 4c). Generally they show a higher amount of fine sand (30 %) than the above described sediments.

Bransfield Strait
The samples from Bransfield Strait exhibit considerably varying granulometrical parameters. Based on these characteristics they can be divided into two different granulometrical groups. Group I consists of samples (n = 8) with an amount of clay + silt of <50 % (Fig. 4a), whereas Group II samples (n = 10) show higher clay+silt portions (Fig. 4b). Group I sediments exhibit a bimodale grain size distribution, which is probably the result of several different overlapping sedimentation processes (Matthies 1986). A further subdivision of this sample group into samples of the Bransfield shelf (water depth <850 m, samples 1183-4, 1337-4, 1353-4, 1355-4) and basin (water depth >1000 m, samples 1138-4, 1141-2, 1186-3, 1187-3) shows weakly to poorly sorted clays to fine gravels in the latter, and a distinct enrichment of the fine sand fraction (36 %) in the former subgroup. The basin samples represent turbiditic layers.

In contrast to Group I sediments, samples of Group II (1147-6, 1148-1, 1181-2, 1182-2, 1184-6, 1324-1, 1333-2, 1336-5, 1338-1, 240) are poorly sorted, negative-skewed clays to fine sand, and represent pelagic sedimentation.

Petrology

Fine grain fractions (<63 µm)
The petrographical composition of the clay and fine silt fraction of all samples is quite uniform. This is in agreement with the findings of Goldberg & Griffin (1964), Biscaye (1965), Jacobs (1974), Anderson et al. (1980), Elverhøi & Roaldset (1983), Holler (1985), and Grobe (1986). Beside illite as a major, and chlorite and montmorillonite as a minor constituent, traces of smectite and other mixed-layers are present. Detrital quartz and plagioclase are always present in minor proportions.

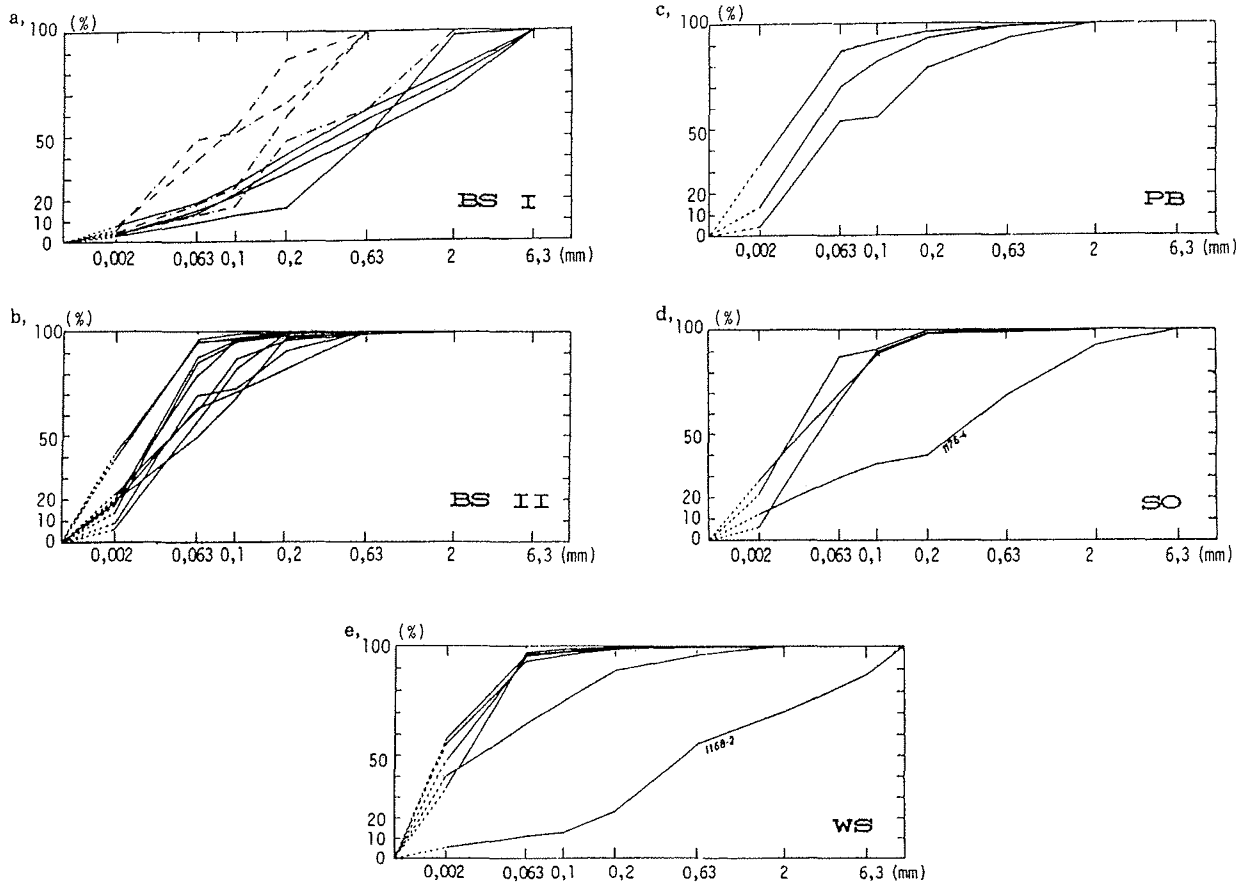

Fig. 4: Cummulative grain-size distribution pattern for marine surface sediments of the investigated area (wt.%); (a)+(b) Bransfield Strait (Group I = BS I Group ll = BS ll), (c) Powell Basin (PB), (d) South Orkney Island Plateau (SO), (e) Weddell Sea (WS).

Abb. 4: Kornsummenkurven der Sedimente des Untersuchungsgebietes; (a)+(b) Bransfield-Straße (Gruppe I = BS 1, Gruppe ll = BS 1 1), (c) Powell-Becken (PB), (d) South-Orkney-Inselplateau (SO), (e) Weddellmeer (WS).

Table 3 shows a semiquantitive comparison of the clay mineral proportions in the clay and fine silt fraction of samples from the Bransfield Strait and the Weddell Sea, respectively. The differences in the proportions of chlorite and feldspar become evident.

