The Expeditions NORILSK/TAYMYR 1993 and BUNGER OASIS 1993/94 of the AWI Research Unit Potsdam

Edited by Martin Melles
with contributions of the participants

Ber. Polarforsch. 148 (1994)
ISSN 0176 - 5027

1 THE EXPEDITION NORILSK/TAYMYR 1993 OF THE AWI RESEARCH UNIT POTSDAM

by M. Melles, U. Wand, W.-D. Hermichen, B. Bergemann, D.Y. Bolshiyanov and S.F. Khrutsky

1.1	INTRODUCTION	3
1.2	ITINERARY	4
1.2.1	Norilsk	6
1.2.2	Taymyr	6
1.3	LACUSTRINE SEDIMENTS	10
1.3.1	Sampling technique	10
1.3.2	Lama Lake	11
1.3.3	Pyasino Lake	11
1.3.4	Lake "X" and Arelakh Lake	14
1.3.5	Levinson-Lessing Lake	14
1.3.6	Khatanga River and Bay	15
1.4	PEAT/SOIL PROFILES	15
1.5	MARINE SEDIMENTS	16
1.6	HYDROLOGY	17
1.7	GLACIOLOGY	24
1.8	ACKNOWLEDGEMENTS	25
1.9	REFERENCES	25

2 THE EXPEDITION BUNGER OASIS 1993/94 OF THE AWI RESEARCH UNIT POTSDAM

by M. Melles, T. Kulbe, P.P. Overduin and S. Verkulich

2.1	INTRODUCTION	29
2.1.1	Objectives	29
2.1.2	Itinerary	29
2.1.3	Geography and climate	32
2.2	MARINE AND LACUSTRINE SEDIMENTS	34
2.2.1	Sampling technique	35
2.2.2	Sample storage and transport	38
2.2.3	Sediments in marine basins (epishelf lakes)	38
2.2.3.1	Edisto Channel	39
2.2.3.2	Kakapon Bay	42
2.2.3.3	Transkriptii Bay	46
2.2.4	Sediments in fresh-water lakes	47
2.2.4.1	Lakes on Geographers Island	48
2.2.4.2	Lakes on Southern Hills	48

2.3	OTHER TERRESTRIAL SEDIMENTS	50
2.3.1	Morainic deposits	50
2.3.2	Snow petrel stomach oil (mumiyo)	50
2.3.3	Marine carbonaceous shells	53
2.3.4	Snow petrel carcasses and fishes	54
2.3.5	Algae, mosses and a carbonaceous crust	54
2.4	HYDROLOGY OF LAKES AND MARINE BASINS	54
2.4.1	Hydrological measurements	55
2.4.2	Water sampling	71
2.5	GROUNDWATER HYDROLOGY	71
2.5.1	Description of study site	71
2.5.2	Method	72
2.5.3	Preliminary results	72
2.6	GLACIOLOGY	74
2.7	GEOMOPHOLOGY	75
2.7.1	Geographers Island	75
2.7.2	Thomas Island	76
2.7.3	Southern Hills	77
2.8	ACKNOWLEDGEMENTS	77
2.9	REFERENCES	77

1 THE EXPEDITION NORILSK/TAYMYR 1993 OF THE AWI RESEARCH UNIT POTSDAM

by

Martin Melles *, **Ulrich Wand** *, **Wolf-Dieter Hermichen** *,
Bert Bergemann *, **Dimitri Y. Bolshiyanov** ** and **Stanislav F. Khrutsky** ***

* Alfred Wegener Institute for Polar and Marine Research, Research Unit Potsdam, Telegrafenberg A43, D-14473 Potsdam, F.R.G.

** Arctic and Antarctic Research Institute, Department of Polar Geography, Bering Street, 199226 Saint Petersburg, Russia

*** Moscow State University, Department of Geocryology, 119 899 Moscow, Russia

1.1 INTRODUCTION

The field work in central Siberia was a pilot study in preparation for a german-russian research project, which is planned to start in 1994 and run for about three years. The main objective is a contribution to the understanding of the late Quaternary environmental history of central Siberia (Figs. 1.1 and 1.2). Within the scope of the project different natural data archives of the palaeoenvironmental conditions, such as lake sediments, soil/peat profiles and ice masses, shall be sampled and investigated. These sequences are, in an ideal case, chronologically accumulated and well preserved. The project shall be carried out in three regions in central Siberia trending along a S-N line; namely: (1) northwest of Putoran Plateau, close to the town of Norilsk, (2) on the Taymyr Peninsula and (3) on Severnaya Zemlya Islands (Fig. 1.2).

These regions today represent forest tundra, tundra, and polar desert, respectively. Investigations of the present-day sediment formation, and comparisons with results from the palaeoenvironmental data archives, therefore, promise reconstructions especially of vegetation zone migrations within the late Quaternary climatic variations. The results shall be compared and connected with the marine geological investigations in the Laptev Sea (Fig. 1.1), which have run as a bilateral german-russian project since the RV "Polarstern" and RV "Kireev" cruises in 1993.

The pilot study reported here was carried out during the summer of 1993 in the surroundings of Norilsk and on the Taymyr Peninsula. Besides acquisition of experience with the logistical possibilities and present-day environmental conditions, the main objective was to select promising research objectives for future field work. For that purpose numerous lakes, as well as ice and soil profiles, were visited and first samples were recovered. The analyses of the sampled material, especially the determination of the sediment composition and stratigraphy, yields important information prior to the multidisciplinary expeditions in the following years.

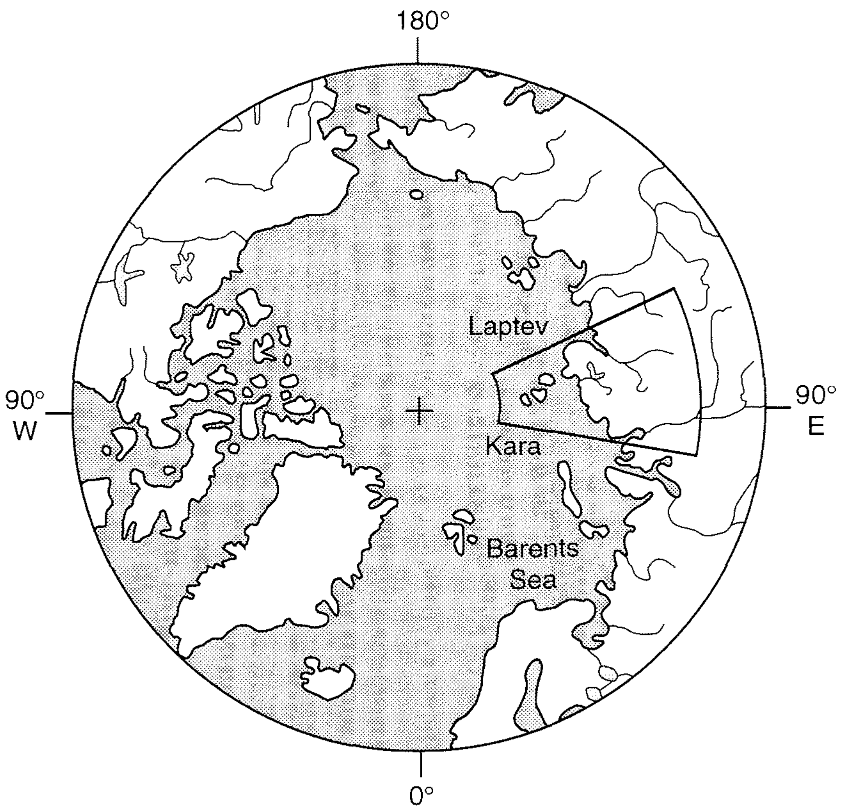


Figure 1.1: Map showing the location of the project study area in central Siberia (encircled, for details see Fig. 1.2)

1.2 ITINERARY

The expedition was conducted in two separate parts. In both parts members of the Alfred Wegener Institute (AWI) and of different russian research institutes participated in the research program. The local transportation and the field camps were organized by the Moscow State University (MSU), Moscow, in the area of Norilsk and by the Arctic and Antarctic Research Institute (AARI), St. Petersburg, on the Taymyr Peninsula.

The AWI field equipment was sent to St. Petersburg by regular shipping and, together with the equipment of the AARI, further to Norilsk and Khatanga by a charter flight (Fig. 1.2). Most of the AWI equipment, including the entire equipment for lake sediment coring, was unloaded in Norilsk. At the end of the expedition it was transported together with the samples and the participants of the Taymyr expedition part back to St. Petersburg again by charter flight from Khatanga via Norilsk.

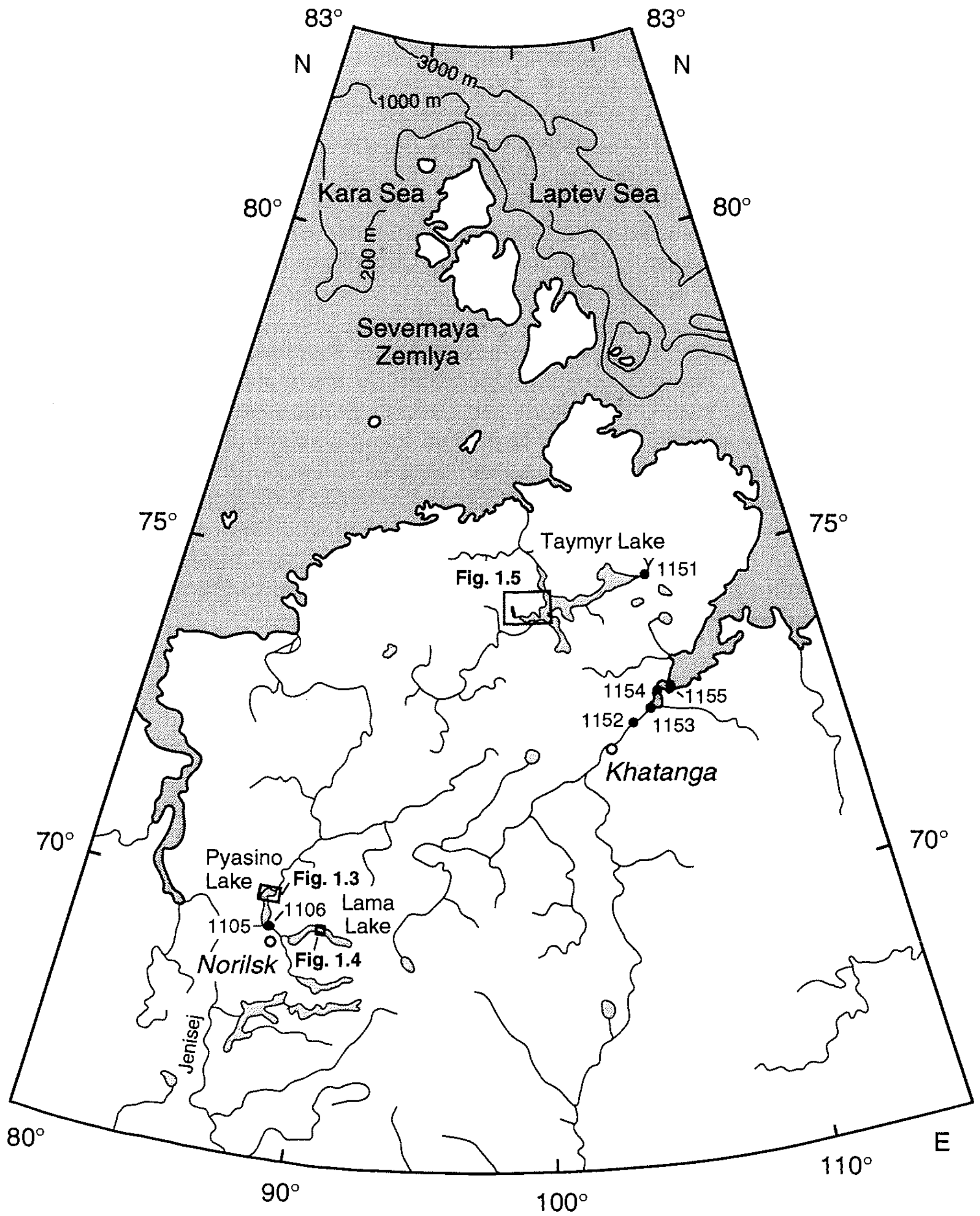


Figure 1.2: Map showing the study area of the project with the three regions of special interest (Norilsk, Taymyr, Severnaya Zemlya) and those sediment sampling sites (heavy dots) situated outside the more detailled maps of Figs. 1.3 - 1.5 (encircled).

