Polarforschung 60 (3): 169–180, 1990 (erschienen 1992)

Composition and Paleoenvironmental Implications of Sediments in a Fresh Water Lake and in Marine Basins of Bunger Hills, East Antarctica

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Summary: Data on the sediment composition from four sediment cores, located in a freshwater lake and in two marine basins of Bunger Hills, East Antarctica, are presented and discussed in respect of their paleoenvironmental implications. All investigated sediments are laminated. They consist predominantly of algae, mosses and clastics, and exhibit various, sometimes very high contents in carbonate, organic carbon and sulfur. The sediment composition is largely influenced by the salinity of the water, by the degree of ice coverage, by the supply of melt water, and by the glaciological and morphological conditions in the vicinity of the lakes. Three individual sediment units can be distinguished, each probably representing the same depositional time intervals at the respective sampling sites. Transitions between the units can be traced back to regional changes in the environmental conditions and therefore provide information concerning the paleoenvironmental and paleoclimatical history in the oasis. Near the Pleistocene/Holocene boundary probably a marine transgression into the oasis occurred, resulting in the formation of marine basins. Presumably as a consequence of the postglacial isostatical uplift, parts of the basins were isolated from ocean water and by meltwater inflow transformed into fresh water lakes. Before reaching the recent environmental conditions, sampling sites in a large fresh water lake as well as in a marine inlet have been under anoxic conditions, presumably as a consequence of a cooler climate than that of today.

Zusammenfassung: Die Zusammensetzung von vier Sedimentkernen aus einem Süßwassersee und zwei Meeresbecken der Bunger-Oase wird vorgestellt und in Bezug auf ihre Bedeutung für die Umweltgeschichte diskutiert. Alle untersuchten Sedimente sind laminiert. Sie sind hauptsächlich aus Algen, Moosen und klastischen Partikeln zusammengesetzt und zeigen unterschiedliche, z.T. sehr hohe Gehalte an Karbonat, organischem Kohlenstoff und Schwefel. Die Sedimentzusammensetzung wird wesentlich vom Salzgehalt des Wassers, vom Grad der Eisbedeckung, vom Eintrag an Schmelzwasser und von den glaziologischen und morphologischen Verhältnissen am Ufer gesteuert. Es lassen sich drei Sedimenteinheiten unterscheiden, die an den einzelnen Probennahmestationen wahrscheinlich jeweils gleiche Ablagerungszeiträume umfassen. Übergänge zwischen den Sedimenteinheiten sind auf Veränderungen der Umweltbedingungen zurückzuführen. Die Sedimentabfolgen liefern daher Informationen über die Entwicklung der Umweltbedingungen und des Klimas im Bereich der Oase. Nahe der Pleistozän/Holozän-Grenze führte wahrscheinlich eine marine Transgression zur Bildung von Meeresbecken innerhalb der Oase. Als Folge der nacheiszeitlichen isostatischen Landhebung wurden vermutlich Teile der Meeresbecken vom Ozean isoliert und durch den Eintrag von Schmelzwasser in Süßwasserseen überführt. Bevor die heutigen Umweltbedingungen erreicht wurden, befanden sich Probennahmestationen in einem großen Süßwassersee und in einem Meeresarm unter anoxischen Bedingungen. Dies war vermutlich die Folge eines kühleren Klimas als heute.

INTRODUCTION

In order to reconstruct the climatic and environmental history of Antarctica during Holocene time, in the last years geological investigations on Antarctic lake sediments were increasingly conducted (e.g., WHARTON et al. 1983, TATUR & DEL VALLE 1986, MÄUSBACHER et al. 1989, VOLKMAN et al. 1988, MATTHIES et al. 1990, SCHMIDT et al. 1990, BIRD et al. 1991, BJÖRCK et al. 1991). Because lakes act as sedimentary basins on the continent, lake sediments generally represent more complete depositional sequences than other terrestrial sediments. Furthermore, commonly occurring high organic carbon contents in the lake sediments often enable detailed age determinations by radiocarbon datings. This frequent possibility of obtaining stratigraphical information, together with a high sedimentation rate, also often differentiates lake sediments from continental shelf sediments. Hence, the lake sediments probably function as the best archives of Holocene environmental history in Antarctica, generally enabling high resolution reconstructions, with good stratigraphic control.

Therefore, geological sampling was carried out on lakes and marine basins in the Bunger Hills (Fig. 1) during the Soviet Antarctic Expedition 1990/1991 (SAE 36). In this study investigations of the sediment composition were made on sediment cores from four sites with distinctly different environmental settings within the oasis. The main purposes of this pilot study are (1) to investigate the influences of the recent environmental conditions on sediment formation, (2) to determine the significance of individual sediment parameters for paleoenvironmental reconstructions, (3) to find indications concerning the evolution of the lakes and marine basins, (4) to reconstruct major changes in environmental conditions, and (5), for future sampling, to identify those areas with best documentations of the Holocene climatic history in the sediment records.