In order to verify the temporal variability of the mineralogical composition samples from two gravity cores were analysed. Semiquantitative determinations of the integral peak area on air dried and glycole treated samples reveal the different mineralogical composition of the grain size fractions <2 µm and 2-6.3 µm, but also differences with depths (Tabs. 4 and 5).

Core 224

According to the proportions of illite, chlorite and feldspar in the clay fraction of samples from Core 224 three sectors within the depth profile can be distinguished (Fig. 5). While the content of illite steadily decreases from sector I with a mean proportion of x = 43±2 % (n = 4, 17-90 cm depth) to sector ll with x = 27±2 % (n = 5, 193-432 cm depth) to sector lll with x = 33±3 % (n = 4, 485-648 cm depth), the chlorite content increases with depth (Tab. 4). There is a significantly higher portion of plagioclase in sector ll with a mean value of x = 14±2 % compared to the sectors I and lll with x = 5±2 and 7±1 %, respectively. The proportions of all the other components remain constant within their estimated standard error deviation. Illite and feldspar as well as chlorite and mixed-layers are strictly negatively correlated. Their correlation coefficients are r = -0.72 (n = 13, P >= 99 % security) for illite vs. feldspar, and r = -0.70 (n = 13, P >= 95 % security) for chlorite vs. mixed-layers, respectively.

Further constituents of the clay and fine silt fraction are amorphous silica components (as in Tab. 4) predominantly biogenic opal from diatom skeleton fragments and volcanic glass, respectively. Their proportions vary considerably between the different sedimentation areas. Powell Basin and Weddell Sea samples contain 4 to 18 % (x = 10±5 %), Bransfield Strait sediments 21-46 % (x = 33±8 %, n =12), while samples from the South Orkney Plateau contain between 52-83 % (x = 68+16 %, n = 3). The portion of volcanic glass shards within the clay fraction of 1-3 % remains relatively constant all over the sedimentation areas.

The fine silt fraction (2-6.3 µm) does not reveal the three fold subdivision of the sediment profile. Detritic minerals, mainly quartz, substitute illite and chlorite to a considerable extent. Smectite and mixed-layers are of subordinate importance. There is a distinct increase in amorphous silica. This is due to frag-

		Bransfield Strait <—> Weddell Sea
MAIN CONSTITUENT	illite	<
MINOR CONSTITUENT	chlorite	> >
	quartz	=
	feldspar	> >
TRACES	montmorillonite	=
	smectite	<
	mixed-layers	<

Tab. 3: Semiquantitative comparison of the clay mineral proportions in the clay and fine silt fractions from samples of Bransfield Strait and Weddell Sea. (= equal proportions; < > one proportion prevails; << >> one proportion prevails markably).

Tab. 3: Halbquantitativer Vergleich der Tonmineralanteile in der Ton- und Feinsiltfraktion von Proben der Bransfield-Straße und Weddellmeer. (= gleiche Anteile, < > ein Anteil überwiegt, << >> ein Anteil überwiegt stark).

depth	musc./ illite	chlorit.	smect.	mixed-l.	fsp.	quartz	‚ac'	sector
grain size fraction <2 µm								
17 cm	36	14	4	15	5	14	12	
35 cm	42	13	5	19	4	9	8	I
62 cm	37	14	3	14	6	13	13	
90 cm	37	21	4	11	6	12	9	
193 cm	21	20	5	15	9	15	15	
255 cm	24	19	5	10	14	14	14	
301 cm	22	19	5	12	12	17	13	II
334 cm	22	15	5	21	13	11	13	
432 cm	27	14	3	18	13	14	11	
485 cm	29	19	4	12	6	13	17	
540 cm	28	25	3	9	4	17	14	III
582 cm	26	17	4	21	6	13	13	
648 cm	32	21	3	10	7	13	14	
grain-size fraction 2-6.3 µm								
17 cm	19	24	+	4	12	30	11	
35 cm	15	18	+	4	9	45	9	I
62 cm	22	21	+	+	14	35	8	
90 cm	18	21	+	3	14	34	10	
193 cm	17	23	+	12	11	31	6	
255 cm	17	21	+	6	12	33	11	
301 cm	18	22	+	3	13	35	9	II
334 cm	15	19	+	5	13	31	17	
432 cm	23	18	+	+	14	33	12	
485 cm	17	21	+	3	11	39	9	
540 cm	17	25	+	6	9	38	5	III
582 cm	18	21	+	6	10	38	7	
648 cm	18	18	+	6	12	36	10	

Tab. 4: Mineralogical composition of the clay and fine silt fraction of core samples from Core 224 (+: detected).

Tab. 4: Mineralzusammensetzung der Ton- und Feinsiltfraktion der Proben aus Kern 224 (+: nachgewiesen).

	Core 224	Core 278
Illite	34±7	27±10
Chlorite	20±4	25±5
Smektite	4±1	11±3
Mixed-layers	17±5	10±3
Feldspar	9±4	14±4
Quartz	16±3	13±4

Tab. 5: The mineral compositions of the clay fractions from Core 224 and Core 278 (in wt.-%).

Tab. 5: Mineralzusammensetzung der Tonfraktionen von Proben der Schwerelotkerne 224 und 278 (in Gew.-%).

ments of diatom skeletons, which derive from excrements of krill. During the digestion of diatoms their skeletons are broken to pieces of 1-10 µm in size (Gersonde & Wefer 1985), which accumulate in the fine silt fraction. (Matthies & Troll 1987).