1.2.1 Norilsk

The first part of the expedition started on July 12, 1993, with regular flights of four AWI members to Moscow and, together with some colleagues from the MSU, further to Norilsk on July 14. On July 16 the joint charter flight with the AARI delivered the AWI field equipment from St. Petersburg. Problems in the organization of foodstuffs, permissions, and means of transportation resulted in a delay of the expedition. Not until July 22 the expedition could start to travel by river boat up the Noril'ka River, and accross Melkoye Lake to Lama Lake. A field camp was set up on the northern shore of Lama Lake (Fig. 1.3) on July 23. The field work in the time period July 24 to Aug. 1 was facilitated by the predominance of good weather.

Between Aug. 3 and 5 the expedition shifted to the Pyasino Lake in two separate groups. While the first group, responsible for the installation of the field camp, took a helicopter (MI-8) flight, the second group together with most of the equipment sailed again by river boat. The camp was set up on the shore of the outflowing Pyasino River in the northeast of Pyasino Lake (Fig. 1.4). In spite of unsettled weather, it was possible to carry out field work almost every day between Aug. 7 and 22. After the departure of one AWI member to the second part of the expedition on Aug. 14, the rest of the expedition took a helicopter flight back to Norilsk on Aug. 23. Further travel to Germany was by regular flights via Moscow on Aug. 26.

1.2.2 Taymyr

The two AWI participants in the second part of the expedition and a colleague from the AARI met each other in Norilsk on Aug. 15. Together with light equipment, they took a helicopter flight (MI-8) to Khatanga (Fig. 1.2) on Aug. 17. Especially low visibility in wide areas of the Taymyr Peninsula resulted in delay of the helicopter flight to the first study area on Levinson-Lessing Lake, which took place as late as Aug. 22. The field camp was set up on the southeastern shore (Fig. 1.5). Due to bad weather with strong winds and heavy precipitation the field work was restricted. This is valid for water and sediment sampling from the lake rather than for exploration and sampling in its surrounding area.

In the time period from Aug. 31 to Sept. 4, an excursion was made with two rubber boats from Levinson-Lessing Lake via Ledyannaya River and Ledyannaya Bay to Taymyr Lake and along its western shore to the north. During this excursion terrestrial deposits and ice wedges along the route were sampled. Another objective was to visit and explore field bases of other russian institutes for possible logistical support during future field work. The departure back to Khatanga was on Sept. 5, again by helicopter.

From Khatanga on Sept. 7 a flight was made over the eastern Taymyr Peninsula with a small biplane (AN-2) in order to explore and photograph possible research objectives of future expeditions. Between Sept. 7 and 9 sediment coring was carried out during a trip with a pilot boat down the Khatanga River and in the Khatanga Bay. The entire field equipment of both the Taymyr and the Norilsk parts of the expedition as well as the Taymyr participants were transported back to St. Petersburg by charter flight (AN-26) via Norilsk on Sept. 12.

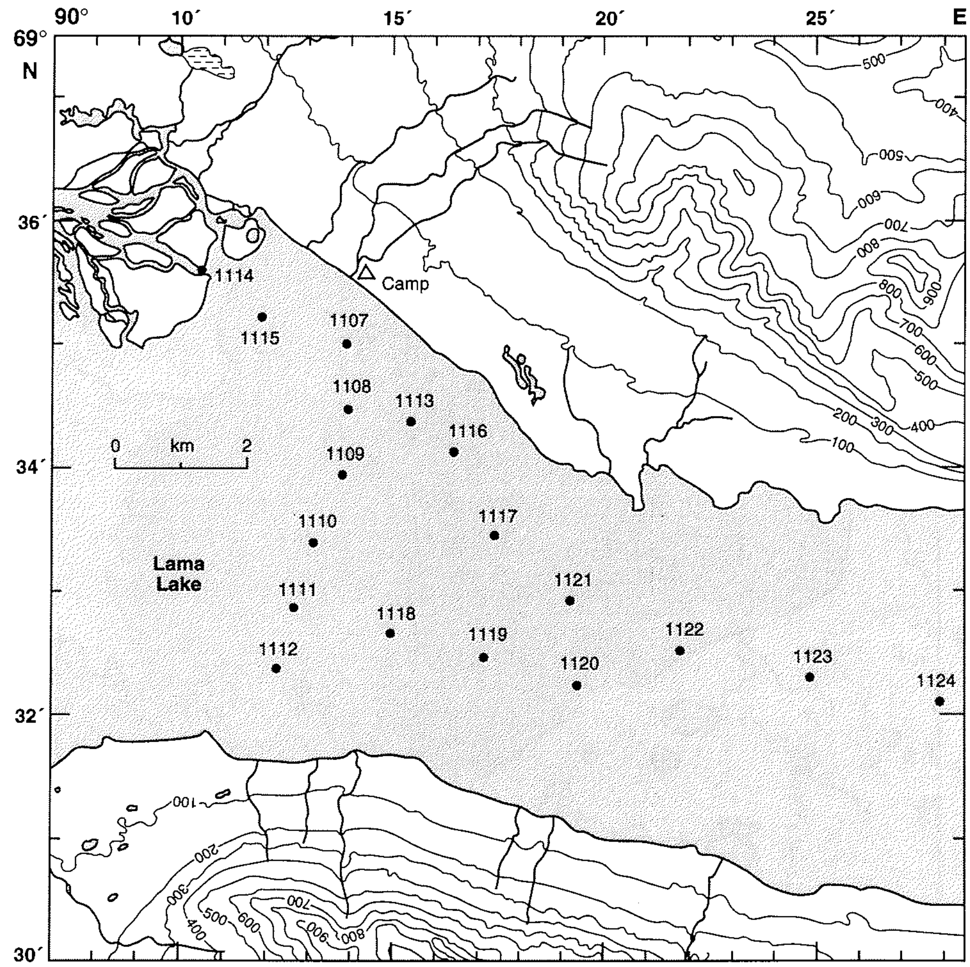


Figure 1.3: Sediment sampling sites (heavy dots) in the central Lama Lake (for overview see Fig. 1.2; altitudes in metres a.s.l.)

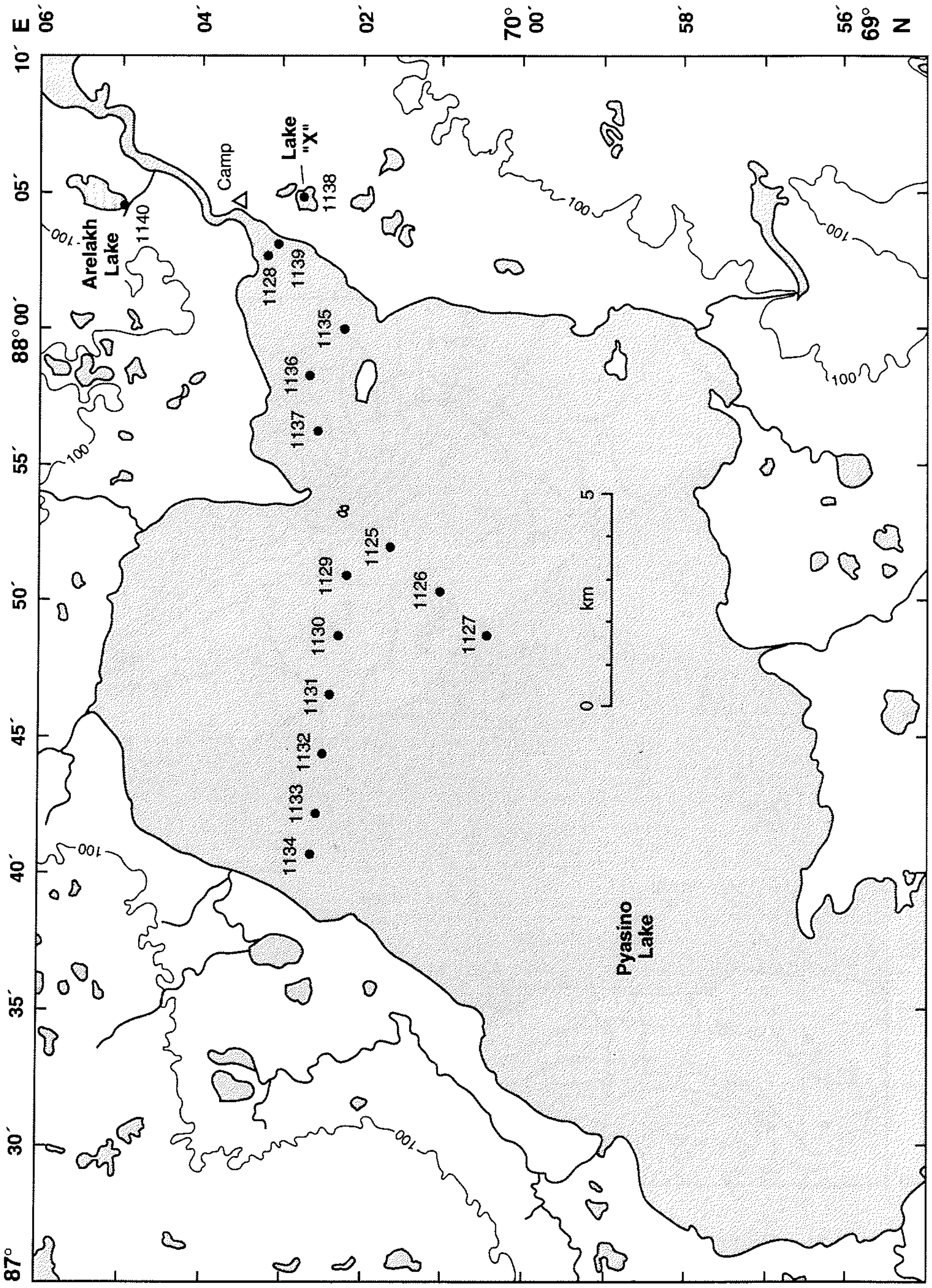
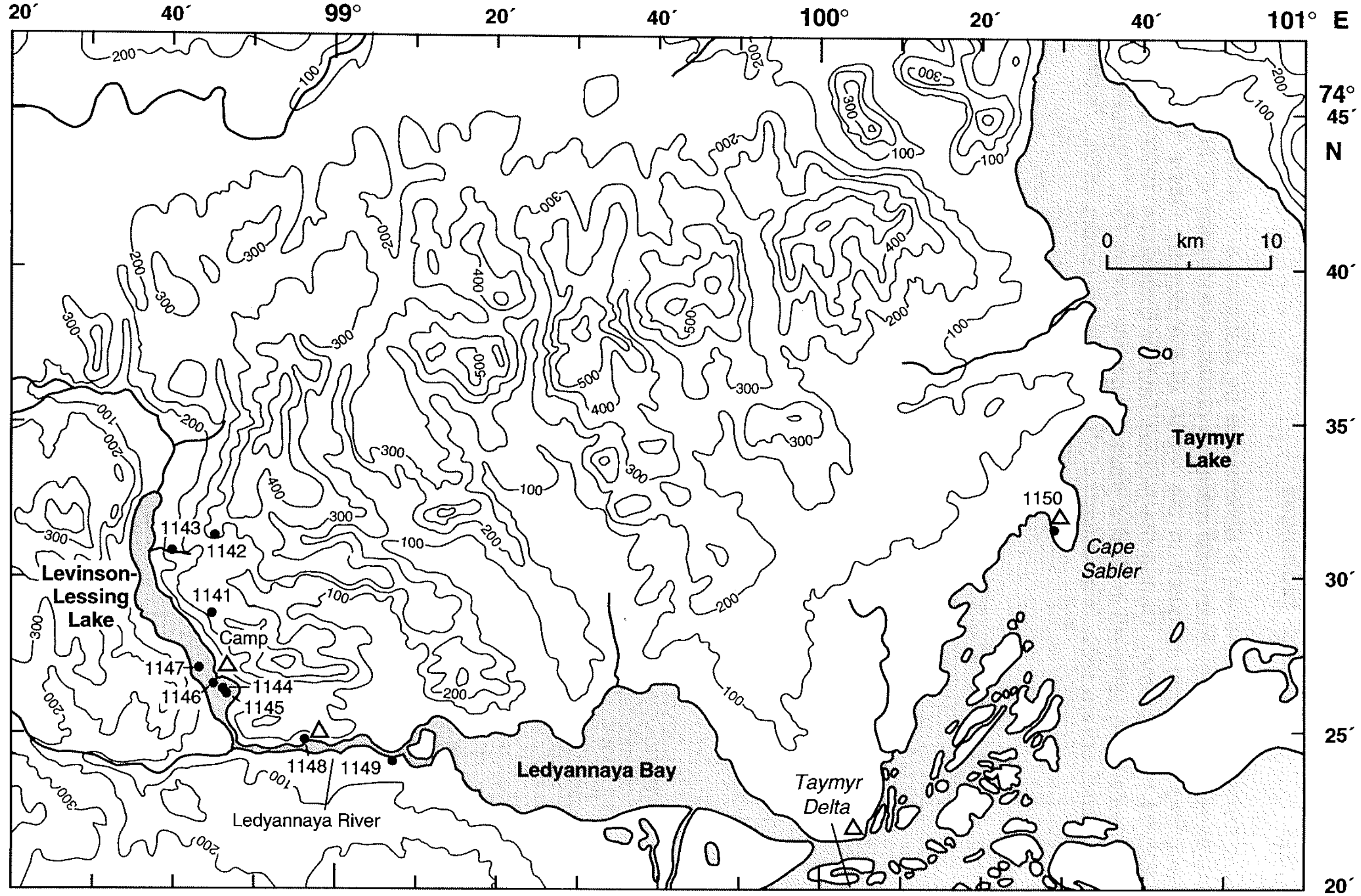


Figure 1.4: (see above) Sediment sampling sites (heavy dots) in the northern Pyasino Lake, Lake "X", and Arelakh Lake (for overview see Fig. 1.2; altitudes in metres a.s.l.)