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Manuscript received: 24 October 1991, accepted 18 February 1992

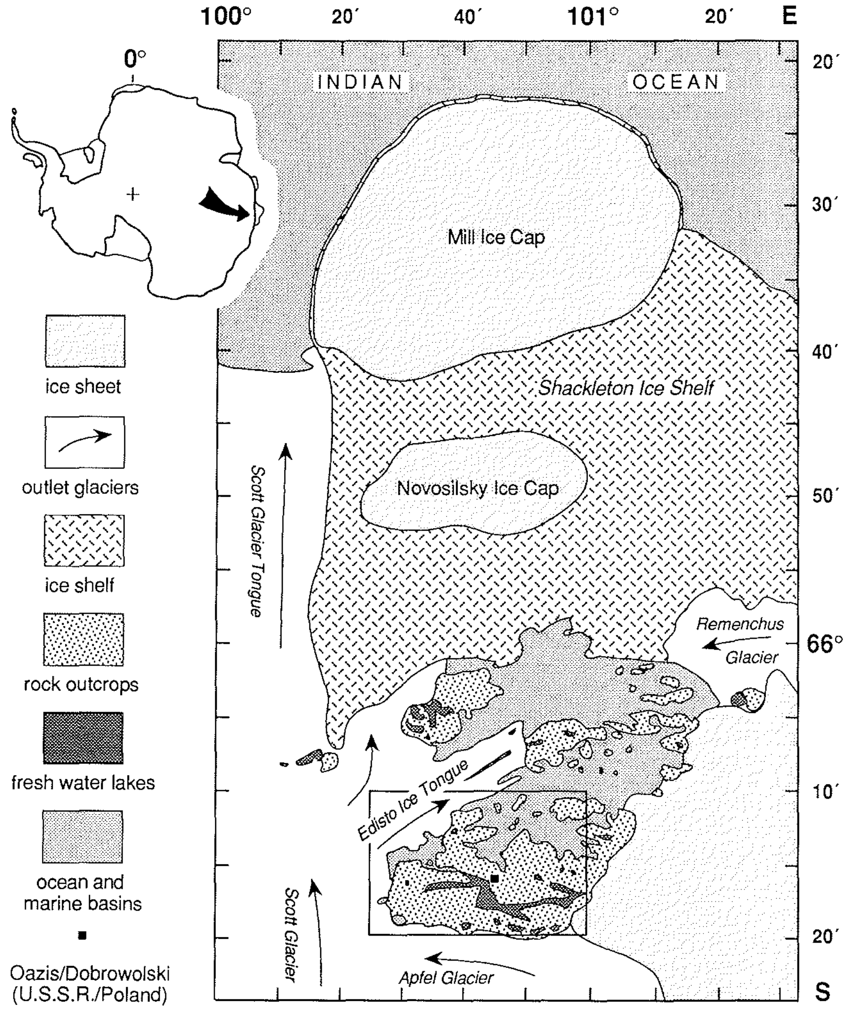

Fig. 1: Location of the Bunger Oasis in East Antarctica and glaciological and hydrographical settings in the surrounding of the oasis. The encircled box marks the location of the detailled map of Figure 2.

Abb. 1: Lage der Bunger-Oase in der Ostantarktis mit den glaziologischen und hydrographischen Gegebenheiten der Oasenumgebung. Der umrandete Kartenausschnitt kennzeichnet die Lage der Detailkarte von Abb. 2.

AREA OF INVESTIGATION

The Bunger Hills (Fig. 1) form one of the largest ice-free areas (oasis) of East Antarctica. In the southern part of the oasis a large connected area of about 280 km^2 occurs, exhibiting a high number of fresh water lakes (Fig. 2). To the north numerous islands of altogether about 170 km^2 are separated from the main area by marine basins and marine inlets. Further to the north the oasis is bordered by the Shackleton Ice Shelf, to the east by the East Antarctic ice sheet and to the south and west by the Apfel and Edisto glaciers, respectively.

The climate in Bunger Hills is mild, relative to other areas of same latitutes in Antarctica (RUSIN 1961). The conditions are characterized by a mean annual air temperature of -9.1° C, a positive annual radiation balance, and a potential annual evaporation of 450-600 mm/a, which is nearly three times higher than the annual precipitation of 200 mm/a.

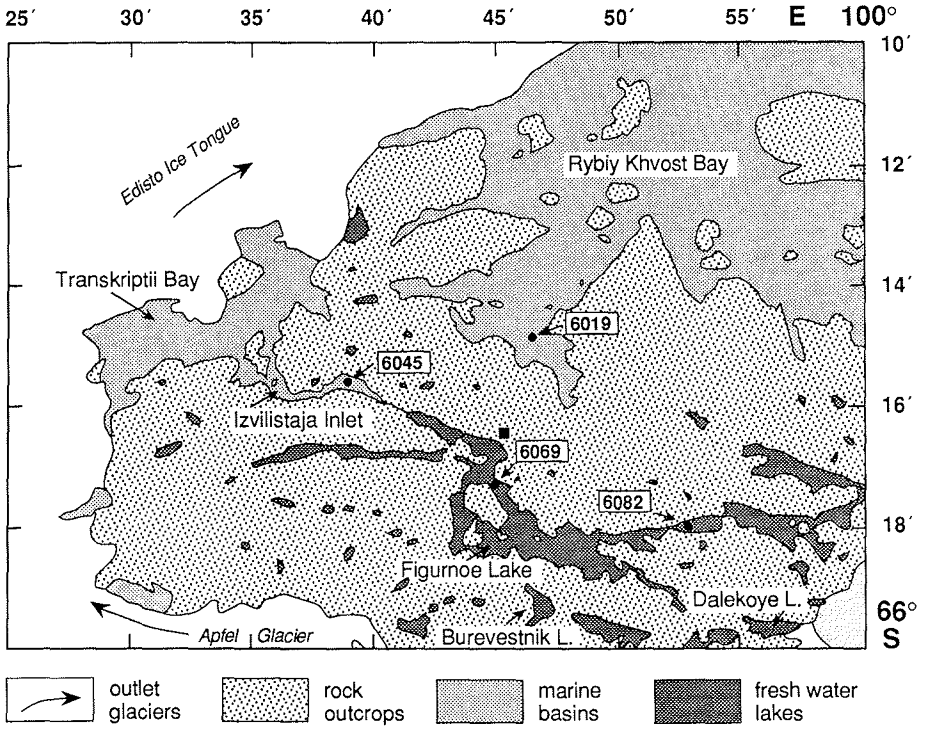

Fig. 2: Detailled map of the Bunger Oasis with core locations and geographical terms mentioned in the text.