Core 278

The clay fraction of Core 278 cannot be subdivided into three sections like the clay fraction of Core 224. Illite and mixed-layers appear in distinctly smaller quantities than in Core 224, while the contents of smectite and amorphous components are increased. Apart from the dependence of chlorite and illite from

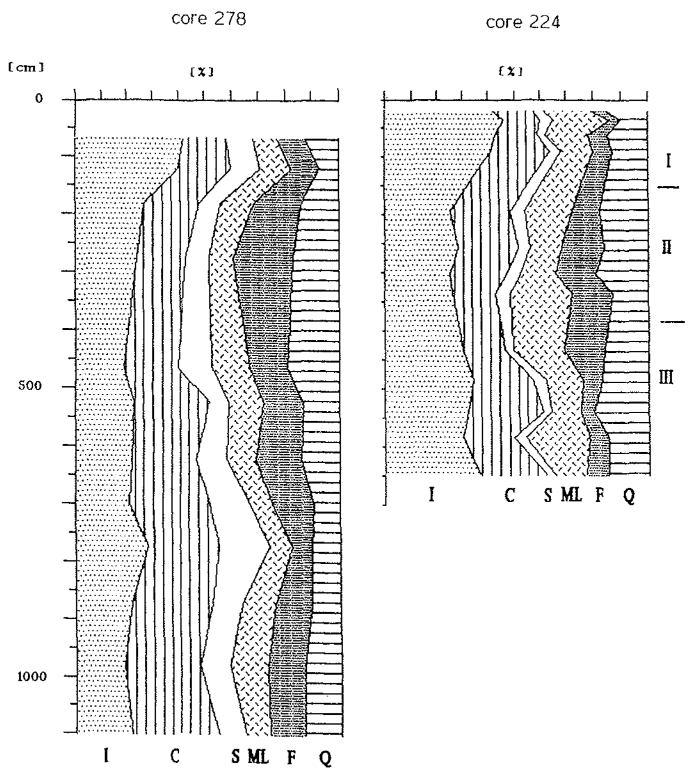

Fig. 5: Clay mineralogical composition of sediment samples from Core 224 and Core 278. Three sections in the profile of Core 224 can be distinguished: sector I 17-90 cm depth, sector II 193-432 cm depth and sector III 485-648 cm depth. I = illite; C = chlorite; S = smectite; ML = mixed-layers; F = feldspar; Q = quartz.

Abb. 5: Tonmineralogische Zusammensetzung der Kerne 224 und 278. Im Kern 224 können 3 Abschnitte unterschieden werden: Abschnitt I in 17-90 cm, Abschnitt II 193-432 cm, Abschnitt III 485-648 cm. I = Illit, C = Chlorit, S = Smektit, ML = Mixed Layers, F = Feldspat, Q = Quarz.

depth (r = 0.84, n = 12, P >99 % security and r = -0.52, n = 12, P >95 % security, respectively) no further interdependencies become obvious.

Heavy mineral composition of medium grain fractions (63–200 μm)

In 41 sediment samples more than 25 heavy mineral species were identified, of which only 10 occur in appreciable amounts. They include garnet, amphibole, augite, hypersthene, titanite, zoisite, spinel, leucoxene and opaque minerals (magnetite and ilmenite). Other minerals present but not common, include apatite, zircon, tourmaline, diopside, sillimanite, glaucophane, kyanite, rutile, and olivine. In the following sections petrographic characteristics of the common heavy minerals are described in their decreasing order of abundance.

Garnet

Reddish to pale pink almandines and colourless grossulares are observed. Generally they are fresh and unaltered. Grains are sharply angular to slighly subrounded. Solution pits were found.

Augite

Augite fragments mostly are short-prismatic and show characteristic saw-tooth marks. Some augites exhibit a weak pleochroism from pale green to greyish green, and a high extinction angle of about 45°.

Amphibole

Three types of hornblendes were identified by their colour, pleochroism, and birefringence. Green hornblende is light or dark green. The mineral is slightly pleochroitic (pale green to greyish green or yellowish green to pale bluish green). Most mineral fragments are prismatic with angular to subangular shape. Glaucophane shows pleochroism (colourless, pale green to bluish violet) with high birefringence and a small extinction angle (4-6°). Brown hornblende varies from greenish brown, reddish brown to dark brown. Like green hornblende the brown hornblende is slightly pleochronitic and has a low birefringence. Glaucophane and brown hornblende are accessory minerals.

Titanite

Titanite exhibits a range of colours from pale yellow to greenish yellow. Full extinction is prevented by characteristic dispersion of the mineral. Pleochroism is very weak or not detectable.