Figure 1.5: (see right) Sediment sampling sites (heavy dots) in the area of Levinson-Lessing Lake and western Taymyr L. (for overview see Fig. 1.2; altit. in m a.s.l.)


20´
40´
99°
20´
40´
100°
20´
40´
101° E
74°
45´
N
40´
35´
30´
25´
20´
0 km 10
Taymyr Lake
Cape Sabler
1150
Levinson-Lessing Lake
1143
1142
1141
Camp
1147
1146
1144
1145
1148
1149
Ledyannaya River
Ledyannaya Bay
Taymyr Delta

1.3 LACUSTRINE SEDIMENTS

1.3.1 Sampling technique

The sampling positions were determined by distance and angle measurements relative to prominent land marks. A detailed description of the sediment sampling technique is given in the report of the Bunger Oasis Expedition 1993/94 (this volume). During the Norilsk/Taymyr Expedition 1993 lacustrine sediments were sampled in similar ways: by gravity corers (SL, "Schwerelot"), hand-push corers (HS, "Handstechrohr"), and piston corers (KOL, "Kolbenlot").

Figure 1.6: The sampling platform at the northern shore of Lama Lake

The sampling differed from that of the Bunger Oasis Expedition especially in the fact that the coring equipment was run from open water exclusively. In the Norilsk area sampling was carried out from the floating platform variant (Fig. 1.6). On the Taymyr Peninsula, due to the restricted transport abilities for the equipment, only the light gravity corer was available and was used from rubber boats on the Levinson-Lessing Lake and from a pilot boat on the Khatanga River and Bay. As a consequence, in the latter area only near-surface sediments were recovered (Table 1.1).

Almost all sediment cores were stored and transported directly in the transparent PVC coring tubes, with a diameter of 6.3 cm. In the case of longer recoveries, the up to 3 m long tubes were cut into pieces of up to 1 m length and closed on both ends, largely air- and waterproof, by suitable plastic caps and flexible tabe. In addition, sediments present in or below the core catcher were recovered, cut into 1 cm or 2 cm thick slices, and stored in plastic flasks of 50 ml volume.

1.3.2 Lama Lake

The Lama Lake (Figs. 1.2 and 1.3) is probably of tectonic origin, being situated in an oblong, east to west trending depression (GALAZIY & PARMUZIN 1981a, b). The lake covers an area of 466 km^2; maximum length and width are 82 km and 13 km, and the maximum water depth is 254 m. Steep mountains reach up to the northern and southern lake shores (Fig. 1.6).

Sediment sampling was carried out on 18 locations in the central part of Lama Lake (Fig. 1.3). Water depth measurements in this area revealed shallow waters of less than 10 m within 1 to 2 km distance from the delta at the northern shore and a steep slope towards the southeast (Table 1.1). At site PG1111, close to the southern shore, water depths reach 52.2 m. They increase further towards the east, along the profile running more or less along the lake axis, and reach 91.0 m at site PG1124.

Due to the storage of most of the sediments in the plastic tubes they could be described only roughly. However, in Lama Lake the near-surface sediments show a distinct succession from well sorted fine gravel and coarse sand in and adjacent to the main delta at the northern shore to fine-grained mud at the slope in front of the delta. At site PG1111 a 10.6 m long sediment sequence was recovered. Although it shows only little differences in grain size, varying between silty clay and silt, changes in sediment color between olive grey and very dark grey indicate that variations in the environmental conditions are reflected in this core.

1.3.3 Pyasino Lake

In contrast to Lama Lake, Pyasino Lake (Figs. 1.2 and 1.4) is believed to be of glacial origin. With 735 km^2 it covers a much larger area (ADAMENKO &

Table 1.1: Sediment samples collected during the expedition Norilsk/Taymyr 1993 (abbreviations see end of table)

core no. station-employ	sediment source (see Fig.)	position latitude	position longitude	water depth [m]	gear	recovery [cm]	prelimin. storage
expedition <u>*Norilsk*</u>							
PG1105 - 1	Pyasino Lake (1.4)	69°30.5´N	88°12.0´E	ca.0.5	SR	0 - 550	AWI/MSU
PG1106 - 1	Pyasino Lake (1.4)	69°30.4´N	88°13.0´E	ca.0.5	SR	0 - 700	AWI/MSU
PG1107 - 1	Lama Lake (1.3)	69°35.0´N	90°13.9´E	7.2	SL	0 - 12	AWI
PG1108 - 1	Lama Lake (1.3)	69°34.5´N	90°13.9´E	12.6	SL	0 - 34	AWI
PG1109 - 1	Lama Lake (1.3)	69°33.9´N	90°13.7´E	31.6	SL	0 - 63	AWI
PG1110 - 1	Lama Lake (1.3)	69°33.4´N	90°13.3´E	48.7	SL	0 - 61	AWI
PG1111 - 1	Lama Lake (1.3)	69°32.9´N	90°12.7´E	52.2	SL	0 - 56	AWI
- 2					SL	0 - 9	AWI
- 3					SL	0 - 65	AWI
- 4					KOL	23 - 131	AWI
- 5					KOL	15 - 312	AWI
- 6					KOL	261 - 562	AWI
- 7					KOL	511 - 812	AWI
- 8					KOL	761 - 1062	AWI
- 9					KOL	0 - 293	MSU
- 10					KOL	243 - 339	MSU
PG1112 1	Lama Lake (1.3)	69°32.5´N	90°12.3´E	42.1	SL	0 - 57	AWI
PG1113 - 1	Lama Lake (1.3)	69°34.4´N	90°15.4´E	13.4	SL	0 - 42	AWI
PG1114 - 1	Lama Lake (1.3)	69°35.6´N	90°10.5´E	3.9	KOL	0 - 132	AWI
PG1115 - 1	Lama Lake (1.3)	69°35.2´N	90°11.9´E	3.8	SR	0 - 25	AWI
- 2					SL	0 - 3	AWI
PG1116 - 1	Lama Lake (1.3)	69°34.1´N	90°16.4´E	25.5	SL	0 - 57	AWI
- 2					SL	0 - 48	MSU
PG1117 - 1	Lama Lake (1.3)	69°33.5´N	90°17.4´E	ca. 50.0	SL	0 - 54	AWI
- 2					SL	0 - 38	MSU
PG1118 - 1	Lama Lake (1.3)	69°32.7´N	90°14.9´E	59.2	SL	0 - 76	AWI
PG1119 - 1	Lama Lake (1.3)	69°32.5´N	90°17.2´E	72.2	SL	0 - 61	AWI
- 2					SL	0 - 48	MSU
PG1120 - 1	Lama Lake (1.3)	69°32.2´N	90°19.3´E	71.9	SL	0 - 62	AWI
PG1121 - 1	Lama Lake (1.3)	69°32.9´N	90°19.2´E	70.6	SL	0 - 64	AWI
- 2					SL	0 - 51	MSU
PG1122 - 1	Lama Lake (1.3)	69°32.5´N	90°21.8´E	87.3	SL	0 - 75	AWI
- 2					SL	0 - 58	MSU
PG1123 - 1	Lama Lake (1.3)	69°32.3´N	90°24.8´E	91.6	SL	0 - 83	AWI
PG1124 - 1	Lama Lake (1.3)	69°32.1´N	90°27.9´E	91.0	SL	0 - 77	AWI
- 2					SL	0 - 73	MSU
PG1125 - 1	Pyasino Lake (1.4)	70°01.7´N	87°56.9´E	7.5	SL	0 - 35	AWI
PG1126 - 1	Pyasino Lake (1.4)	70°01.0´N	87°50.3´E	12.2	SL	0 - 60	AWI
PG1127 - 1	Pyasino Lake (1.4)	70°01.7´N	87°48.7´E	10.9	SL	0 - 57	AWI
PG1128 - 1	Pyasino Lake (1.4)	70°03.2´N	88°02.6´E	9.5	SR	0 - 4	AWI
PG1129 - 1	Pyasino Lake (1.4)	70°02.2´N	87°50.9´E	8.5	SL	0 - 45	AWI
PG1130 - 1	Pyasino Lake (1.4)	70°02.3´N	87°48.7´E	17.0	SL	0 - 57	AWI
PG1131 - 1	Pyasino Lake (1.4)	70°02.4´N	87°46.5´E	15.9	SL	0 - 62	AWI
- 2					KOL	52 - 350	AWI
- 3					KOL	298 - 600	AWI

Table 1.1: Continuation

core no. station-employ	sediment source (see Fig.)	position latitude	longitude	water depth [m]	gear	recovery [cm]	prelimin. storage
PG1132 - 1	Pyasino Lake (1.4)	70°02.5´ N	87°44.3´ E	9.0	SL	0 - 49	AWI
PG1133 - 1	Pyasino Lake (1.4)	70°02.6´ N	87°42.1´ E	27.7	SL	0 - 62	AWI
PG1134 - 1	Pyasino Lake (1.4)	70°02.7´ N	87°40.8´ E	9.6	SL	0 - 30	AWI
PG1135 - 1	Pyasino Lake (1.4)	70°02.2´ N	88°00.0´ E	4.1	SR	0 - 18	AWI
PG1136 - 1	Pyasino Lake (1.4)	70°02.7´ N	87°58.3´ E	9.2	SL	0 - 50	AWI
PG1137 - 1	Pyasino Lake (1.4)	70°02.6´ N	87°56.2´ E	7.5	SL	0 - 23	AWI
- 2					SL	0 - 27	AWI/MSU
- 3					KOL	6 - 276	AWI
- 4					KOL	228 - 526	AWI
PG1138 - 1	lake "X" (1.4)	70°02.7´ N	88°04.9´ E	17.5	SL	0 - 48	AWI
PG1139 - 1	Pyasino Lake (1.4)	70°03.1´ N	88°03.1´ E	6.5	SR	0 - 19	AWI
PG1140 - 1	Arelakh Lake (1.4)	70°05.0´ N	88°04.5´ E	above	SR	63 - 168	AWI
- 2			present-day	lake level	SR	0 - 74	AWI
expedition <u>*Taymyr*</u>							
PG1141 - 1	pond (1.5)	74°28.8´ N	98°44.9´ E	0.2	hand	0 - 2	AWI
PG1142 - 1	marine sediments (1.5)	74°31.3´ N	98°45.1´ E	a.s.l.	exposure	20	AWI
PG1143 - 1	coal (1.5)	74°30.8´ N	98°39.9´ E	a.s.l.	exposure	10	AWI
PG1144 - 1	Levinson-Lessing Lake (1.5)	74°26.3´ N	98°46.4´ E	47.0	SL	0 - 45	AWI
PG1145 - 1	Lev.-Less. L. (1.5)	74°26.2´ N	98°46.8´ E	49.0	SL	0 - 37	AWI/AARI
PG1146 - 1	Lev.-Less. L. (1.5)	74°26.6´ N	98°45.1´ E	73.0	SL	0 - 88	AWI/AARI
PG1147 - 1	Lev.-Less. L. (1.5)	74°27.1´ N	98°43.3´ E	83.0	SL	0 - 28	AWI
PG1148 - 1	marine Sed. (1.5)	74°24.8´ N	98°56´5´ E	a.s.l.	exposure	100	AWI
PG1149 - 1	soil / peat profile (1.5)	74°24.1´ N	99°07.2´ E	a.s.l.	exposure	0 - 300	AWI
PG1150 - 1	soil / peat profile (1.5)	74°31.6´ N	100°29.0´ E	a.s.l.	exposure	0 - 1180	AWI
PG1151 - 1	Bikada River (1.2)	74°49.5´ N	106°08.4´ E	0.1	hand	0 - 1	AWI
PG1152 - 1	Khatanga River (1.2)	72°42.0´ N	104°47.3´ E	29.0	SL	0 - 5	AWI
PG1153 - 1	Khatanga R. (1.2)	72°50.0´ N	105°45.0´ E	27.0	SL	0 - 4	AWI
PG1154 - 1	Khatanga R. (1.2)	73°08.5´ N	106°13.0´ E	24.0	SL	0 - 6	AWI
PG1155 - 1	Khatanga Bay (1.2)	73°11.6´ N	107°04.0´ E	16.0	SL	0 - 19	AWI
					sum Σ	82.69 m	

SR = ´Stechrohr´ (hand-push corer)
SL = ´Schwerelot´ (gravity corer)
KOL = ´Kolbenlot´ (piston corer)

AARI = Arctic and Antarctic Research, St. Petersburg
AWI = Alfred Wegener Institute, Potsdam
MSU = Moscow State University, Moscow

a.s.l. = above sea level

EGOROV 1985). In the lake surrounding a high number of smaller thermocarst and glacial lakes are located between hills of less than 200 m altitudes. The smooth relief is continued into the Pyasino Lake. The lake is much shallower than Lama Lake, reaching water depths of more than 20 m only close to the northwestern shore (site PG1133). As a consequence, thermocarst processes probably resulted in strong variations of the shore line positions within Holocene time.