Abb. 2: Detailkarte der Bunger-Oase mit den Kernpositionen und den im Text erwähnten geographischen Bezeichnungen.

The Bunger Hills show a rugged relief with a maximum elevation of 165 m a.s.l. and maximum water depth in the fresh water lakes and marine basins of at least 145 m. The main geomorphological features are connected to the tectonic structures and probably were related before the onset of Antarctic glaciation (BOLSHIYANOV 1990).

During the Weichselian time the Bunger Hills were probably completely covered by ice (BOLSHIYANOV et al. 1990). The deglaciation started near the Pleistocene-Holocene boundary. In early Holocene time the ice had retreated from most areas of the Bunger Hills. This is evident from the settlement of snow petrels at various places in the oasis, whose organic deposits were dated by ^{14}C as far back as about 10,000 y BP. Approximately the same age was determined by a ^{14}C measurement on lake sediments, which probably were located a few centimeters above the bedrock (BOLSHIYANOV & VERKULICH 1991). The ice retreat was followed by a marine trangression into the oasis, documented in marine terraces up to 10 m a.s.l., which contain autochthoneous shells of marine organisms (VERKULICH 1991). During the entire Holocene time most parts of the Bunger Oasis remained ice-free, however, small-scale variations in the extent of glacier ice and of snow fields are believed to have taken place.

MATERIAL AND METHODS

The four sediment cores available for this study were collected during the Soviet Antarctic Expedition 1990/1991 (SAE 36) from two marine basins and one lake of Bunger Hills (Fig. 2). Site 6019 is located in the Rybiy Khvost Bay (Fig. 2), a typical marine bay with only slightly diluted seawater and a semi-permanent ice cover (KAUP et al. 1990). Izvilistaja Inlet, from which the sediment core of Site 6045 was taken, is part of Transkriptii Bay at the western border of the oasis (Fig. 2). The occurence of seawater in the lower parts of Transkriptii

Bay, overlaid by chemically transformed meltwater, document a connection of the bay with the ocean (KAUP et al. 1990). Transkriptii Bay is described as being perennially ice-covered at least for 30 years (KAUP et al. 1990, BOLSHIYANOV et al. 1991), however, we have observed parts of Izvilistaja Inlet ice-free in austral summers. Sites 6082 and 6069 are located in Figurnoe Lake (Fig. 2), a fresh water lake with a semipermanent ice cover (KAUP et al. 1990). Major parts of the meltwater from the ice sheet reaching the oasis are flowing through Figurnoe Lake into Transkriptii Bay. Sites 6082, 6069 and 6045 are situated along this flow path from fresh water conditions in the east to almost marine conditions in the west.

The cores were taken through the ice cover by gravity corers, having tube diameters of about 3 cm. A steel plate at the top of the tube closes during heaving and thus protects the sediment against washing out. Additionally, due to underpressure in the tube, the plate protects against core loss at the base. The core recoveries were between 96 cm and 138 cm. After recovery, the sampled columns were stored on fresh air for several hours to obtain a higher stability of the sediment, before they were cut into pieces of 5-15 cm length. To protect the pieces against damage during transportation and against complete drying out during storage, they were wrapped up in paraffin (three cores) or frozen in plastic folios (one core).

The sedimentological analyses were carried out at the Alfred Wegener Institute in Bremerhaven. Primarily, the cores were cut parallel to the core axis into two halves and described in respect to the sediment color (MUNSELL SOIL COLOR CHARTS 1954) and sediment composition. The sediment structures were described also directly on the sediment cores, but especially on X-radiographs, which were taken from 1 cm thick slabs parallel to the core axis of the three paraffin packed cores.

In order to quantify the coarse-grained terrigenous content of the bulk sediment, in the X-radiographs the clastic grains >1 mm were counted per centimeter core depth (GROBE 1987). Grain-size distributions were analysed in bulk sediment samples of 5-20 cm^3, which were taken at mean intervals of 10 cm. The samples were oxidized and disaggregated by means of a 5 % H_2O_2 solution. The contents of the gravel (>2 mm), sand (63 µm to 2 mm) and mud fractions (<63 µm) were determined by wet sieving. The dried coarse fractions (>63 µm) were inspected in respect of biogenic components using a binocular microscope.

The sulfur, organic carbon and carbonate contents were analysed on a CS-125 Carbon-Sulfur Determinator (LECO Corporation) in mean intervals of 5 cm. The total carbon and sulfur contents were measured in freeze-dried and ground bulk sediment samples, the organic carbon contents were measured in corresponding samples, which have been treated with hydrochloric acid to remove the carbonate. The carbonate contents were calculated from the contents of carbonaceous carbon, the difference between total and organic carbon.

RESULTS

All analysed sediment cores are well defined laminated. Bioturbation structures due to infaunal activity do not occur. The sediments consist mainly of three different types of sediment components, which can be easily distinguished: algae, mosses and clastic grains. The individual algal layers have grayish, yellowish and greenish colors and vary in thickness between a few tenths of millimeters and about 2 mm. The thicknesses of the moss layers range from 1-7 mm. With gray, dark gray, greenish gray, olive gray and black their colors are much darker than those of the algal layers. Terrigenous sediment components may occur as single dispersed grains, single defined layers, or as coherent multi-layered horizons. Their colors are generally gray and light gray, the thicknesses of individual layers are often much less than 1 mm.

Site 6082 was sampled in the eastern part of Figurnoe Lake in a water depth of 67 m (Fig. 2). Two distinct units can be distinguished in the sediment sequence (Fig. 3).

Unit 1 (0-104 cm): The sediment consists predominantly of laminated algal mats. In the algal mats moss bands, increasing in number and thickness downcore, are interbedded. The sediment contains high amounts of clastic grains >1 mm, possibly exhibiting cyclic fluctuations. However, almost no gravel and relatively low, weakly varying sand contents result in a clear dominance of mud in the grain-size distribution. The carbonate contents have a wide range. In contrast, the contents of organic carbon and sulfur are very constant in low values.