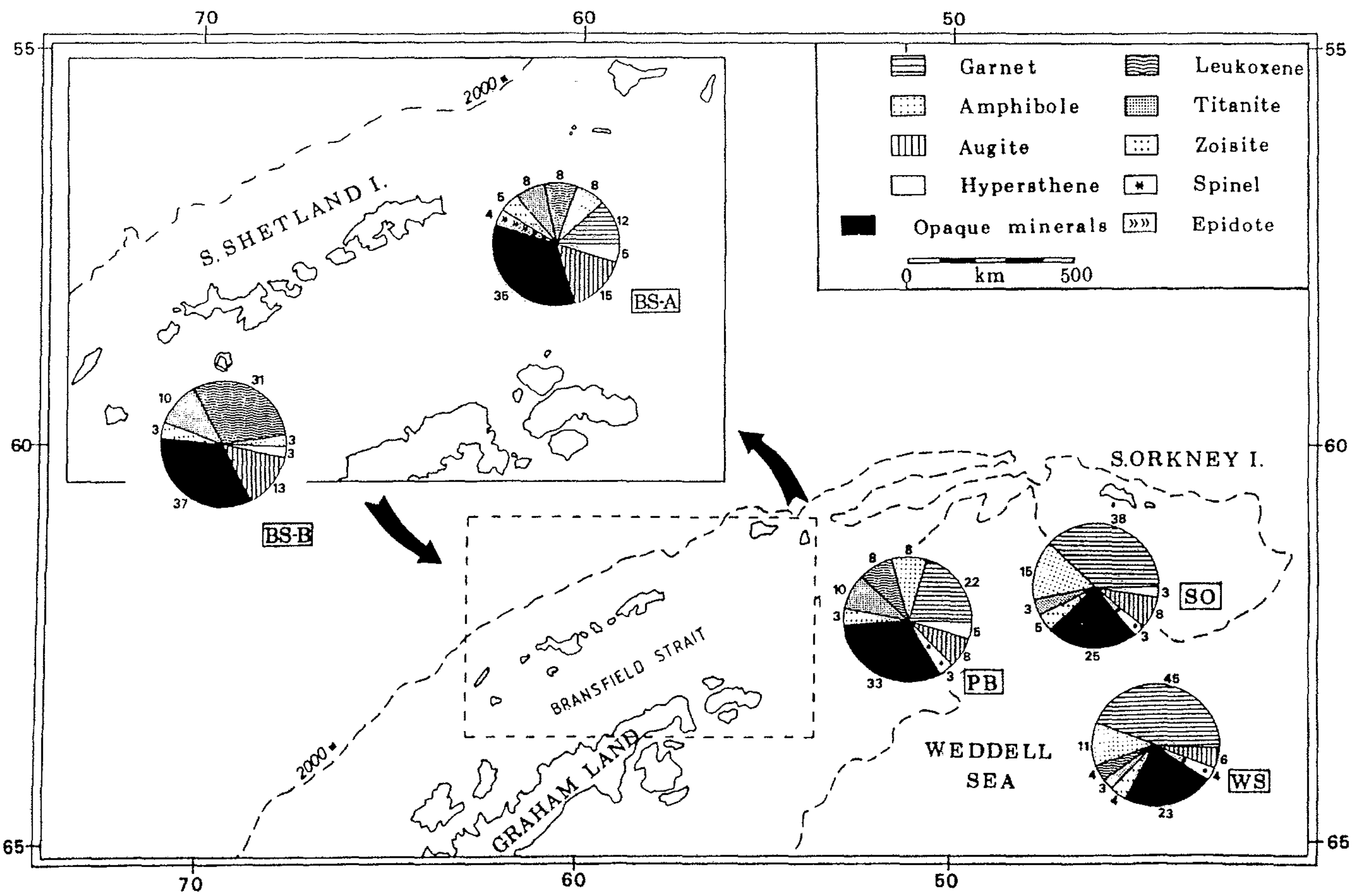

Fig. 6: Distribution of heavy minerals in the investigated area (mineral frequency expressed in per cent by number); Bransfield Strait (Group A = BS A, Group B = BS B), Powell Basin (PB), South Orkney Island Plateau (SO), Weddell Sea (WS).

Abb. 6: Schwermineralverteilung im Untersuchungsgebiet (Häufigkeit in Prozent Kornzahl); Bransfield-Straße (Gruppe A = BS A, Gruppe B = BS B), Powell-Becken (PB), South-Orkney-Inselplateau (SO), Weddellmeer (WS).

Leucoxene
Leucoxene consists of mineral aggregates of mostly anatase and titanite. Under crossed polars bluish green and yellow colours can be seen. Leucoxene shows high birefringence and no extinction. The aggregate rims often exhibit lower birefringence, and consist mainly of zoisite and clinozoisite.

Zoisite
Colourless zoisite shows a weak pleochroism and low birefringence. An anomalous bluish interference colour has been observed.

Hypersthene
All grains of orthopyroxene present are hypersthene. It occurs in prismatic grains with rare saw-tooth termination and a distinct pleochroism was evident (pale brownish red to pale green).

Epidote
Dark yellow epidote exhibits a weak pleochroism (pale green to yellowish green) and very high birefringence. The grains are mostly angular to subrounded.

Spinel
Dark red spinel shows a high index of refraction and is isotropic. The grains are often intersected by several cracks.

Heavy mineral distribution of medium grain fractions (63–200 µm)
The total amount of heavy minerals in the investigated sediment samples ranges from 10-60 %. On the average sediments from the Bransfield Strait area contain 37 % heavy minerals in the fine sand fraction, whereas sediments from the Powell Basin, the Weddell Sea, and the South Orkney Island Plateau hold about 25 % heavy minerals. According to the geographic sample locations the following heavy mineral characteristics of each location are evident (Fig. 6).

Weddell Sea
The six investigated samples of the Weddell Sea area are characterized by their high amounts of garnet (45 %, average mineral frequency expressed in percent by number). On the average, opaque minerals comprise 23% of total heavy minerals followed by green hornblende (11 %), augite (6 %), spinel, zoisite, leucoxene, kyanite, and titanite (all < 5 %).

South Orkney Plateau
The mineral association of the South Orkney group (3 samples) is similar to the Weddell Sea area. As in the Weddell Sea area garnet (38 %) is the predominant heavy mineral. Slightly higher amounts of opaque minerals (25 %), amphibole (15 %) and augite (8 %) are shown.

Powell Basin
The Powell Basin group (4 samples) comprises opaque minerals (33 %) as the main constituent followed by garnet (22 %), titanite (10 %), green hornblende, augite, and leucoxene (8 % each). Less common minerals include hypersthene, spinel, zoisite, apatite, diopside, epidote, rutile, sillimanite, tourmaline, and zircon. A minor amount of garnet and a higher amount of opaque minerals distinguish this sample group from the Weddell Sea and South Orkney sediments.

Bransfield Strait
The above described mineral associations are quite different from those of the Bransfield Strait where the highest amounts of opaque minerals, augite, and leucoxene occur. Garnet is only a minor constituent.

The Bransfield samples can be divided into two different heavy mineral assemblages. Group A consists of 17 samples of the northeastern part of Bransfield Strait and is characterized by high amounts of opaque minerals (35 %) and augite (15 %). Less common minerals include garnet (12 %), leucoxene, titanite, green hornblende (8 % each), hypersthene (5 %), zoisite (5 %) and epidote (4 %). Accessory minerals are apatite, diopside, kyanite, glaucophane, rutile, tourmaline, and zircon. Samples (263, 240, 1147-6, 1148-1) near Elephant and Clarence Islands exhibit high „amphibole-epidote-zoisite“ concentrations.

Sample Group B (n = 6) is located at the southwestern end of Bransfield Strait and is dominated by high amounts of opaque minerals (37 %) and leucoxene (31 %). Despite less common amounts of augite (13 %) and titanite (10 %), all other minerals have accessory character (glaucophane, green hornblende, hypersthene, kyanite, olivine, sillimanite, and zoisite).

Dropstone classification system of coarse sized detritus (>1 cm)
The rock type, group and society classification system introduced for the purpose of these investigations is not in accordance with commonly used rock terms and classifications. In addition no chemical standard was used here.

The rock type with narrowly defined features referring to its mineral content, structure and texture also within extensive populations, is represented mostly as a single specimen. In the source area it is a homogeneous and distinct rock body. The conception „rock group“ means broader defined limits for the mineral percentages and for textural and structural features. Frequently it includes several rock types. The terminus „rock society“ includes several rock groups, which show similar genesis and spacious source areas.