Lake Pyasino was sampled on 2 locations in the main inflow delta at the southern shore (Fig. 1.2) and on 14 locations in the northern part of the lake (Fig. 1.4, Table 1.1). In the inflow delta as well as close to the outflow the water is shallower than 10 m. The sediments consist predominantly of coarse-grained sands and gravelly sands. Most promising sequences for the reconstruction of the inflow and outflow histories were recovered on sites PG1106 and PG1137, having lengths of 7.0 and 5.3 m, respectively.

In the northwestern part of Pyasino Lake the water depths vary between 8 and 28 m. In spite of these only slightly deeper waters than those in the inflow and outflow areas, the sediments recovered are much more fine-grained. They consist predominantly of well sorted muds and sandy muds and show only little variation downcore. This fine grain-size distribution indicates weak current velocities of the bottom water favouring a continuous accumulation independent from sediment redeposition. Maximum recovery (6.0 m) was obtained on site PG1131.

1.3.4 Lake "X" and Arelakh Lake

Besides lake Pyasino two smaller lakes in the vicinity of the field camp were sampled (Fig. 1.4, Table 1.1). Lake "X" is a small glacial lake with a diameter of less than 1 km, but a maximum water depth of more than 20 m. At site PG1138 from 17.5 m water depth a short near-surface sediment sequence was recovered by gravity coring from a rubber boat, consisting of fine-grained, well sorted, predominantly terrigeneous deposits.

The thermocarst lake Arelakh, situated northeast of Pyasino Lake, is today reduced in its size due to an outflow event a few years ago, which resulted in thermo-abrasion processes. At one location on the former southern lake shore (PG1140) a 1,7 m long, partly dried sequence was recovered by hand-push coring. The sediment is predominantly terrigeneous, showing strong variations in sediment colour, structure, composition and consistency.

1.3.5 Levinson-Lessing Lake

The Levinson-Lessing Lake is an oblong, south to north trending lake which is situated in a narrow valley about 50 km to the west of the Taymyr Lake (Figs. 1.2 and 1.5). From geomorphological studies carried out by the AARI within the last years, it was assumed that the lake surrounding was deglaciated during the Late Weichselian Glaciation. Hydrological and bathymetrical investigations have shown that today the major inflow enters the Levinson-Lessing Lake at its northern shore, and that the lake is very deep, reaching more than 80 m water depth in some parts along the lake axis.

During this expedition lake sediment coring was carried out for the first time in the southern Levinson-Lessing Lake. At four locations only short gravity cores were taken (Table 1.1). All sediments recovered are fine-grained muds without significant variations in grain-size distributions downcore. This proves that in the southern Levinson-Lessing Lake a quiet, fine-grained accumulation took place for a considerable time span. Very dark layers from a few millimetres to some centimetres thickness were found in different sediment depths at all locations. They indicate times of very high organic carbon accumulation, and probably make these sediments suitable for radiocarbon datings. Hence, deeper coring in this area during following expeditions promises a high resolution palaeoenvironmental reconstruction with good stratigraphic control.

1.3.6 Khatanga River and Bay

At the end of the expedition four near-surface sediment samples were recovered by gravity coring from a pilot boat in the lower Khatanga River and southern Khatanga Bay (Fig. 1.2, Table 1.1). The objective of this sampling was a contribution to the understanding of the present-day sediment transport from the central siberian continent into the Laptev Sea. This knowledge will support the interpretation of sediment compositions in cores taken during the RV "Polarstern" and RV "Kireev" cruises in the Laptev Sea in 1993 (FÜTTERER, in press).

The sediments recovered in the Khatanga River and Bay show strong differences in colour, structure, and composition, both within the individual sequences and between different locations. The sediment colours comprise olive grey, dark grey, and very dark grey. Grain-size distributions vary predominantly between poorly sorted sandy muds and muddy sands with different contents of gravel. Well sorted medium sands were recovered at site PG1153. Stratification was observed in sediments from sites PG1152 and PG1155. At site PG1152 the sediment contains a high amount of wood particles and leaves.

1.4 PEAT/SOIL PROFILES

Soil profiles with inserted peat layers are common on the Taymyr Peninsula, reaching thicknesses up to more than ten metres in some areas. During the expedition 1993 two locations were visited and sampled: a 3 m thick profile exposed at the shore of lower Ledyannaya River (PG1149), and a 12 m thick sequence situated between ice wedges at Cape Sabler, western shore of Taymyr Lake (PG1150, Figs. 1.6 and 1.7, Table 1.1).

Objectives of the sampling are geochemical, mineralogical and isotopical analyses in order to obtain information concerning the depositional history and, in comparison with the results from lake sediment cores, the quantity and quality of sediment transport into the adjacent lake areas. In addition, several radiocarbon datings are planned in order to test whether these sequences represent a continuous deposition and a preservation of chronological order.

First radiocarbon datings of the peat/soil profile at Cape Sabler revealed maximum ages of ca. 32 ka BP (SULERZHITZKY 1982). Hence, this profile could be a palaeoenvironmental data archive representing both the Late Weichselian and Holocene times. Similar ages were determined on wood fragments from the northern shore of Taymyr Lake and on a sediment profile at the shore of Taymyr River. These results indicate that large areas of the Taymyr Peninsula were deglaciated during the Sartan (corresponds with the Late Weichselian) glaciation.

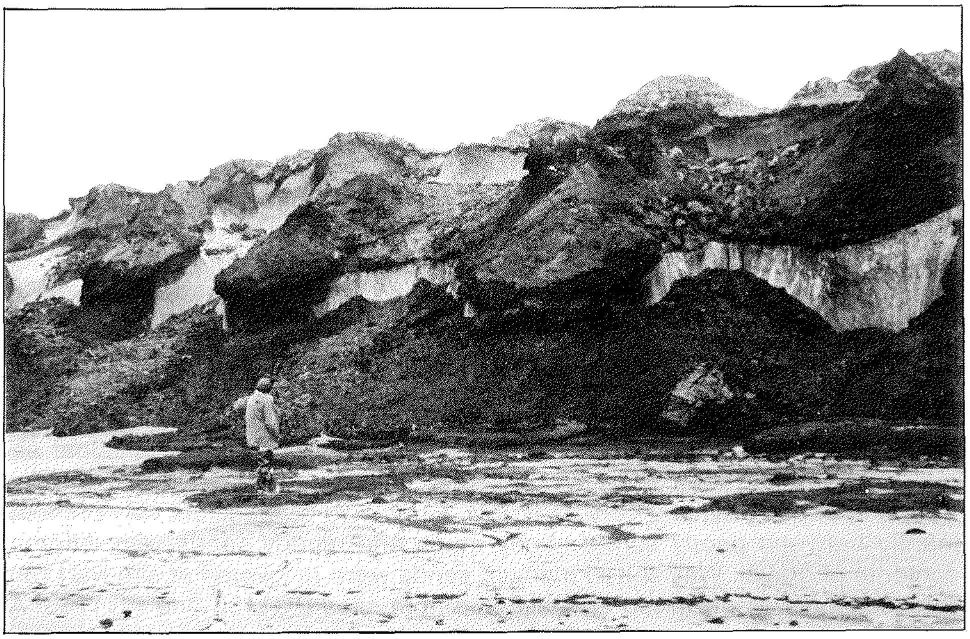


Figure 1.7: Peat/soil profiles and enclosed ice wedges at Cape Sabler, western Taymyr Lake (for location see Fig. 1.5)

1.5 MARINE SEDIMENTS

During the Kazantsev interglacial (corresponds with the Eemian) and, with a smaller extension, during the Karginskiy interstadial (ca. 35 ky BP), marine transgressions took place on the Taymyr Peninsula (ANDREEVA *et al.* 1982). During the Murukinsk (Early Weichselian) or Sartan (Late Weichselian) glaciations, parts of the marine sediments were glacially redeposited and incorporated into morainic deposits. As a consequence, the interpretation of the sediment genesis (autochthonous or allochthonous) is still in discussion at some locations.

Sediments of marine origin were sampled at two locations on the Taymyr Peninsula. The first sample contains only a few small shell fragments. It was taken from a shallow, hand-made burrow on a hill ca. 3 km east of Levinson-Lessing Lake, in an altitude of ca. 150 m a.s.l. (PG1142, Fig. 1.5, Table 1.1). At the second location (PG1148), on the northern shore of Ledyannaya River, probably fluvial erosion has exposed a ca. 25 m high profile (top ca. 50 m a.s.l.) of deposits which contain a high number of marine mussel shells. Both the good preservation of the shells and the clear stratification of the sediments argue against glacial redeposition. In order to get a first impression about the sediment age and composition, some samples were taken from the uppermost sediment metre of the profile.

1.6 HYDROLOGY/HYDROCHEMISTRY

Investigations of the hydrological settings of lake water bodies contribute to the understanding of the present-day sediment formation, and may reveal information concerning the lake history and evolution.

Water samples of 0.5 - 1.0 l volume were taken from lake and pond waters, from rain and snow, from brooks and rivers flowing into the lakes, from tap water in Khatanga, and from the Khatanga River and Khatanga Bay (Table 1.2). Objectives are hydrogeochemical (main cations and anions) and isotopic hydrological ($\delta\,^2H$, $\delta\,^{18}O$) measurements in order to get a first impression concerning the evolution and possible stratification of lake water bodies, and concerning the modern composition of meteoric waters in the study area.

First results of the hydrogeochemical studies are presented in Table 1.3 and Figs. 1.8. and 1.9. All surface waters analyzed in the Norilsk area are of fresh-water; they are characterized by relatively low concentrations of dissolved solids (TDS below 50 mg/l, where TDS = sum of measured anion and cation concentrations). This is also reflected by low values of the electrical conductivity which ranges between ca. 55 and 130 µS/cm (Table 1.3). Unfortunately, bicarbonate could not be analyzed in the field. According to water analyses given by ADAMENKO & EGOROV (1985), the bicarbonate content in the lakes Lama and Pyasino varies from 15 to 50 mg/l, depending on the sampling date. Calcium is the predominating cation in the analyzed surface waters (Fig. 1.8). The atmospheric (summer) precipitation, in contrast, is richer in sodium and potassium. This is probably due to the greater presence of marine aerosols in the precipitation, as being indicated by their higher Cl/SO_4 ratios (Fig. 1.9).

Isotopic hydrological analyses on water samples along depth profiles in the lakes Lama, Pyasino and "X" gave no significant variations (Table 1.2), indicating that the lake water bodies are completely mixed during late summer. This suggestion is supported by in situ measurements of pH, dissolved oxygen, and temperature carried out along depth profiles in the same lakes

(Tables 1.4, 1.5 and 1.6). They also show only small variations both between the lakes and within individual profiles.

The $\delta\,^{18}O$ and $\delta\,^{2}H$ values of all samples, including those from shallow ponds and thermocarst lakes, plot on or near the 'Global Meteoric Water Line' (Fig. 1.10), indicating that the water is widely unaffected by evaporation. This is the basic requirement for the palaeoclimatological interpretations of the isotopic composition of palaeowaters, which are preserved as ground ice bodies (see below).