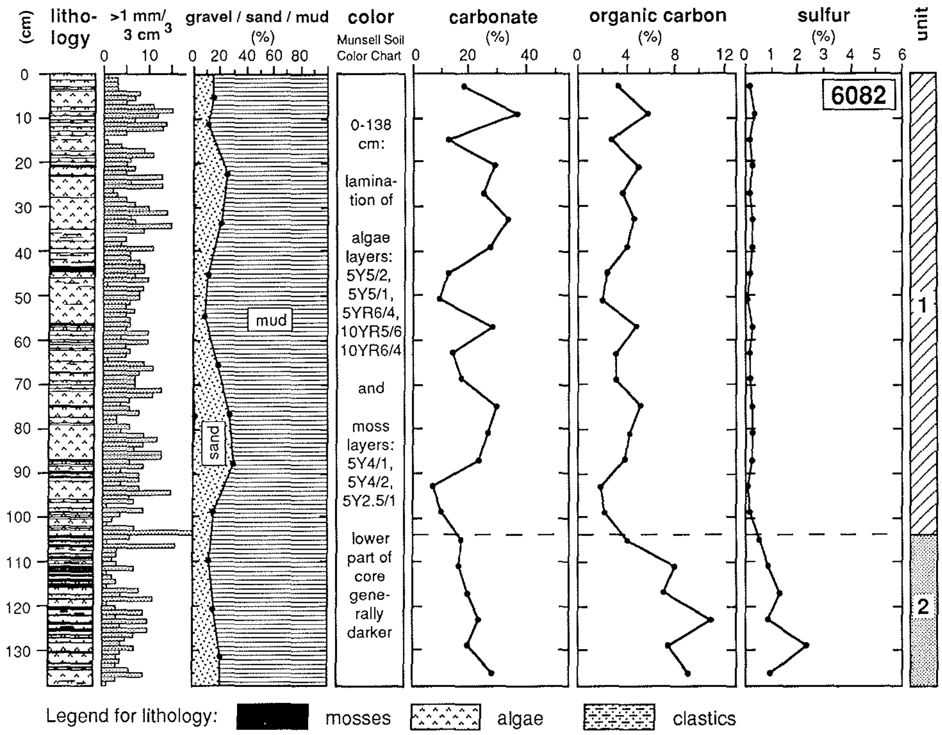

Fig. 3: Core log of the sedimentary succession at Site 6082 from the eastern Figurnoe Lake.

Abb. 3: Kerndiagramm der Sedimentabfolge an der Station 6082 vom östlichen Figurnoe-See.

Unit 2 (104-138 cm) consists of algal mats with distinctly higher amounts of moss bands than in Unit 1, especially in the upper part. Similar to Unit 1 the sand content is low, gravel is absent and the carbonate content is in the same range. Beside the higher moss content, Unit 2 differs from Unit 1 in lower numbers of clastic grains >1 mm and higher contents of organic carbon and sulfur.

The sediment at Site 6069 from the western part of Figurnoe Lake in 56.5 m water depth (Fig. 2) can be subdivided into three units (Fig. 4). The first two units show many similarities with those of Site 6082 from the eastern part of Figurnoe Lake.

Unit 1 (0-53 cm): As in Unit 1 at Site 6082, the sediment consists predominantly of laminated algal mats with a downcore increasing interbedding of moss layers. Additional similarities are relatively high contents of clastic grains >1 mm, lack of gravel in the sediments, relatively low sand contents, similar values and high variability of the carbonate contents, and relatively low and constant contents in organic carbon and sulfur. Unit 1 at Site 6069 differs from that of Site 6082 by a lower absolute number of moss layers, by lower absolute numbers of clastic grains >1 mm and, less clearly, of the sand fraction, and by the much lower thickness, approximately half of that at Site 6082.

Unit 2 (53-85 cm): Conformity between the units 2 at sites 6082 and 6069 lies in the high moss content, especially in the upper part, distinctly higher than in the corresponding units 1. Similarity in units 2 at both sites additionally lies in the lack of gravel, relatively low contents in sand and in clastic grains >1 mm, similar values in carbonate contents, and high contents in organic carbon and sulfur, relative to the units 1. Unit 2 at Site 6069 differs from that at Site 6082 by higher absolute contents in moss and sulfur, and by lower absolute numbers of clastic grains >1 mm.

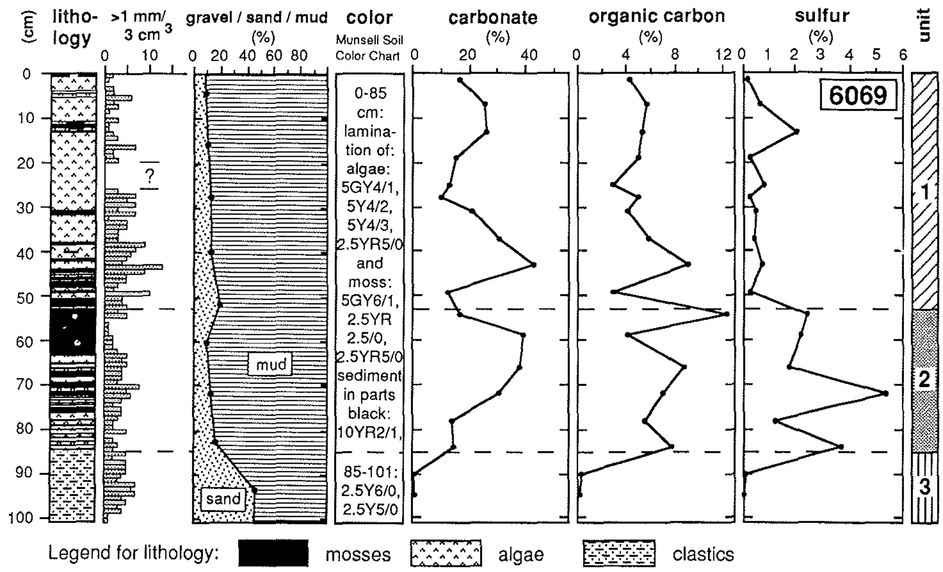

Fig. 4: Core log of the sedimentary succession at Site 6069 from the western Figurnoe Lake.