Dropstone composition and distribution of coarse sized detritus (>1 cm)

The weight distributions of the rock societies are shown in Figs. 7 and 8. Starting from the percentage frequencies in these figures it is intended to look for the origin of the freight.

In addition, rock societies in the dropstone population were compared with rock societies of outcrops on the Antarctic Peninsula. The area of comparison is shown in Fig. 9. In order to estimate the square percentages of each rock society outcropping in the separate sectors west and east of the ice divide and

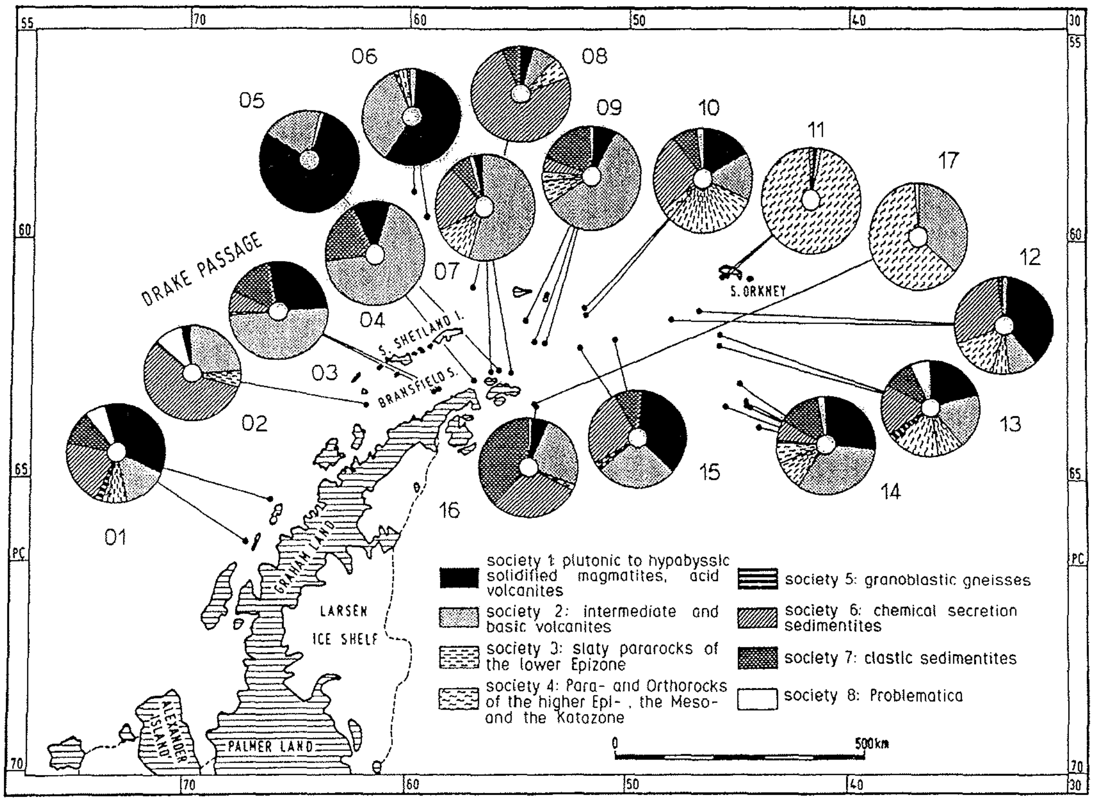

Fig. 7: Lateral distribution of eight dropstone rock societies (wt.%), Bransfield Strait area excluded.

Abb. 7: Flächenhafte Verteilung von 8 Eisfracht-Gesteinsvergesellschaftungen (Gew.%) ohne Bransfield-Straße.