Table 1.2: Water samples collected during the expedition Norilsk/Taymyr 1993 and first results of the stable oxygen and hydrogen isotope ratios

sample no. station / employ	location (see Fig.)	water depth [m]	date	$\delta\,^{18}O$ * [‰]	$\delta\,^{2}H$ ** [‰]
OL-5 / 1	Lama Lake, at sampling site 1111 (1.3)	1.0	07-30-93	-20.5	-152
/ 2		2.0	07-30-93	-20.4	-152
/ 3		4.0	07-30-93	-20.4	-152
/ 4		6.0	07-30-93	-20.4	-152
/ 5		8.0	07-30-93	-20.5	-152
/ 6		10.0	07-30-93	-20.4	-152
/ 7		12.0	07-30-93	-20.5	-151
/ 8		14.0	07-30-93	-20.4	-152
/ 9		16.0	07-30-93	-20.4	-151
/ 10		18.0	07-30-93	-20.3	-152
/ 11		20.0	07-30-93	-20.4	-152
/ 12		25.0	07-30-93	-20.5	-152
/ 13		30.0	07-30-93	-20.3	-152
/ 14		35.0	07-30-93	-20.4	-152
/ 15		40.0	07-30-93	-20.3	-151
/ 16		45.0	07-30-93	-20.3	-151
/ 17		50.0	07-30-93	-20.2	-152
/ 18		52.0	07-30-93	-20.3	-150
OL-Z1	brook at camp Lama Lake (1.3)	0.0	07-31-93	-20.6	-154
OL-1121	Lama Lake, at sampling site 1121 (1.3)	70.4	08-01-93	n.d.	-151
OL-1122	Lama Lake, at sampling site 1122 (1.3)	79.0	08-01-93	n.d.	-150
OL-1123	Lama Lake, at sampling site 1123 (1.3)	91.5	08-01-93	n.d.	-150
OL-1124	Lama Lake, at sampling site 1124 (1.3)	90.8	08-01-93	n.d.	-150
OP-1129	Pyasino Lake, at sampling site 1129 (1.4)	0.0	08-09-93	-20.7	-157
OP-1131	Pyasino Lake, at sampling site 1131 (1.4)	0.0	08-09-93	-20.8	-156
OP-1133 / 1	Pyasino Lake, at sampling site 1133 (1.4)	2.0	08-20-93	-20.1	-152
/ 2		5.0	08-20-93	-20.1	-153
/ 3		10.0	08-20-93	-20.1	-152
/ 4		15.0	08-20-93	-20.3	-153
/ 5		20.0	08-20-93	-20.5	-154

Table 1.2: Continuation

sample. no. station / employ	location (see Fig.)	water depth [m]	date	δ ¹⁸O * [‰]	δ ²H ** [‰]
OP-1135 / B1	Pyasino L., close to sampling site 1135 (1.4)	1.0	08-10-93	-20.3	-153
/ B2		2.0	08-10-93	-20.3	-153
/ B3		3.0	08-10-93	-20.4	-153
/ B4		4.0	08-10-93	-20.4	-153
/ B5		5.0	08-10-93	-20.4	-153
/ B6		6.0	08-10-93	-20.4	-153
/ B7		7.0	08-10-93	-20.3	-153
/ B8		8.0	08-10-93	-20.3	-154
/ B9		8.5	08-10-93	-20.4	-154
P1	central Pyasino Lake	1.0	08-21-93	-19.4	-146
P2	central Pyasino Lake	1.0	08-21-93	-19.4	-146
P3	central Pyasino Lake	2.0	08-21-93	-19.0	-145
P4	central Pyasino Lake	2.5	08-21-93	-19.3	-147
P5	central Pyasino Lake	2.2	08-21-93	-19.9	-150
OP-N1	snow field, 200 m S´ camp Pyasino L. (1.4)	0.0	08-08-93	-20.2	-153
OP-N2	rain, at camp Pyasino Lake (1.4)	—	08-06-93	-20.2	-158
OP-N3	rain, at camp Pyasino Lake (1.4)	—	08-19-93	-8.9	-68
OP-Z1	brook at camp Pyasino Lake (1.4)	0.0	08-08-93	n.d.	-140
OA-1140	at shore of Arelakh Lake (1.4)	0.0	08-21-93	-18.5	-142
OX / 1	lake "X", close to sampling site 1138 (1.4)	1.0	08-17-93	-18.3	-142
/ 2		2.0	08-17-93	-18.3	-142
/ 3		3.0	08-17-93	n.d.	-142
/ 4		5.0	08-17-93	-18.2	-142
/ 5		8.0	08-17-93	-18.5	-142
/ 6		10.0	08-17-93	-18.5	-142
/ 7		15.0	08-17-93	-18.4	-142
/ 8		20.0	08-17-93	-18.4	-142
SW-1	shore of pond, at sampling site 1141 (1.5)	0.0	08-24-93	-19.7	-151
SW-2	Levinson-Lessing Lake, at site 1145 (1.5)	49.0	08-25-93	-21.7	-163
SW-3	Levinson-Lessing Lake, at site 1145 (1.5)	0.0	08-25-93	-21.7	-164
SW-4	Levinson-Lessing Lake, at site 1147 (1.5)	83.0	08-27-93	-21.8	-163
SW-5	Levinson-Lessing Lake, at site 1147 (1.5)	0.0	08-27-93	-21.7	-164
SW-6	Ledyannaya River, at camp (1.5)	0.0	09-01-93	-21.2	-159
SW-7	central Ledyannaya Bay (1.5)	<0.5	09-01-93	-21.0	-162
SW-8	thermocarst lake, at camp Taymyr Delta (1.5)	0.0	09-02-93	-19.3	-144
SW-9	delta Taymyr River, at camp (1.5)	0.0	09-02-93	-20.9	-159
SW-10	brook from terrace at Cape Sabler (1.5)	0.0	09-04-93	-18.1	-141
SW-14	shore of Taymyr L., 5 km N´ Cape Sabler (1.5)	0.0	09-05-93	-22.6	-172
SW-11	tap water in Khatanga (1.2)	—	09-06-93	-18.7	-144
SW-12	shore of Khatanga River, 2 km NE´ town (1.2)	0.0	09-08-93	-18.8	-147
SW-1152	Khatanga River, at site 1152 (1.2)	29.0	09-09-93	-18.6	-145
SW-1153	Khatanga River, at site 1153 (1.2)	27.0	09-09-93	-18.6	-145
SW-1154	Khatanga River, at site 1154 (1.2)	24.0	09-09-93	-18.8	-145
SW-1155	Khatanga Bay, at site 1155 (1.2)	16.0	09-09-93	-18.9	-145
BW-5	Khatanga R., betw. sites 1152 and 1153 (1.2)	32.0	09-09-93	-18.6	-145

n.d. = not determined
* measurements of Alfred Wegener Institute Bremerhaven (N. SCHEELE); total error ±0,1 ‰
** measurements of Freie Universität Berlin (K. FRIEDRICHSEN); total error ca. ±1 ‰

Table 1.3: Hydrogeochemical characteristics of selected water samples collected during the expedition Norilsk/Taymyr 1993 (Analyses by Dr E. BRÜGGEMANN, Institut für Troposphärenforschung e.V., Leipzig)

Sample No.	OL-5/1	OL-Z1	OP-1133/1	OP-1135/B1	OP-Z1	OA-1140	OX-1	OP-N1	OP-N2	OP-N3
Lake/Sample	Lama Lake	Inflow Lama L.	Pyasino Lake	Pyasino Lake	Inflow Pyasino	Arelakh Lake	Lake "X"	snow-bank	rain	rain
Date (1993)	07-30	07-31	08-20	08-10	08-08	08-21	08-17	08-08	08-06	08-19
Sampling depth	1 m	surface	2 m	1 m	surface	surface	1 m			
Conductiv.* [µS/cm]	74.0	127.0	77.0	82.0	96.5	54.5	93.5	19.0	7.6	29.7
pH-value*	6.42	7.24	6.50	6.66	7.20	6.94	6.93	5.89	5.84	4.50
Cl [mg/l]	3.30	0.62	2.70	2.50	0.50	0.04	0.98	1.40	1.09	3.28
SO4 [mg/l]	14.63	6.70	13.84	14.31	5.38	3.27	5.73	1.01	0.27	3.22
NO3 [mg/l]	0.40	<0.1	1.06	2.33	<0.1	0.13	0.87	3.36	0.17	0.25
NH4 [mg/l]	0.17	0.50	0.18	0.05	0.08	<0.04	0.23	0.07	0.08	0.40
Na [mg/l]	2.58	4.44	2.65	2.88	0.84	0.53	0.90	0.88	0.72	2.13
K [mg/l]	0.11	0.70	0.29	0.36	0.30	0.27	0.54	0.81	0.25	0.14
Ca [mg/l]	8.35	15.56	8.78	8.86	13.12	6.69	11.54	1.04	0.43	0.23
Mg [mg/l]	1.39	4.94	1.72	1.84	4.14	2.19	3.66	0.34	0.10	0.03
TDS [mg/l]	30.93	33.46	31.22	33.13	24.36	13.12	24.45	8.91	3.11	9.68
Cl/SO4 [wt.]	0.23	0.09	0.20	0.17	0.09	0.01	0.17	1.39	4.04	1.02
Na/K [wt.]	23.45	6.34	9.14	8.00	2.80	1.96	1.67	1.09	2.88	15.21
Ca/Mg [wt.]	6.01	3.15	5.10	4.82	3.17	3.05	3.15	3.06	4.30	7.67

* laboratory measurement; cation and anion analyses by ion chromatography, TDS total dissolved solids

Figure 1.9: (see right) Triangular plot of hydrogeochemical ratios (wt.-% basis) of selected water samples from the Norilsk area (data are presented in Table 1.3)

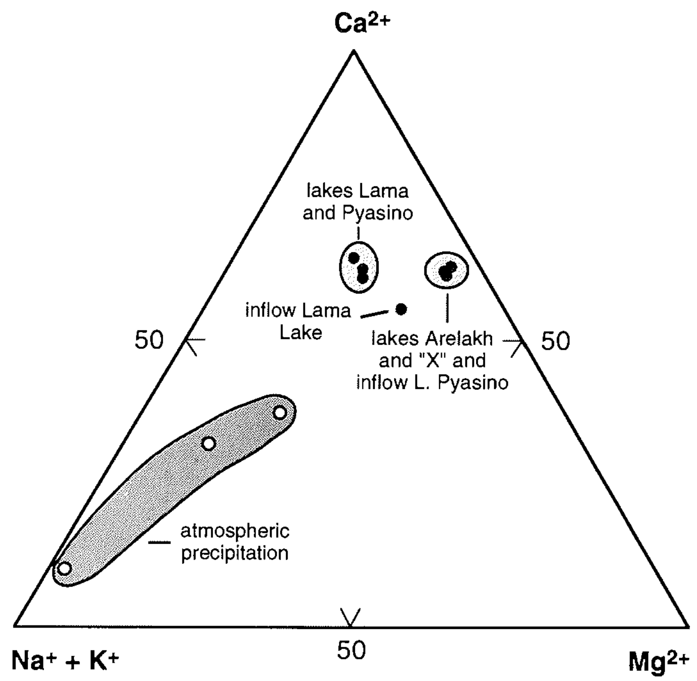


Figure 1.8: Cationic composition (in equiv.-%) of surface waters in the Norilsk area (data are presented in Table 1.3)

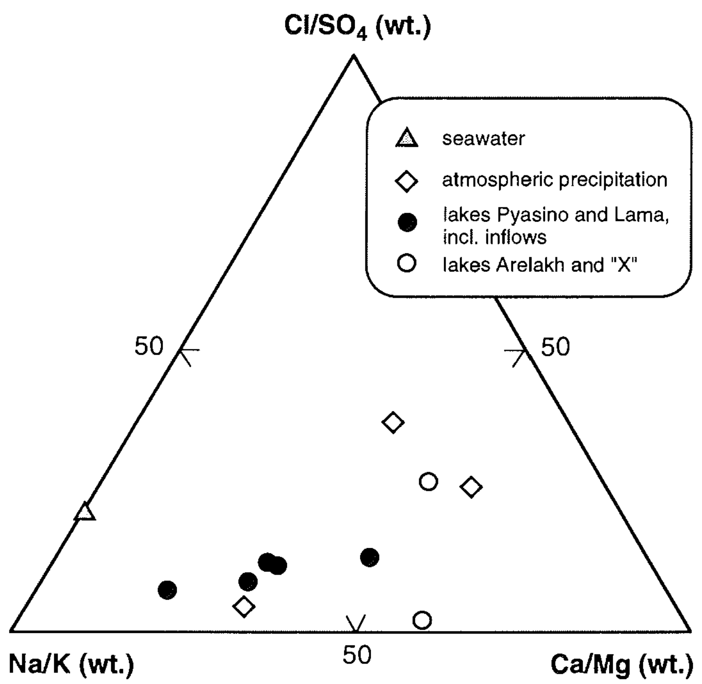


Table 1.4: In situ measurements of hydrological parameters at sampling site OL-5 in Lama Lake (corresponds with sediment sampling site PG1111, see Fig. 1.3); water depth is 52.2 m, sampling date was 07-30-93 (measurements carried out with WTW instruments)

sample depth [m]	temperature [°C]	pH	temperature [°C]	diss. oxygen [mg/l]
0.2	6.8	8.08	6.9	12.2
1	6.6	7.98	6.7	12.4
2	6.6	8.01	6.6	12.9
3	6.5	7.97	6.5	13.2
4	6.5	7.97	6.5	13.5
5	6.5	7.97	6.5	13.9
6	6.4	7.97	6.4	14.2
8	6.4	7.95	6.4	15.7
10	6.2	7.94	6.2	15.9
12	6.4	7.94	6.4	16.3
14	6.4	7.94	6.4	16.6
16	6.3	7.94	6.3	16.5
18	6.2	7.94	6.2	16.5
20	5.8	7.92	5.8	16.3
25	5.7	7.90	5.7	16.4
30	5.6	7.89	5.6	9.0
35	5.5	7.88	5.5	8.3
40	5.3	7.84	5.3	2.7
45	5.1	7.80	5.1	3.3
50	4.9	7.84	5.0	2.1
51	4.9	7.84	4.9	2.8