Abb. 4: Kerndiagramm der Sedimentabfolge an der Station 6069 vom westlichen Figurnoe-See.

Unit 3 (85-101 cm): The sediment of Unit 3, separated from Unit 2 by a distinct color change, differs clearly from those of all other units. It consists almost totally of terrigenous, finely laminated components of gray and light gray colors. Algae occur in very low contents in Unit 3 and mosses are completely lacking. The sediment is highly consolidated. It shows relatively low contents in clastic grains >1 mm while having higher sand contents than the overlying sediments. Unit 3 sediments are the only ones which are almost free of carbonate, of organic carbon, and of sulfur. At the base of the column the core tube was nearly filled by a single grain of about 2.5 cm diameter, overlain by a few centimeters of coarse sandy to gravelly sediments.

Site 6045 was sampled in 37.5 m water depth in Izvilistaja Inlet (Fig. 2). Although the sediment sequence shows minor differences in composition than the cores from Figurnoe Lake, two different units can be distinguished (Fig. 5).

Unit 1 (0-83 cm): Finely laminated algal material without any moss. The sediment contains high amounts of clastic grains >1 mm and of sand, however, gravel is lacking in the grain-size samples. The carbonate contents are relatively high, especially in the upper part of Unit 1, with a decreasing trend to the lower part. Organic carbon and sulfur show a high constancy over the whole unit and low values in respect to Unit 2 of this site. These relatively low values as well as the high numbers of clastic grains >1 mm are similar to Unit 1 sediments at sites 6082 and 6069 from Figurnoe Lake.

Unit 2 (83-96 cm): As Unit 1 at this Site 6045, Unit 2 also consists predominantly of algal material lacking any moss. The differences between these two units are distinctly lower numbers of clastic grains >1 mm and lower contents in sand in Unit 2. Additionally, in Unit 2 the contents of organic carbon and sulfur are higher than in Unit 1. Except the lack of any moss, Unit 2 of Site 6045 exhibits several similarities to units 2 of sites 6082 and 6069, including the relatively low numbers of clastic grains >1 mm, and the high contents of organic carbon and sulfur.

Site 6019 is located in 88 m water depth in Rybiy Khvost Bay (Fig. 2). The 123 cm thick sediment sequence recovered at this site is characterized by a large homogeneity, preventing the distinction of individual sediment units (Fig. 6).

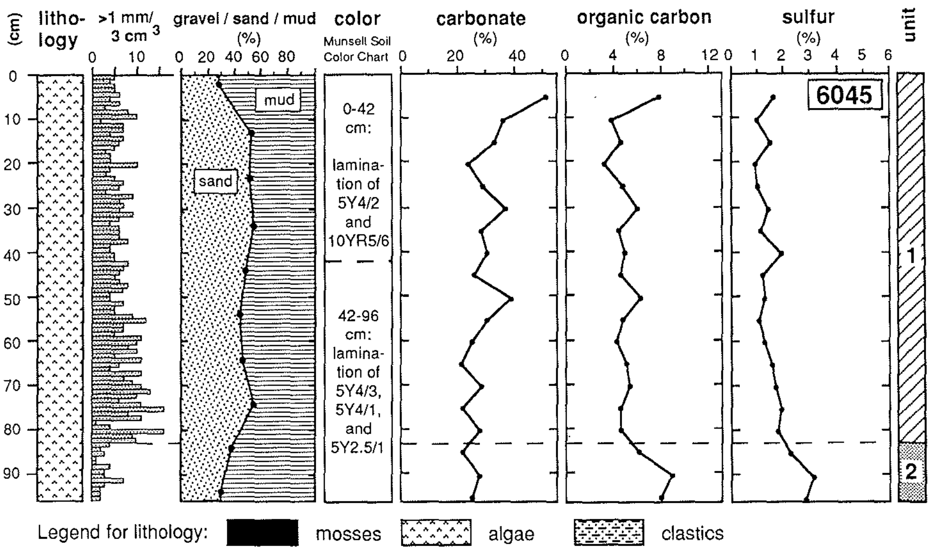

Fig. 5: Core log of the sedimentary succession at Site 6045 from the Izvilistaja Inlet, eastern Transkriptii Bay.

Abb. 5: Kerndiagramm der Sedimentabfolge an der Station 6069 vom Izvilistaja- Meeresarm in der östlichen Transkriptii-Bucht.