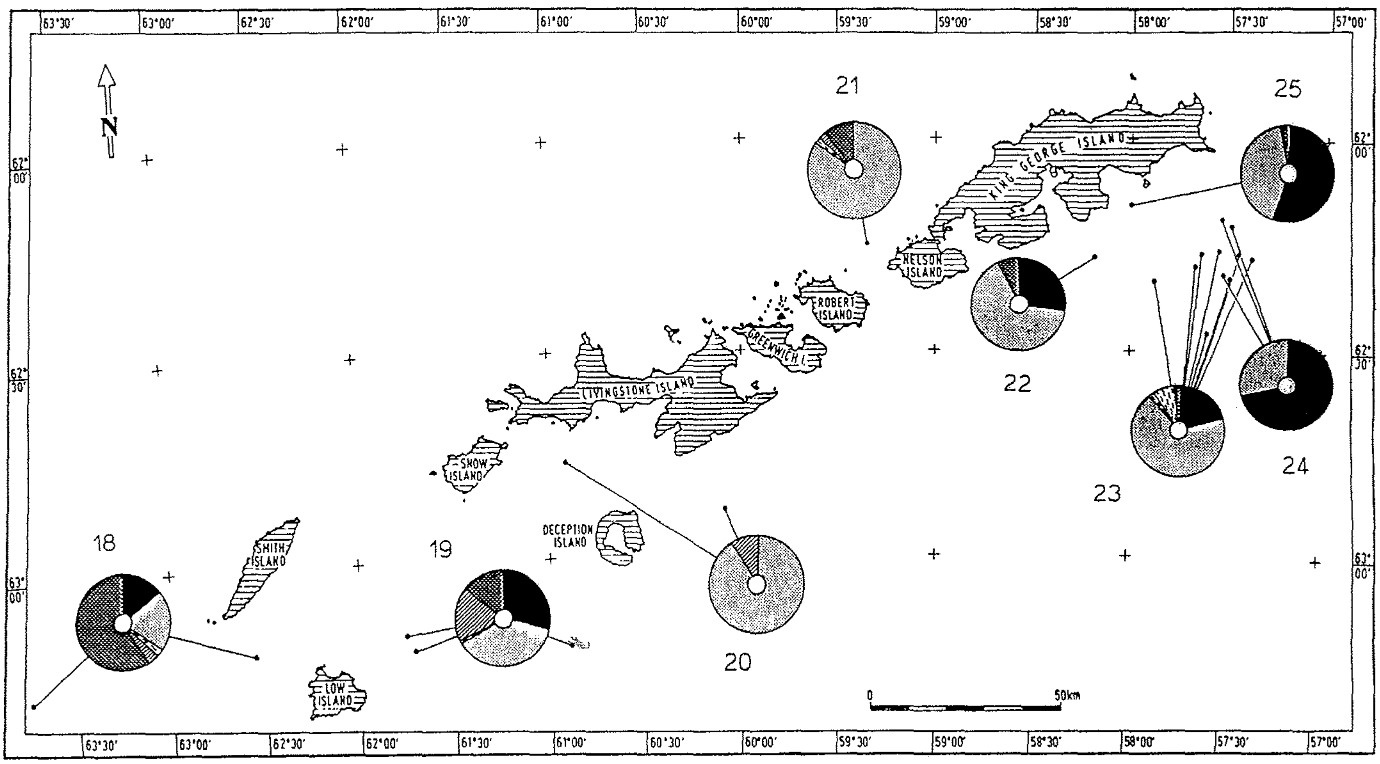

Fig. 8: Lateral distribution of eight dropstone rock societies in Bransfield Strait.

Abb. 8: Verteilung von acht Eisfracht-Gesteinsvergesellschaftungen in der Bransfield-Straße.

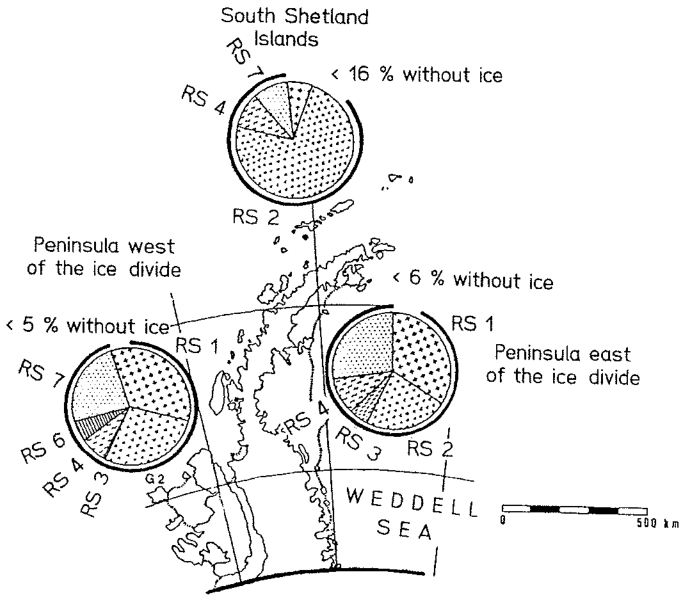

Fig. 9: Areal proportions of 6 rock societies on the Antarctic Peninsula and South Shetland Islands according to the geological map of the British Antarctic Survey (1979-1982). Broken ring around circular plot represents ice cover in square percentages. RS 1: magmatites in hyp-abyssic to plutonic solidification; RS 2: intermediate to basic volcanic rocks; RS 3: slaty pararocks of the lower greenshist facies; RS 4: para- and orthorocks of intermediate to high grade metamorphism (except granulites). RS 6: chemical secretion sedimentites; RS 7: clastic sedimentary rocks.

Abb. 9: Flächenanteile von 6 Gesteinsvergesellschaftungen auf der Antarktischen Halbinsel und den Süd-Shetland-Inseln entsprechend der geologischen Karte des British Antarctic Survey (1979-1982). Der unterbrochene Kreis gibt die Eisbedeckung in Flächenprozent an. RS 1: Magmatite in hyp-abyssischer bis plutonischer Erstarrung, RS 2: intermediäre bis basische Vulkanite, RS 3: Paraschiefer der niedrigen Grünschieferfazies, RS 4: Para- und Orthogesteine höhergradiger Metamorphosestufen (ausgenommen Granulitfazies), RS 6: chemische Sedimente, RS 7: klastische Sedimentgesteine.

the South Shetland Islands, the geological maps 1: 500,000 of the British Antarctic Survey (1979-1982) serve for reference.

DISCUSSION

The investigated sediments of Bransfield Strait, Powell Basin and northwestern Weddell Sea reveal, from a granulometrical point of view, the well known grain-size distribution pattern of a decreasing median with increasing water depth. Within the grain-size classification the sediments vary from clayey to sandy silts. The similar proportions of clay, silt and sand in one surface sample (box core) and its corresponding gravity core profile can be taken as an indication of more or less constant sedimentation conditions during the last 400,000 years maximum.

Freshness, angularity and composition of the detrial material can be interpreted as a direct sediment input by melting icebergs, which is in accordance with results reported by ANGINO & ANDREWS (1968), and WRIGHT & ANDERSON (1982). Both studies suggest that the sediments of the Weddell Sea are mainly transported as ice-rafted detritus. An additional sediment input by turbidity currents into the abyssal regions of the Weddell Sea can be demonstrated by the presence of a moderately sorted sediment assemblage from clay to gravel in sample 1168-2. The increase in sand percentages in sediments from the South Orkney Island Plateau is caused by the greater relative input of ice-rafted detritus from the Weddell Sea pack-ice and the South Orkney Island glaciers, respectively. These poorly sorted deposits have the granulometrical characteristics of „basal tills" (ANDERSON et al. 1980). Beside these typical glacial marine sediments turbiditic layers occur in the continental slope area of the South Orkney Island Plateau (see sample 1176-4).

Different sedimentation processes are responsible for the observed sediment distribution in the Bransfield Strait. Our granulometrical results correspond with investigations of EDWARDS & GOODELL (1969), who described high sand concentrations (>50 %) in marine sediments of the shelf regions of the Antarctic Peninsula and the South Shetland Islands. Two strong bottom counter-currents in the northern and southern part of Bransfield Strait coming from the Bellingshausen Sea and the Weddell Sea (WITTSTOCK & ZENK 1983), respectively, holding the finer sediment fractions in suspension, are responsible for the predominance of the coarser fractions in this region (Group I). In contrast to these results a remarkable decrease of sand concentrations can be noted at both ends and in the deeper basins (>2000 m) of the Strait (Group II). Marine currents had little or no effect on these sediments after deposition. An important feature of the continental shelf of the Antarctic Peninsular are submarine canyons reaching into the Bransfield Strait basins. Through these canyons remarkable amounts of coarser size fractions are transported as turbidity currents into the basins. The eastern part of the Powell Basin does not exhibit any particular granulometrical characteristics probably representing a combined model of the different sedimentary mechanisms of the surrounding regions.