Table 1.5: In situ measurements of hydrological parameters at at sediment sampling site PG1136 in Pyasino Lake (see Fig. 1.4); water depth is 9.2 m, sampling date was 08-17-93 (measurements carried out with WTW instruments)

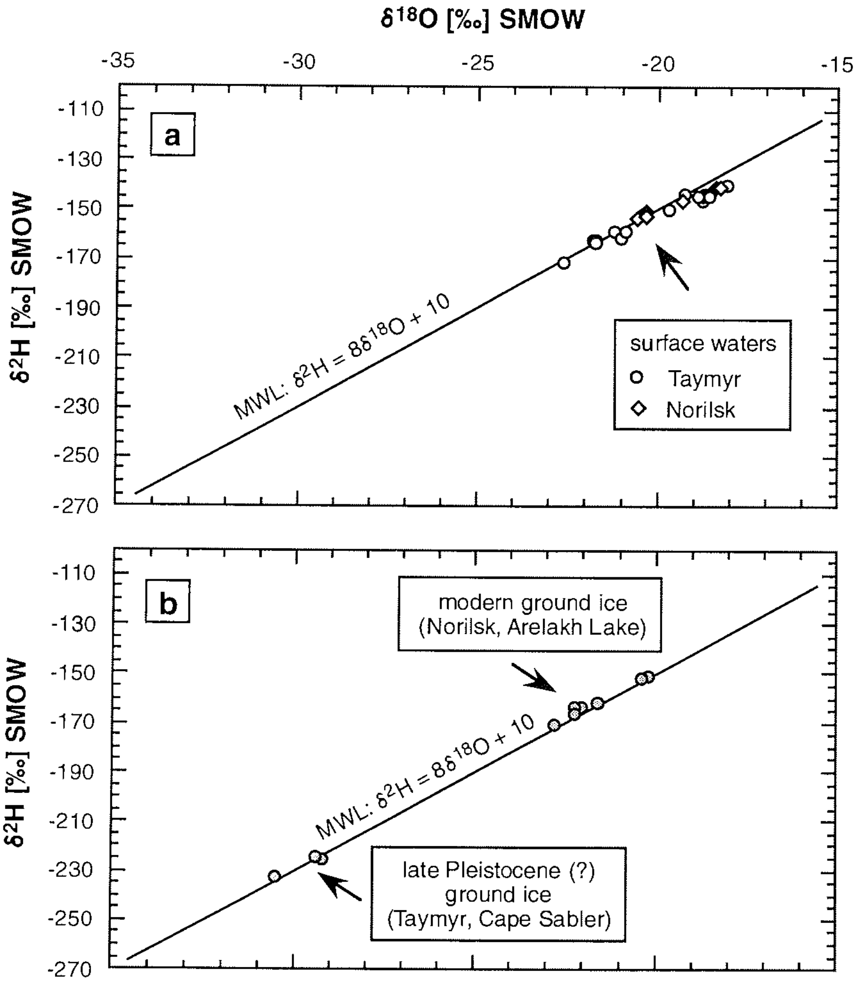
sample depth [m]	temperature [°C]	pH	temperature [°C]	diss. oxygen [mg/l]
1	14.4	8.12	15.4	15.3
2	14.1	8.09	15.1	15.8
3	13.7	8.00	14.7	17.0
4	13.7	7.95	14.5	17.4
5	13.6	7.93	14.4	17.6
6	13.6	7.93	14.3	18.5
7	13.5	7.92	14.3	19.3
8	13.2	7.79	13.9	19.2
9	13.0	7.71	13.7	19.2

Figure 1.10: (see right) Stable oxygen and hydrogen isotopic compositions of (a) surface waters and (b) ground ice samples collected duringthe Norilsk/Taymyr Expedition 1993. Due to small variations within depth profiles of lake water bodies (see Table 1.2), mean values for every location are presented in (a). MWL = Meteoric Water Line after CRAIG (1961)

Table 1.6: In situ measurements of hydrological parameters at sampling site OX in lake "X" (close to sediment sampling site PG1138, see Fig. 1.4); water depth is 21 m, sampling date was 08-17-93 (measurements carried out with WTW instruments)

sample depth [m]	temperature [°C]	pH	temperature [°C]	diss. oxygen [mg/l]
1	15.5	8.15	n.d.	13.0
2	15.2	8.31	n.d.	n.d.
3	15.2	8.23	n.d.	n.d.
5	15.6	8.18	n.d.	12.5
8	15.3	8.12	n.d.	n.d.
10	15.3	8.10	n.d.	14.6
15	15.0	8.06	n.d.	n.d.
20	14.9	8.06	n.d.	10.9

n.d. = not determined



1.7 GLACIOLOGY

Today, the Norilsk area as well as the Taymyr Peninsula are widely deglaciated, small glaciers occur only at high altitudes of the Byrranga Mountains in the northeast of Taymyr Lake. On the other hand, ground ice bodies are common, being partly exposed at river and lake shores due to rapid lateral erosion. Palaeoclimatic information may be available from the isotopic composition of the ground ice bodies which may reflect the climatic conditions during the ice formation.

Ground ice bodies were sampled at two locations close to the lake Aralakh in the northeast of Norilsk and at Cape Sabler, western Taymyr Lake (Table 1.7, Fig. 1.7). Their stable oxygen and hydrogen isotopic compositions plot on the 'Global Meteoric Water Line' (Fig. 1.8, Table 1.7), indicating ice formation by freezing of meteoric waters, without subsequent alteration of the isotopic composition for example by evaporation.

The differences of the $\delta^{18}O$ and $\delta^{2}H$ values between both ice bodies probably are due to different temperatures during ice formation. The similarity in values between the present day surface waters (Fig. 1.8 a) and the ground ice samples from lake Arelakh Lake (Fig. 1.8 b) can best be explained by modern ice formation. Significantly lower values of the samples from ice wedges of Cape Sabler, on the other hand, indicate ice formation under a much colder climate than that of today, which could have existed during late Pleistocene time.

Table 1.7: Ice samples collected during the expedition Norilsk/Taymyr 1993 and first results of the stable oxygen and hydrogen isotope ratios

sample. no. station / employ	location (see Fig.)	sample depth [m]	date	$\delta^{18}O$ * [‰]	$\delta^{2}H$ ** [‰]
GE-1140a / 0.1	ground ice profile, Arelakh Lake, (1.4)	0.1	08-21-93	-22.0	-164
/ 1		1.0	08-21-93	-22.2	-164
/ 2		2.0	08-21-93	-22.8	-171
/ 4		4.0	08-21-93	-20.2	-151
/ 5		5.0	08-21-93	-22.2	-167
/ 6		6.0	08-21-93	-21.6	-162
/ 6.5		6.5	08-21-93	-20.4	-153
/ 7		7.0	08-21-93	-21.6	-162
GE-1140b / 2	permafrost profile, 0,5 km from GE-1140a	2.0	08-21-93	-17.6	n.d.
/ 2.5		2.5	08-21-93	-17.5	n.d.
GE-SW13 / 1	ice wedge Cape Sabler, (1.5)		09-04-93	-29.3	-226
/ 2			09-04-93	-29.4	-225
/ 3			09-04-93	-30.5	-233

n.d. = not determined

* measurements of Alfred Wegener Institute Bremerhaven (N. SCHEELE); total error ±0,1 ‰

** measurements of Freie Universität Berlin (K. FRIEDRICHSEN); total error ca. ±1 ‰

1.8 ACKNOWLEDGEMENTS

We are grateful to our russian colleagues Vladimir Zaitsev, Olga Lisitsina and Oleg Volkhov from the first part of the expedition and Vladimir Savin, Mikhail Anisimov, Vladimir Pitul'ko und Andrej Gorban' from the second part of the expedition for the active help and the friendly atmosphere during the sometimes hard field work. Gerald Müller is acknowledged for his engaged and qualified technical support, Valery and Valentina Grebenets for their extraordinary hospitality and for their help during the transport of the expedition equipment from Norilsk back to St. Petersburg. We are also indebted to N. Scheele and K. Friedrichsen for measuring the stable oxygen or hydrogen isotopic compositions on the water and ice samples, and to E. Brüggemann for carrying out the hydrogeochemical analyses. B. Beeskow kindly created first versions of the digitalized maps.

1.9 REFERENCES

ADAMENKO, V.N. & EGOROV, A.N. (Eds.) (1985): *Geography of Lakes of the Taymyr Peninsula.* - Nauka, Leningrad 1985, 224 pp. [in Russian].

ANDREEVA, S. M., ISAEVA, L.L., KIND, N.V. & NOKOLSKAJA, M.V. (1982): Glaciations, sea transgressions and climate in the Late Pleistocene and Holocene. - In: N.V. KIND & B.N. LEONOV (Eds.), *The antropogene of the Taimyr Peninsula*, Nauka, 157-165 [in Russian].

CRAIG, H. (1961): Standard for reporting concentrations of deuterium and oxygen-18 in natural waters. - *Science*,133: 1833-1834.

FÜTTERER, D.K. (in press): The Expedition ARK-IX/4 of RV "Polarstern" 1993. - *Reports on Polar Research.*

GALAZIY, G.I. & PARMUZIN, Y.P. (Eds.) (1981a): *History of the large lakes of the central Sub-Arctic.* - Nauka, Novosibirsk 1981, 137 pp. [in Russian].

GALAZIY, G.I. & PARMUZIN, Y.P. (Eds.) (1981b): *The lakes of the northwestern part of the Siberian Platform.* - Nauka, Novosibirsk 1981, 190 pp. [in Russian].

KASSENS, H. (in press): The Expedition ARK-IX/4 of RV "Kireev" 1993. - *Reports on Polar Research.*

SULERZHITZKY, L.D. (1982): Reliability of the radiocarbon age and exactness of the dates. - In: N.V. KIND & B.N. LEONOV (Eds.), *The antropogene of the Taimyr Peninsula*, Nauka, 10-17. [in Russian]

2 THE EXPEDITION BUNGER OASIS 1993/94 OF THE AWI RESEARCH UNIT POTSDAM

by M. Melles, T. Kulbe, P.P. Overduin and S. Verkulich

Content:

2.1	INTRODUCTION	29
2.1.1	Objectives	29
2.1.2	Itinerary	29
2.1.3	Geography and climate	32
2.2	MARINE AND LACUSTRINE SEDIMENTS	34
2.2.1	Sampling technique	35
2.2.2	Sample storage and transport	38
2.2.3	Sediments in marine basins (epishelf lakes)	38
2.2.3.1	Edisto Channel	39
2.2.3.2	Kakapon Bay	42
2.2.3.3	Transkriptii Bay	46
2.2.4	Sediments in fresh-water lakes	47
2.2.4.1	Lakes on Geographers Island	48
2.2.4.2	Lakes on Southern Hills	48
2.3	OTHER TERRESTRIAL SEDIMENTS	50
2.3.1	Morainic deposits	50
2.3.2	Snow petrel stomach oil (mumiyo)	50
2.3.3	Marine carbonaceous shells	53
2.3.4	Snow petrel carcasses and fishes	54
2.3.5	Algae, mosses and a carbonaceous crust	54
2.4	HYDROLOGY OF LAKES AND MARINE BASINS	54
2.4.1	Hydrological measurements	55
2.4.2	Water sampling	71
2.5	GROUNDWATER HYDROLOGY	71
2.5.1	Description of study site	71
2.5.2	Method	72
2.5.3	Preliminary results	72
2.6	GLACIOLOGY	74
2.7	GEOMOPHOLOGY	75
2.7.1	Geographers Island	75
2.7.2	Thomas Island	76
2.7.3	Southern Hills	77
2.8	ACKNOWLEDGEMENTS	77
2.9	REFERENCES	77

2 THE EXPEDITION BUNGER OASIS 1993/94 OF THE AWI RESEARCH UNIT POTSDAM

by

Martin Melles *, **Thomas Kulbe** *, **Pier Paul Overduin** * and **Sergej Verkulich** **

* Alfred Wegener Institute for Polar and Marine Research, Research Unit Potsdam, Telegrafenberg A43, D-14473 Potsdam, F.R.G.