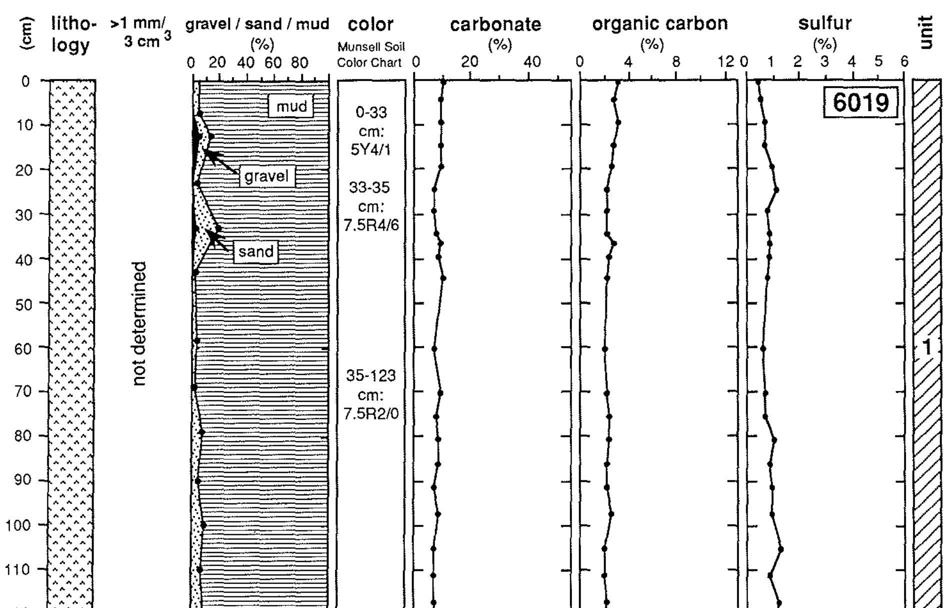

Fig. 6: Core log of the sedimentary succession at Site 6019 from the southern Rybiy Khvost Bay.

Abb. 6: Kerndiagramm der Sedimentabfolge an der Station 6069 von der südlichen Rybiy-Khvost-Bucht.

The sediment smelt strongly of H_2S when extruded from the core tube in the field. It consists predominantly of laminated algal material, mosses are absent. The contents of the coarse fraction in 6019 are much lower than in the other three cores mentioned in this study, except two samples in the upper part of the core, which contain significant amounts of gravel. The values of carbonate, organic carbon, and sulfur are very constant and low in respect to the sediments from the other sites. As the only one core, the coarse fraction of 6019 contains biogenic components, occurring throughout the core. These components include arenaceous foraminiferal tests of *Miliammina arenacea*, a marine organism. In addition, marine diatoms were found in the mud fraction (Z. PUSHINA pers. comm.). The occurrence of a marine fauna in the sediments of Rybiy Khvost Bay was also described by BOLSHIYANOV et al. (1991).

DISCUSSION

Paleoenvironmental significance of sediment parameters determined

The contents of the main sediment components algae, mosses, and clastics depend on a number of processes. The contents of algae and mosses are influenced by their production in the water column, by their deposition on the lake floor, by their redistribution due to bottom currents or gravitational transport, by their dilution with other sediment components, and by their bacterial or chemical decomposition. The absence of bioturbation structures indicates that an influence of a grazing fauna on the algae and moss contents may be negligible.

The thicknesses of the regularly layered algal mats vary between a few tenth of millimeters and about 2 mm. This is within the range of annual sedimentation rates determined on Antarctic lake sediments from Vestfold Hills, about 1,000 km to the west from Bunger Hills (BIRD et al. 1991), as well as from Livingston Island, in the Antarctic Peninsula region (BJÖRCK et al. 1991). This indicates that each individual layer may represent an annual deposition, possibly due to a spring or summer algal bloom. In contrast, the moss layers are less regularly distributed in the sequences and exhibit more variable thicknesses. Their occurence therefore might represent environmental conditions more independent from the annual cycle. In Bunger Hills the moss layers were sampled only in the sediment cores from the fresh water Burevestnik Lake (BOLSHIYANOV et al. 1991) and Figurnoe Lake (sites 6069 and 6082). Mosses were described from other regions of Antarctica also exclusively from fresh water lakes, e.g., from Schirmacher Oasis (INGOLE & PARULEKAR 1990, MELLES in press), Livingston Island (BJÖRCK et al. 1991) and King George Island (MATTHIES et al. 1990). This indicates that salinity is a limiting factor for moss growth.

The clastic sediment components may have different sources and transport mechanisms. Glaciers or the ice sheet, when reaching the lake, may supply poorly sorted clastic material, containing all grain-size fractions, from large distances directly in the lake water or on the lake ice cover. Similar poorly sorted debris, but from a local source, may be delivered by gravitational transport downslope adjoining hills. Material of much better sorting, and with limited maximal grain sizes, could be carried out into the lakes by meltwater inflow streams and, probably in a lesser amount, by eolian transport.

The grain-size distribution shows a clear dominance of the mud fraction in all investigated sediments. This indicates that during the time span represented by the sediments the current velocities at the bottoms of the lakes and marine basins were not strong enough at least for transporting sand, i.e. they were lower than about 3 cm/sec (SINGER & ANDERSON 1984). The almost exclusively terrigenous sand fraction as well as the fraction >1 mm, whose grain numbers were determined per centimeter core depth at three sites, are irregularly distributed in the sediments or concentrated in thin layers. The low thickness of the layers and the lack of graded bedding makes their deposition by gravitational transport events, such as turbidity currents, slumps or slides, unlikely. More likely, therefore, is their supply by lake ice or icebergs, either by downward transport through the ice cover as described by SQUYRES et al. (1991) or by melting of the ice in austral summer. The degree of the coarse-grained material in the sediments is not necessarily related to the supply of coarse-grained material into the lake, but also to the dilution by biogenic components, as well as enrichment or diminishing with fine-grained biogenic or clastic material as a result of currents.

The carbonate contents in the investigated sediments generally are high, except in Unit 3 at Site 6069, where carbonate is almost lacking. In spite of the high carbonate values microscopical examinations of the coarse fractions did not reveal carbonate components, neither biogenic nor terrigenic, proving a major carbonate occurrence in the mud fraction. The carbonate probably is the result of precipitation of carbonate minerals, a process which has been widely reported in Antarctic lakes (BURTON 1981, WHARTON et al. 1982, 1983; BIRD et al. 1991). Carbonate dissolution at least today is negligible because the water in all lakes of Bunger Oasis exhibit almost neutral or slightly alkaline reaction (KAUP et al. 1990). Because variations in the carbonate profiles generally do not correlate with other sediment parameters, the carbonate precipitation is probably largely independent from the large-scale environmental conditions. Therefore the carbonate contents in the lake sediments are difficult to interpret in respect to paleoenvironmental reconstructions.