In contrast to terrestrial and lake sediments from the Bransfield Strait region, the age of the marine sediments is still uncertain. On the basis of tephrostratigraphical investigations on limnetic and marine ash-layers from this region, MATTHIES et al. (1990) reported marine sedimentation rates of 7 cm/1000 a (station 1338-1) and 24 cm/1000 a (station 1347-1), respectively. From this a maximum age of 110,000 a (7 cm/1000 a) or 27,000 a (24 cm/1000 a) for Core 224 (lenght 648 cm) can be deduced. HOLLER (1985) carried out geotechnical investigations on the same sediment core and found 2 hiatus of 10 m each within the sediment sequence. They are located in 17-35 cm depth and at 355 cm depth, respectively. Own geochemical investigations (unpublished) confirm these findings by distinct chemical discontinuities in the postulated depths. According to this, Core 224, which is 650 cm in length, most probably represents three sections from an originally 26.5 m thick sediment sequence. This results in the new estimation of the maximum sediment age of 380,000 a (7 cm/1000 a) or 100,000 a (24 cm/1000 a) given in Table 6. These evaluations are based on the assumption of constant sedimentation rates as well as of no further hiatus. This can be judged as most unlikely, if the following is taken into account. Earlier results from tephrostratigraphical investigations on three other sediment cores from Bransfield Strait (1346-1, 1347-1 and

Station 224	without hiatus	with 2 hiatus each 10 m	sedimentation rate
Sector I	700-4000	700-45000	24 cm/1000 a
(17-90 cm)	2400-13000	2400-156000	7 cm/1000 a
Sector II	8000-18000	28000-62000	24 cm/1000 a
(193-432 cm)	50000-100000	170000-350000	7 cm/1000 a
Sector III	20000-27000	69000-100000	24 cm/1000 a
(485-648 cm)	103000-110000	355000-380000	7 cm/1000 a

Tab. 6: Sediment ages on the basis of sedimentation rates of 7 and 24 cm/1000 a for core profile 224.

Tab. 6: Sedimentalter basierend auf Sedimentationsraten von 7 bzw. 24 cm/1000 a für das Kernprofil 224.

1357-1) (MATTHIES et al. 1988) indicate several considerable hiatus, each longer than the entire sediment cores considered. Therefore, according to the present state of knowledge it must be assumed that the sediment sequences in the cores from this region are in most cases not complete. Furthermore, several glaciation periods took place on the southern hemisphere during the last approximately 400,000 a. They caused large-scale ice avalanches and extended pack ice fields accompanied by sea level changes of several hundred meters causing dryness of large shelf areas. It is for sure that during these climatic changes the sedimentation processes in this region changed several times, too.

While comparing the clay mineralogical findings in Core 224 with the climatic history of the Atlantic sector of Antarctica (according to ANDERSON 1972) the warm and cold stages correspond fairly well with the sequence of sectors I to III, a sedimentation rate of 7 cm/1000 a including two hiatus. Sector I (1,000-45,000 a) represents the last warm stage, sector II (50,000-56,000 a) corresponds with the last cold stage, while sector III (103,000-110,000 a) represents the isotope stage 5, a warm period. Furthermore, sectors II and III would also agree with the sedimentological findings of GROBE (1986), who investigated sediment cores from the eastern part of the Weddell Sea, off Kap Norvegia. According to these findings a sedimentation rate of 7 cm/1000 a seems to be most likely as it also meets the mean sedimentation rate of 1-2 cm/1000 a given by GROBE (1986) for the more eastern area. As a conclusion the cold stage is characterized by an increased presence of detritic minerals, like quartz and feldspar, while simultaneously illite decreases. According to this the sequence of 183-465 cm depth of Core 278 must be attributed to a cold stage. As the sections in the top and the bottom of this core differ distinctly from the mineralogical pattern of sectors I and III of Core 224, an assignment to the climatic pattern of ANDERSON (1972) is not done. Due to the great uncertainties in the sediment age an assignment to the climatic record of the Antarctic ice shield (LORIUS et al. 1985) is not possible, either.

The aeolian sediment input has not been described too much in the recent Antarctic literature, yet. There are comprehensive investigations on the mode, composition and extent of wind load over the Atlantic and the Pacific Oceans by DELANY et al. (1967), PARKIN et al. (1970), CHESTER et al. (1971), LANGE (1982), and BLANK et al. (1985). The grain-size spectra cover the whole clay and silt fraction. In decreasing order the wind load carries illite, kaolinite, chlorite, montmorillonite, smectite, quartz, feldspars, as well as diatom frustrules. WINDOM (1969) and LEINEN & HEATH (1981) calculated the aerosol proportion of the Pacific and Atlantic sediments to be as much as 75-95 %. Corresponding estimations for the Antarctic marine sediments are missing due to the lack of aerosol investigations. However, this factor should not be neglected when sediments from this region are going to be interpreted for their climatic and sedimentary records.

The heavy mineral distribution in the sediments of the investigated area points to several petrographic provinces. A province characterized by metamorphic minerals occurs in the sediments of the Weddell Sea, the South Orkney Island Plateau, and a small area near Elephant Island. The dominant mineral assemblage consists of garnet and green hornblende with minor amounts of epidote, spinel, sillimanite, and kyanite. The Weddell Sea sediments probably originated along the eastern coast of the Antarctic Peninsula. ADIE (1957) describes almandine-rich sillimanite-garnet-biotite hornfelses at Cape Christmas (72° 20' S, 60° 41' W). As already mentioned a majority of these sediments is transported by icebergs. However, several local sources for garnet, green hornblende and epidote exist in the metamorphic rocks of Elephant and Clarence Islands (DALZIEL 1984, LOSKE et al. 1985) and the South Orkney Islands (THOMSON 1968, 1974), and in the quartzdiorite and the sandstones of the northern part of the Antarctic Peninsula (SMELLIE 1987).