** Arctic and Antarctic Research Institute, Department of Polar Geography, Bering Street, 199226 St. Petersburg, Russia

2.1 INTRODUCTION

2.1.1 Objectives

The field work in Bunger Oasis was part of a bilateral research project, now running for about three years, with the 'Arctic and Antarctic Research Institute' (AARI), St. Petersburg. The objective of the project is a contribution to the understanding of the late Quaternary environmental history of East Antarctica. For this purpose different natural data archives of the palaeoenvironmental conditions, such as marine and lacustrine sediments, other terrestrial deposits, water bodies, and ice masses, shall be sampled and investigated in four ice-free coastal areas (oases) of East Antarctica, namely: (1) Schirmacher Oasis, (2) Untersee Oasis, (3) Bunger Oasis, and (4) Jetty Oasis (see inlet Fig. 2.1).

The expedition to Bunger Oasis, Wilkes Land, during the 1993/94 summer season was the second within the scope of the bilateral project. The first joint expedition was carried out in the Schirmacher and Untersee Oases, Dronning Maud Land, in 1991/92 (for report see MILLER in press); the sample and datum sets from these areas will be completed in 1994/95. An expedition to Jetty Oasis, Mac Robertson Land, will be undertaken within the next five years.

2.1.2 Itinerary

The AWI field equipment was loaded onto the russian RV "Akademik Federov" in Bremerhaven on Nov. 27, 1993, during a stop on its way from St. Petersburg to Cape Town and further to Antarctica. The four AWI participants of the Bunger Oasis Expedition boarded the vessel in Cape Town on Dec. 22. While some of the eight AARI participants took the "Akademik Federov" for the whole way from St. Petersburg, others joined the group after their wintering on russian stations in Antarctica.

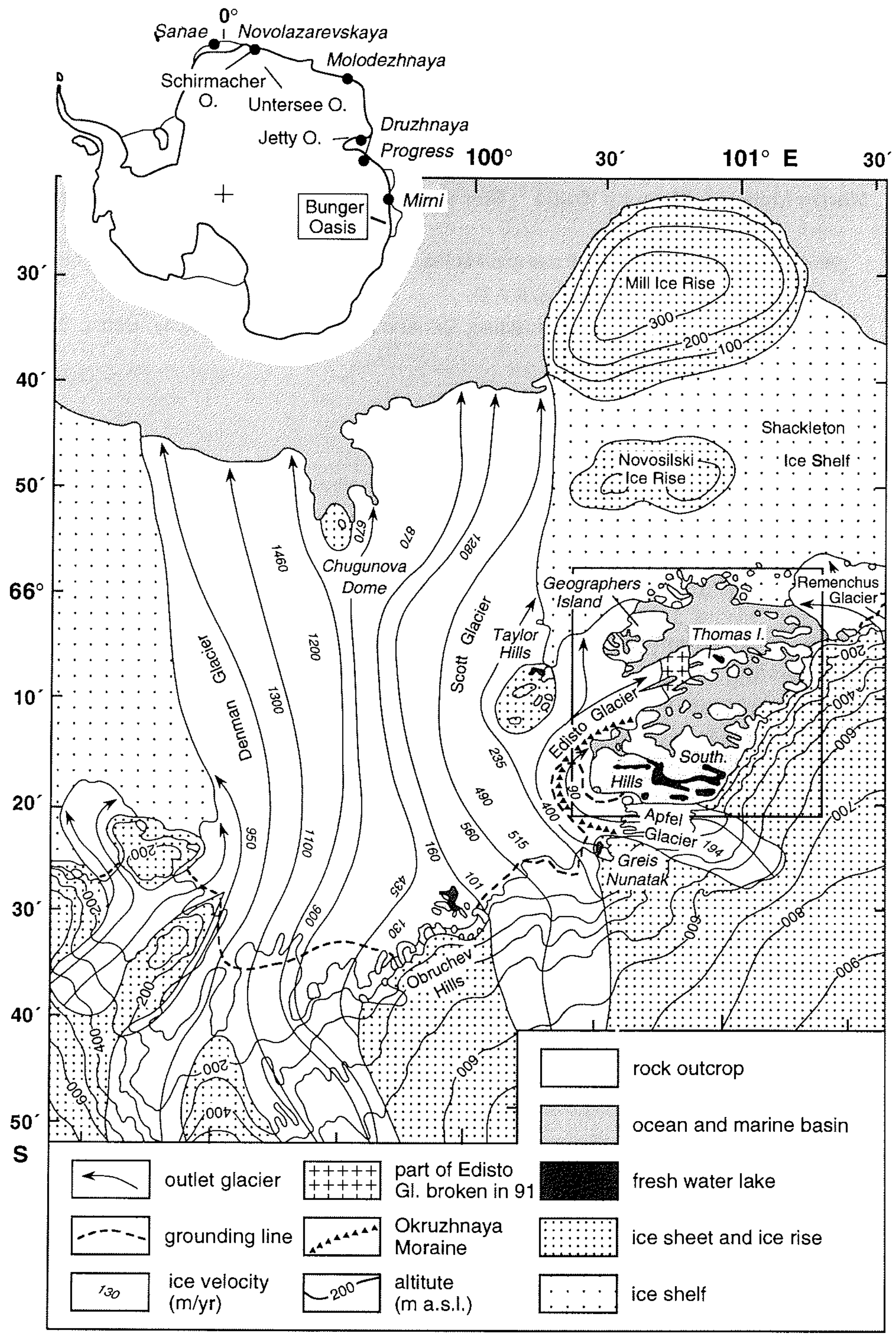


Figure 2.1: Location of the Bunger Oasis and glaciological and hydrological settings in the oasis surroundings. The encircled box marks the position of the detailled maps of Figs. 2.2, 2.4, 2.7 and 2.8.

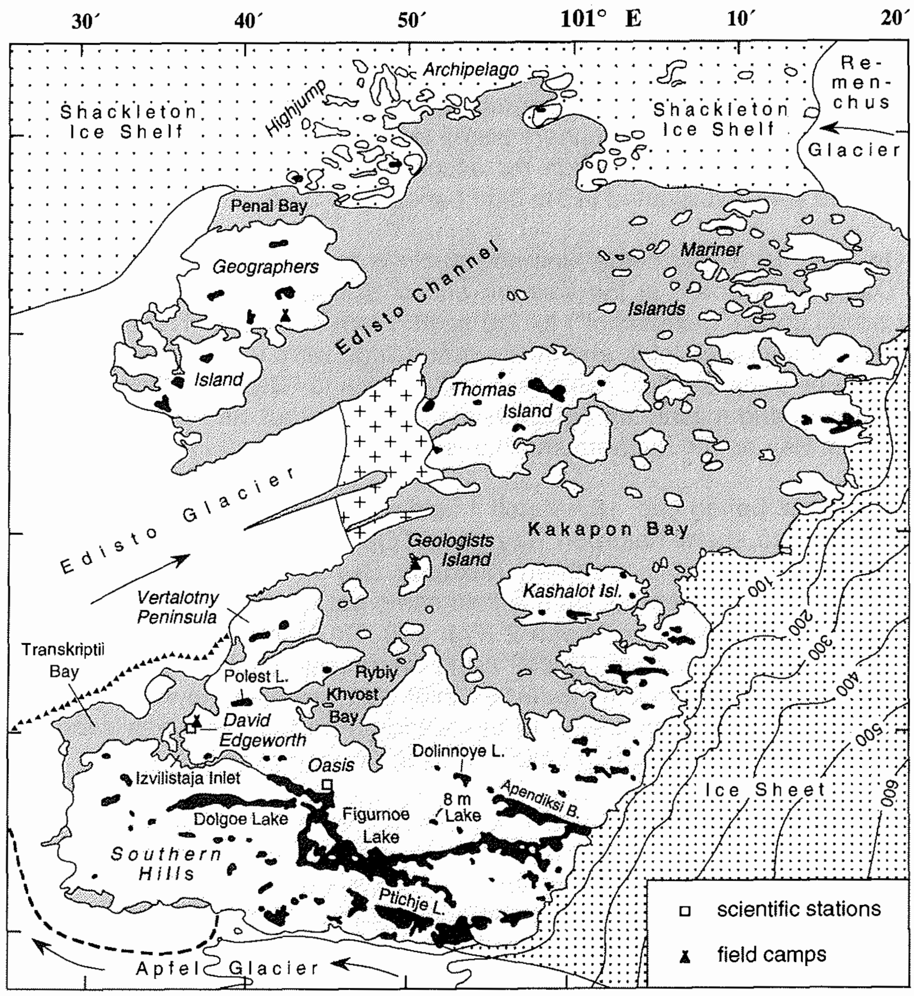


Figure 2.2: Detailled map of the Bunger Oasis with the scientific stations, the field camps of the 1993/94 expedition, and the geographical terms mentioned in the text (for additional legend see Fig. 2.1)

The "Akademik Federov" left Cape Town on Dec. 24. On its way to the Bunger Oasis logistical operations were performed for the south african station "Sanae" (Jan. 1 - 7) and for the russian stations "Novolazarevskaya" (Jan. 9 - 11) and "Molodezhnaya" (Jan. 15 - 17). On Jan. 22 the vessel reached the Shackleton Ice Shelf to the west of the Scott and Denman Glaciers (Fig. 2.1), ca. 250 km from Bunger Oasis. In three helicopter (MI-8) flights, the four AWI participants and two scientists from AARI were brought, together with some of the equipment, to Geographers Island in the northwest part of the oasis (Fig. 2.2). There the first phase of the expedition was carried out from a field camp during the time period Jan. 22 - 31.

At the same time the "Akademik Federov" supplied the russian station "Mirni". On Jan. 31 the vessel came back to the Shackleton Ice Shelf and reached a position within 70 km of the russian summer station "Oasis" (Fig. 2.2). Several helicopter flights delivered the remaining equipment on the "Akademik Federov" and all expedition members to the station, and the field equipment from the camp on Geographers Island to a small lake ca. 5 km east of "Oasis" (Fig. 2.2). Using the station for accomodation, this unnamed lake of 8 m altitude was investigated in the time period Feb. 2 - 8.

On Feb. 10 a field camp was set up close to the australian summer station "David Edgeworth" at the western end of Bunger Oasis (Fig. 2.2), using the russian track ("westdechot") for transport. From this camp, Transkriptii Bay and western Izvilistaja Inlet, and their surroundings were investigated until Feb. 16. Again by track, the field camp was shifted back to "Oasis" on Feb. 17, while the sampling and measuring equipment was transported via Polest Lake to Rybiy Khvost Bay on the northern shore of the Southern Hills (Fig. 2.2).

In the time period Feb. 18 - March 1 field work was carried out in Rybiy Khvost Bay and southern Kakapon Bay using "Oasis" for accomodation. Sampling and measurement in northern Kakapon Bay and on Thomas Island were subsequently carried out from a field camp set up on the northwestern shore of Geologists Island on March 2 (Fig. 2.2). On March 7, all of the equipment was transported back to "Oasis" using the russian track for transport on land. From the station, eastern Izvilistaja Inlet was sampled between March 9 and 11. The remaining time prior to evacuation from the oasis was used for field work on the large Figurnoe Lake and its surroundings (Fig. 2.2).

On April 3 the entire expedition was transported to the "Akademik Federov" by five helicopter flights. On the way to Cape Town the vessel performed logistical operations for the russian summer stations "Druzhnaya" (April 6 - 11) and "Progress" (April 12), and the wintering station "Mirni" (April 16 - 19). From Cape Town the four AWI participants took a flight back to Germany on May 2. The field equipment and samples were delivered by the "Akademik Federov" to Bremerhaven, where they arrived on May 18, 1994.