The contents of organic carbon and sulfur in the investigated sediments generally show a similar distribution pattern. Their contents are influenced for example by the biogenic production in the water column, which depends mainly on the availibility of nutrients and of light. Another factor influencing the organic carbon and sulfur contents is the biological or chemical decomposition in the water column or after deposition in the sediment. In addition, the contents of organic carbon and sulfur are influenced by their redistribution due to currents and gravitational sediment transport, and by the degree of dilution with other sediment components.

Paleoenvironmental reconstructions by the lake sediment composition

The sediment units (1, 2, and 3), distinguished in the four investigated sediment cores, have a number of similarities in sediment composition, respectively. Because the composition of the sediment is directly dependent on the regional environmental conditions, the individual units probably are comparable at the different sites and represent same time intervals of deposition. The interpretation of the individual units therefore provides informations concerning the environmental history in and around the lakes and marine basins of Bunger Hills.

Unit 1, sampled at all four sites, includes the surface sediments and therefore represents environmental conditions similar to those of today. Unit 1 in eastern Figurnoe Lake (Site 6082) differs from that in western Figurnoe Lake (Site 6069) in higher sand contents, in lower moss contents and in an almost twice as high sedimentation rate (Figs. 3 and 4). The higher sand content at Site 6082 could be due to higher current velocities in the water column, causing an enrichment of the coarse fraction by diminishing of fine material. However, sediment diminishing at Site 6082 is unlikely because of the distinctly higher sedimentation rate. More likely, therefore, is enhanced sand supply by lake ice or icebergs at Site 6082 as a result of the higher proximity to the ice sheet. This higher terrigenous sand supply alone cannot explain the doubled sedimentation rate at Site 6082, relative to Site 6069. The higher rate of sedimentation is probably additionally the result of a distinctly higher algae accumulation at Site 6082 in eastern Figurnoe Lake, because the moss content there is even lower and the carbonate contents are in the same range at both sites. This suggestion is supported by measurements of nutrient inflows with glacial meltwater into Dalekoye Lake (Fig. 2), which are connected with high biogenic production (KAUP et al. 1990). The lower moss content at Site 6082 is not necessarily the result of a lower production, but rather of dilution by algal and clastic material.

At Site 6045 from Izvilistaja Inlet, eastern Transkriptii Bay, as well as at Site 6019 from Rhybiy Khvost Bay Unit 1 does not contain any mosses due to the high salinities of the water in these marine basins (Figs. 5 and 6). In spite of the lack of mosses, the thickness of Unit 1 at Site 6045 again is higher than at Site 6069 from western Figurnoe Lake (Fig. 4). This higher sedimentation rate could be the result of higher accumulation of algae, because the nutrient concentrations in Transkriptii Bay are significantly higher than those in Figurnoe Lake (KAUP et al. 1990). However, the existence of an almost perennial ice cover on Izvilistaja Inlet could have limited algae production by reducing light penetration into the water. Hence, the most probable explanation for the higher sedimentation rates at Site 6045, relative to Site 6069, is a higher terrigenous sediment supply, which could be documented in distinctly higher sand contents at Site 6045 (Fig. 5). The high sand content cannot be due to diminishing of fine material as a result of higher current velocities in Transkriptii Bay, because below 88 m water depth (well below Site 6045) a stagnant water body with high contents of H_2S and phosphates occurs (KAUP et al. 1990), indicating only very weak circulation. In the uppermost sediment centimeters of Unit 1 at Site 6045 the carbonate and organic carbon contents increase. In these sediments the first occurence of fresh water diatoms is observed (Z. PUSHINA pers. comm.), indicating an increase of meltwater input into Izvilistaja Inlet during the last decades or centuries.

In the recovered sediments from Site 6019 in Rybiy Khvost Bay (Fig. 2) no significant changes in the sediment parameters occur (Fig. 6), including the continuous presence of marine organisms. Hence, the whole sediment sequence represents environmental conditions similar to those of today, and the sediments were deposited probably within the time interval of Unit 1. This means, that the sedimentation rate in Unit 1 at Site 6019 presumably is much higher than at all other sites investigated in this study. The high sedimentation rate could only be due to a very high algae accumulation, because the sand and carbonate contents are low and mosses are absent. A high algae production is expected, because the nutrient concentration in Rybiy Khvost Bay waters is very high and, different to Transkriptii Bay, the ice cover is only semipermanent (KAUP et al. 1990).

Unit 2 sediments were recovered in the cores from sites 6082 and 6069 from Figurnoe Lake and Site 6045 from Izvilistaja Inlet (Fig. 2). At all of these sites units 2 differ from units 1 in higher organic carbon and sulfur contents, and in lower contents of coarse-grained material (Figs. 3-5). Additionally, at the two sites from the fresh water Figurnoe Lake the moss contents in Unit 2 are higher than in Unit 1.

According to BIRD et al. (1991) the distinctly higher organic carbon and sulfur contents in Unit 2 sediments, relative to Unit 1, are interpreted as representing a situation with lack of organic carbon oxidation and occurrence of bacterial sulfate-reduction. These anoxic conditions probably existed during the deposition of Unit 2 in the water depths of the investigated sites of both the Figurnoe Lake and the Izvilistaja Inlet. Anoxic conditions could be the result of a very high organic flux to the bottom or of only weak water circulation which may result in limited mixing of the water column. A high organic accumulation could be demonstrated by the higher moss contents in Unit 2, relative to Unit 1, however, this also could be an effect of lower accumulation rates in Unit 2. In contrast, a weaker water circulation in Unit 2 than in Unit 1 could clearly be documented in lower contents of coarse-grained sediment components, promoting the settlement of large amounts of fine material. Lower current velocities could be due to less meltwater supply as well as to a more permanent ice coverage, reducing wind induced water movements - both of these processes would indicate cooler climatic conditions than those of today.