A province remarkably characterized by minerals of volcanic origin can be distinguished south and north of the South Shetland Islands, especially around the still active volcano of Deception Island. The dominant mineral assemblage consists of augite and leucoxene with minor amounts of hypersthene and olivine. This result does not surprise as the South Shetland Islands are of volcanic origin. The volcanic suite interfingers with the metamorphic mineral assemblage east of Elephant and Clarence Islands and the Weddell Sea (EDWARDS & GOODELL 1969).

A small strip of an intrusive mineral assemblage occurs along the west coast of the northern Antarctic Peninsula. This intrusive mineral suite is characterized by green hornblende and minor concentrations of ruffle, tourmaline, and zircon. They originate in lowgrade metamorphic sediments of the Antarctic Peninsula (e.g. Mount Bransfield at 63° 17' S, 57° 06' W; ADIE 1957).

Some selected rock types give rise to search for distinct rock bodies in ice free outcrops. One of those is leuco-mangerite with light red feldspars, which was found halfway from the tip of the Antarctic Peninsula to the South Orkney Islands. Due to its fabric it might derive from the Red Ridge Granite at Marguerite Bay, which is described by ADIE (1955). A reddish rhyolith with fluidal texture found at the same locality, might originate from the Gambacorta Formation in the Pensacola Mountains (LAIRD & BRADSHAW 1982). A „dry" diorite with orthopyroxene from a sample location 150 km south of the South Orkney Islands probably is derived from the East Antarctic Craton. Some specimens of acid to intermediate fine grained magmatites with dispersed inclusions of sulphides were found in sample locations offshore the Pacific coast. Rocks with similar enrichments in sulphide occur in outcrops at the west coast and also on some offshore islands (Cox et al. 1980, Rowley & Pride 1982, Rowley & Williams 1982, Hoecker & Amstutz 1986).

Referring to the reconstruction of migration paths of rock groups and rock societies estimations of origin remain more spacious. Several groups of acid volcanic rocks are culminating northwest of the Antarctic Peninsula. Perhaps they moved along a tongue-like path in an acute angle to the coast line and the main surface stream, out into the Drake Passage. A similar distribution in the northwestern area can be observed with the rock society of magmatites in plutonic to hypabyssic intrusion levels (Figs. 7 and 8).

The samples with the highest proportion of intermediate to basic volcanic rocks (>50 %) are found in the vicinity of Elephant Island. This rock society appears to be composed predominantly of rocks from the volcano islands of the South Shetland Islands (Birkenmeyer et al. 1991), while volcanic rocks from the southwest probably Palmer Land, contribute a minor proportion. According to Watkins & Self (1972) volcanic detritus is generally enriched at 55° S. This is not generally valid as our results reveal. The findings of Roessler-Viana (1985) are in good agreement with our results concerning the percentages of volcanic rocks, although the percentage estimations of Roessler-Viana (1985) seem to be too high for the Bellingshausen Sea, and too low for the area around Astrolabe Island.

It is still an open task to search for the distribution path of pumice. Although pumice usually remains on the water surface, it is also deposited in surficial sediments of Bransfield Strait. Summed up together with pyroclastites in the statistical evaluation, it culminates between 10-30 % around Deception Island. One possibility for its deposition in the marine sediments might be the sudden release of a major lens of detritus sweeping it downwards, and burrying it within the dropstone deposit. The other possibility could be an autochthonous formation by submarine volcanic eruptions.

The society of para- and orthometamorphites of the upper lowgrade, medium- and highgrade zones can be found nearly everywhere. Their almost exclusive occurrence near the South Orkney Islands obviously indicates their origin from there.

The society of granoblastic gneisses mainly found in the open northwestern Weddell Sea, is supposed to be a typical facies within the Precambrian of East Antarctica. Mostly, it is represented by pyroxene-granualite (Suwa 1968, Grew 1984, Harley 1985, Fitzimons & Thost 1992). The most western outcrop of this facies is found in the Kottas Mountains south of the Weddell Sea (Arndt et al. 1986, Spaeth & Fielitz 1986, Jacobs 1991). The results of dropstone investigations (Oskierski 1985, 1988, Kuhn et al. 1993) give rise to assume a far more southern extension of the granulite facies underneath the ice. In addition, the relatively great thickness of the crust in East Antarctica (Kamenev 1980) is hinting at highly metamorphosed terrains.

Only few outcrops of granoblastic gneisses occur at the western coast of Graham Land. Within the basement complex Adie (1954) describes them in the Cape Calmette gneiss.

The rock group of dark blue-grey slaty claystone occurs on the Antarctic Peninsula (Rowley & Williams 1982), in Ellsworth Land (Buggisch & Webers 1982) and in the sediment cover of Dronning Maud Land (sample by M. Peters). The group of brown and red sandstones and arcoses can be seen for example in the western part of the Shackleton Range (Blaiklock Glacier Group, according to Laird & Bradshaw 1982) and in the eastern Dronning Maud Land. Both groups point to far more southern source areas.

Referring to the close vicinity of the northern part of the Antarctic Peninsula (Fig. 9), the dropstone populations show some relationships between weight percentages and areal proportions of the terrestial outcrops. For example, the samples from Powell Basin and the northwestern Weddell Sea partly ressemble the ones from the sector east of the ice divide. Along the Pacific coast three offshore sample fields show a good similarity to the sector west of the ice divide. The sample fields nearby the South Shetland Islands only partly resemble the ones on the islands.

CONCLUSIONS

The results from this study lead to the following conclusions:

- The sedimentary sequences in the Bransfield Strait basin can be subdivided into cold and warm stage sediments by their mineralogical composition. In combination with tephrostratigraphical considerations a sedimentation rate of approximately 7 cm/1000 a can be established.

- Off the Pacific coast along the Antarctic Peninsula acid volcanic rocks occur together with tourmaline, zircon and rutile. They also coincide with sulphide impregnated intermediate to acid magmatites. Their source bodies are located on the Antarctic Peninsula.

- Near the South Shetland Islands the basic volcanic rocks are associated with single grains of olivine.

- In the northwestern Weddell Sea pyroxene-granulite dropstones occur together with garnet, red spinel and orthopyroxene. They mainly originate from the East Antarctic Craton.

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