Similar to Unit 1, Unit 2 at Site 6082 (eastern Figurnoe Lake) differs from that of Site 6069 (western Figurnoe Lake) in lower moss contents, in higher sand contents and in a higher sedimentation rate (Figs. 3 and 4). These differences are again interpreted as being the result of a higher accumulation of algae and terrigenous material in eastern Figurnoe Lake, which results in relatively lower moss contents. In contrast to Figurnoe Lake, Unit 2 at Site 6045 from Izvilistaja Inlet, equivalent to Unit 1, lacks mosses and contains marine diatoms. The similarities in the regional differences within units 1 and 2 indicate that the large-scale paleogeographical situation was relatively constant and that the transition from Unit 1 to Unit 2 represents changes in the climatic conditions rather than changes in the geographical situation.

Unit 3 sediments were recovered exclusively at Site 6069 from western Figurnoe Lake (Fig. 2), where they occur at the base of the sediment sequence (Fig. 4). It is the only unit, which consists predominantly of terrigenous sediment components. Additionally, in Figurnoe Lake Unit 3 is the only unit lacking any mosses, indicating a marine origin of Unit 3 sediments. This suggestion is supported by the occurence of a marine neritic diatom assemblage in similar highly terrigenous sediments at the bases of sediment cores from both Burevestnik Lake (BOLSHIYANOV et al. 1991, Fig. 2) and Figurnoe Lake (Z. PUSHINA pers. comm.). Radiocarbon datings on overlaying algal sediments from these lakes (BOLSHIYANOV et al. 1991) indicate an age of >9,000 y BP for the terrigenous sediments.

The very low content of biogenic components in Unit 3 could be the result of a thick, perennial lake ice cover, possibly additionally covered by snow, which could have limited biogenic production due to reduced light penetration into the water column. However, this is unlikely, because recently in Izvilistaja Inlet a high accumulation of algae occurs, documented in the surface sediment at Site 6045 (Fig. 5), although the inlet is almost perennially ice-covered. More likely, therefore, is a covering by floating glacier ice, preventing light penetration and significant biogenic production in the water column. The terrigenous material could have been supplied into the water by melting of the ice. Subsequently, marine currents or melt water streams of varying velocities could have resulted in sorting and stratification of the deposited material. The fining upward within Unit 3 could be due to increasing distances from the terrigenous source.

Hence, it is probable that the sediments of Unit 3 represent the initial lake stage, joint with a marine transgression, which possibly caused the floating of ice masses in the area of Bunger Hills. A transgression onto the oasis is also deduced from marine terraces, today located up to 10 m a.s.l., by VERKULICH (1991). And marine conditions in early Holocene times were also reconstructed for lakes from Vestfold Hills (PICKARD et al. 1986, BIRD et al. 1991). The border between units 3 and 2 in Figurnoe Lake corresponds with the transition from marine to lacustrine conditions. This could be a result of postglacial isostatical uplift in this region, cutting the water path between the lake and the ocean.

CONCLUSION

Based on the experience from this pilot study the following conclusions can be drawn concerning sedimentological work on sediments from fresh water lakes and marine basins in the Bunger Hills.

(1) No indication for erosional processes was found in the sediment record. Hence, at least parts of Figurnoe Lake, Transkriptii Bay and Rybiy Khvost Bay existed during the entire depositional time of the investigated sediments.

(2) The fresh water Figurnoe Lake probably originates from a marine inlet which was formed by a marine transgression during latest Pleistocene or earliest Holocene time (Unit 3). Later, the inlet became isolated from ocean water, presumably due to the postglacial isostatical uplift, and meltwater gradually replaced the original seawater (Unit 2).

(3) During a considerable time span within the Holocene (Unit 2) at least parts of Figurnoe Lake and Izvilistaja Inlet met anoxic conditions, which presumably can be traced back to a cooler climate than that of today. In more recent times (Unit 1) all core locations exhibit oxic conditions.

(4) All sediment parameters determined in this study, except carbonate content, exhibit significant variations within the cores and probably reflect the regional environmental conditions. The determination of sediment color, composition, structure, grain-size distribution, organic carbon content and sulfur content therefore can be used for paleoenvironmental interpretation and reconstruction.

(5) Sediment cores from the marine basins differ from those from fresh water lakes by higher sedimentation rates. Hence, the marine sediments expect a higher resolution of the environmental changes. In contrast, lakustrin sediments of same length comprise a longer time period. Additionally, they expect a better stratigraphy due to often higher organic carbon content.

(6) For future work, the frequently occuring high content of organic carbon, carbonate, sulfur, and algae in the sediments will enable the determination of additional parameters for a more detailled reconstruction of the Holocene environmental conditions in the Bunger Hills area. These parameters include radiocarbon dating, measurements of stable carbon, oxygen and sulfur isotopes as well as micropaleontological investigations.

ACKNOWLEDGMENT

We thank the collegues on the Soviet Antarctic Expedition 1990/1991 (SAE 36) for their help during field work. Prof. Dr. Fütterer (AWI) and Prof. Dr. Klokov (AANI) are gratefully acknowledged for enabling our joint laboratory work in Bremerhaven. Z. Pushina is thanked for providing unpublished results from diatom analysis. We are also indebted to Dr. R. Mäusbacher for a critical and helpful review of the manuscript and to Dr. G. Kuhn for fruitfull discussions. This is contribution No. 530 of the Alfred Wegener Institute for Polar and Marine Research, Bremerhaven.

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