2.1.3 Geography and climate

The Bunger Oasis (Fig. 1) forms one of the largest ice-free areas of East Antarctica. The southern part of the oasis (Southern Hills) is a large contiguous land area of about 280 km^2 with a high number of fresh-water lakes (Fig. 2.2). To the north, numerous islands of about 170 km^2 altogether are separated from the Southern Hills by marine basins and marine inlets (epishelf lakes). 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 relief in Bunger Oasis is rugged, with a maximum elevation of 165 m a.s.l. and water depths in the fresh water lakes and marine basins of much more

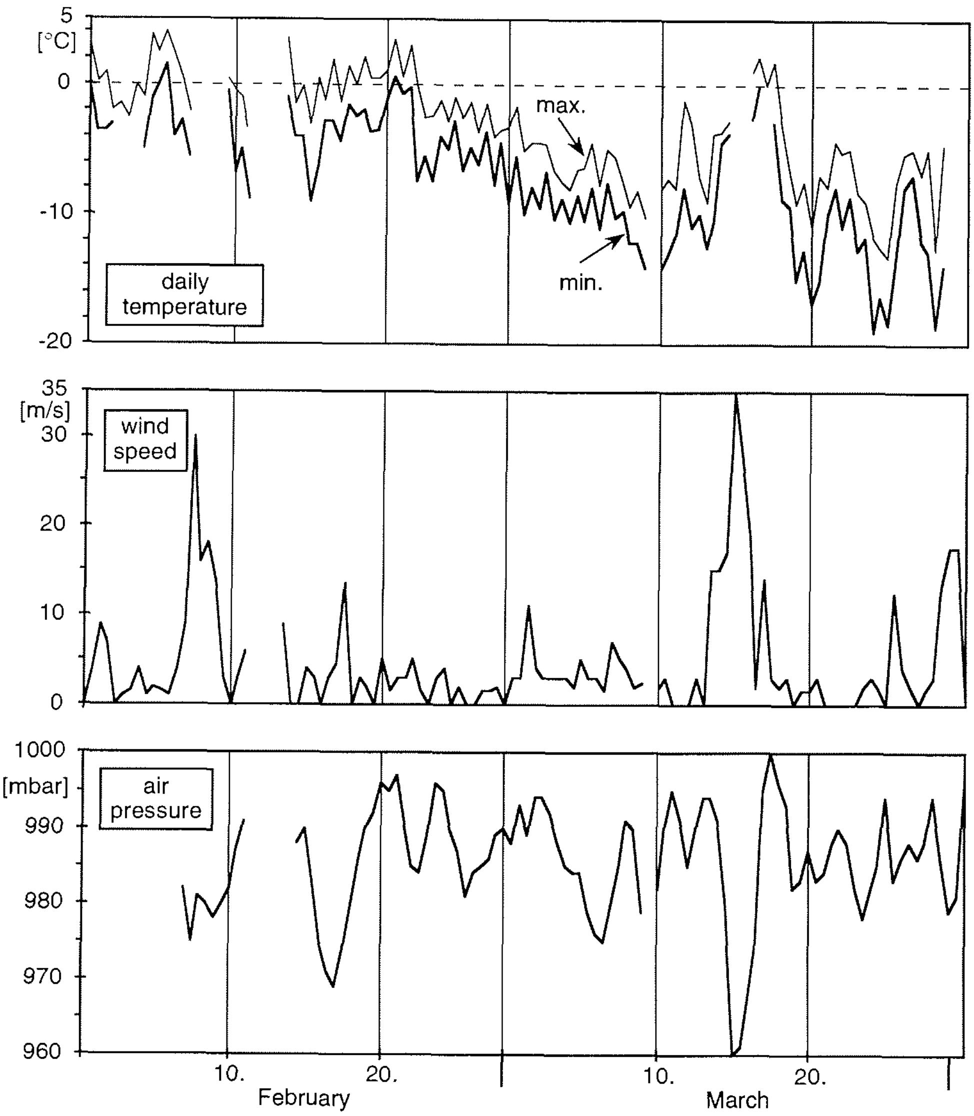


Figure 2.3: Development of the daily minimum and maximum temperatures, the wind speed (estimated), and the air pressure during the Bunger Oasis Expedition 1993/94 (A. Maksuta, unpubl. data)

than 100 m. The main geomorphological features are connected to tectonic structures and were probably present in some form before the onset of antarctic glaciation (BOLSHIYANOV 1990).

Relative to other antarctic areas of the same latitude, the climate in Bunger Oasis is mild (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.

During the field work in 1993/94 meteorological data were collected by A. Maksuta (AARI) on "Oasis" station (Fig. 2.3). They show relatively warm temperatures between +5 and -8° C until Feb. 22, followed by a more or less regular temperature decrease until March 10. During the remaining expedition time temperatures varied between -4 and -20° C, interrupted by two more warm episodes in the middle of March, when maximum temperatures reached about 0° C. Times of strong winds, which always came from eastern directions, corresponded with times of low air pressure (Fig. 2.3). Two heavy storms, with winds reaching more than 30 m/s, occurred on Feb. 7 - 9 and March 14 - 16, barring any field work. In addition, field work was restricted at the end of March, on days when wind speeds of more than 10 m/s coincided with temperatures of less than -10° C.

2.2 MARINE AND LACUSTRINE SEDIMENTS

Geological investigations of antarctic lake sediments have become increasingly common over last few years as a means of reconstructing the climatic and environmental history of Antarctica during Holocene time (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, DORAN *et al.* 1994).

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 lake sediments often enable detailed age determinations via radiocarbon dating. This frequent possibility of obtaining stratigraphic information, together with a high sedimentation rate, differentiates lake sediments from continental shelf sediments. Hence, the lake sediments probably function as the best archives of Holocene environmental history in Antarctica, generally allowing high resolution reconstruction, with good stratigraphic control.

In Bunger Oasis, some first, short lake sediment cores were recovered during Soviet and later Russian Antarctic Expeditions in 1986/87, 1988/89, 1990/91, and 1991/92 (SAE 32, 34, 36 and RAE 37). Stratigraphic, geochemical, and sedimentological investigations on these cores supplied very promising initial information concerning the Holocene environmental history (VERKULICH*et al.* 1990, BOLSHIYANOV *et al.* 1990, 1991, VERKULICH & MELLES 1992, MELLES *et al.* in press.). However, for a detailed and wide-ranging complete postglacial palaeoenvironmental reconstruction, these first cores had to be extended in number and depth, as they are restricted to a limited area around the russian summer station "Oasis" and as they represent only the most recent history, without the interesting time period of the oasis formation via deglaciation.

2.2.1 Sampling technique

The positioning of geological sampling locations was by satellite navigation (GPS, Global Positioning System) with a general accuracy of $\pm$ 100 m. An echo sounder (Furuno) was sometimes employed to obtain initial information concerning the water depth at the sampling locations, while a more accurate depth was always determined during sediment coring by a rope-length meter.

Sampling of marine and lacustrine sediment sequences was carried out by two different coring systems, from a platform. This equipment was entirely produced by the austrian company UWITEC and represents standard gear, in some cases modified for the specific requirements of high-latitude areas.

The platform has a ground area of 3,5 x 2,7 m. It can be used for sampling from open water as well as from lake ice cover. For the floating variant either 4 inflatable rubber pontoons or 16 standard gasoline barrels of 200 l volume can be mounted below the platform, resulting in a payload of more than 2 to. The floating platform was driven by a 15 horse-power engine, reaching velocities of up to ca. 5 knots. For use on lake ice, the same platform can be transformed into a sledge with 4 runners, easily pulled by ski-doo.

The various coring devices were run by hand winches, having rope lengths of up to 500 m. The winches are fixed to the legs of a 4 m high tripod which is situated above a hole in the platform. A rope-length meter at a pulley on the tripod head supplies information about the depth of the gear in the water column.

A light gravity corer (SL, "Schwerelot") was employed for the sampling of undisturbed near-surface sediments from deep waters. Its exchangeable coring tube consists of transparent PVC with an inner diameter of 5.9 cm. The SL penetrates the sediment under its own weight and up to three additional weight bodys of 4 kg each. Due to this variability, similar recoveries can be obtained from sediments of different consistencies and grain sizes. During recovery of the SL a hinged lid at the top of the core tube and a core catcher at its base prevent sediment losses by slipping or washing out. Hence, the SL supplies the complete, undisturbed transition from the near-surface sediments to the bottom water.

The SL can be used with two different core catchers:

- The first core catcher consists of a tennis ball, which is fixed by lines along the core tube during the movement of the SL to the bottom. By the slackening of the rope at penetration of the corer into the sediment, the lines are released by the descent of a hook in the head of the SL. When the core tube leaves the sediment during recovery, a rubber band pulls the tennis ball in front of the basal tube mouth. This core catcher worked with a very high success rate even in well sorted, sandy sediments. However, due to the defined line lengths, it can only be used in combination with a 60 cm long core tube. This restricts core recoveries in fine-grained and highly biogenic sediments, in which the weight of the corer could result in deeper penetration. In coarse-grained or highly consolidated sediments, the tennis ball at the tube side, ca. 20 cm from the bottom, hampers deeper penetration of the corer.

- The second core catcher is fixed at the base of up to 150 cm long core tubes by straps. It consists of a rubber sleeve, surrounded by a metal ring with a core cutter at its base. With this core catcher, a slackening of the rope results in the opening of a spring-loaded clamp, which fixes a piston in the water-filled head tube of the SL during its movement to the bottom. In the first stage of core recovery the piston is pulled out of the tube, pressing the water through a flexible pipe along the core tube into the core catcher. This inflates the rubber sleeve, which closes the core tube completely before the gear is pulled out of the sediment. In fine-grained and highly biogenic sediments the use of this hydraulic core catcher generally resulted in better core recoveries than with the tennis ball catcher, due to the possibility of using longer core tubes. In contrast, at locations with low penetration depths of the tube, common in highly consolidated or well sorted coarse-grained sediments, the recoveries were smaller, because the unprotected sediment between the core cutter and the sleeve generally became lost due to slipping or washing out during movement through the water column.

In low water depths of up to ca. 10 m, undisturbed near-surface sediments were recovered with a hand-push corer (HS, "Handstechrohr"). For that, the gravity corer (SL) with the tennis ball core catcher (see above) was provided with aluminium tubes of variable lengths at its head and pushed into the sediment by hand. The core catcher was released by slackening of a core rope, which was guided and held taut inside the aluminium tube.

Long sediment cores were recovered with a piston corer (KOL, "Kolbenlot"). The KOL can be used with 2 m and 3 m long steel tubes, covering exchangeable inner PVC liners of similar lengths. These transparent liner tubes (5.9 cm inner diameter) also serve as core tubes for the gravity and hand-pushed corers. On the lower end of the KOL liner a core catcher is attached and fixed by screwing a steel core cutter into the base of the core tube. The KOL top is closed by a head, on which rods of variable length can be screwed. The uppermost rod (striking rod) is constructed with plates on the top and base and serves as a guide for a cylindrical weight (20, 40 or 50 kg), used to hammer the apparatus into the sediment.

The KOL is operated by three ropes, which are run by hand winches on each of the tripod legs:

- With the 'gear cable' (5 mm steel) the whole KOL is moved through the water column and pulled out of the sediment at the end of the coring process. This cable can be fixed directly on the top of the striking rod. Alternatively, for a reduced load of the winch, it can be run over a pulley at the top of the striking rod to the top of the tripod. In the latter case, a stabilizing wing can be mounted at the pulley, to prevent screwing of the cables in the water.

- The 'striking rope' (8 mm plastic) is used to repeatedly lift and drop the weight. The energy released by dropping the weight on the lower plate of the striking rod propels the core tube into the sediment.

- The 'piston cable' (5 mm steel) is needed to start the coring process, to support an undisturbed coring, and to protect the sediment against loss during recovery. Until the coring process begins, the piston is fixed in the core cutter. It is released by an initial strong pull on the piston cable, which takes place by fixing the cable and lowering the corer via repeated dropping of the weight. The core tube descends into the sediment around the piston which is held at constant depth by the piston cable. In this way, a negative pressure is built up in the tube, supporting the receipt of an undisturbed, representative sediment sequence, and protecting against sediment loss by slipping out during recovery.

To prevent sediment loss at the tube base the KOL can in addition be supplied with two different core catchers:

- The first core catcher is similar to the hydraulic catcher of the gravity corer (see above), differing only by the releasing mechanism. When the piston reaches the top of the core tube, it penetrates the KOL head. The water in the head becomes displaced and is forced between the liner and the core tube into the rubber sleeve in the catcher. Inflating of the sleeve closes the core tube and protects the sediment against loss by slipping or washing out. The problem with this core catcher is that it can work only when the core tube is completely filled with sediment, in order for the piston to penetrate the head. Hence, when the coring process stops earlier (e.g. encountering big stones or the sediment base), it is useless. In addition, the sleeve is easily damaged by stones. This core catcher, therefore, is most promising in thick and fine-grained sediment sequences.

- The second core catcher consists of flexible steel lamella which are fixed to the inner wall of a metal cylinder and extend from its lower towards its upper end. The sediment depresses the lamella against the cylinder wall during penetration, but is held in the core tube by the closing of the lamella on withdrawal. This catcher was used successfully in relatively stiff terrigeneous sediments. Soft sediments, which are not firm enough to depress the steel lamella, tend to be partly destroyed.

In addition to the described KOL, a smaller variant was available, with a length of 2 m and a diameter of only 3 cm. In general, it works without a core catcher, as the small diameter allows the high friction at the tube wall, relative to the small sediment weight, to hold the material in the tube. This small KOL was used only once (PG1161-2) in a lake accessible only by foot. All other KOL cores were recovered with the larger variant, which worked very successfully and supplied larger sample volumes.

The maximum recovery with every employment of the KOL is limited by the tube length to 3 m. Deeper sediment horizons can also be sampled, however, because the start of the coring process during penetration of the gear can be controlled by the release of the piston, which is fixed in the tube mouth on its way through both the water column and the overlaying sediments. Hence, by coring of several overlapping horizons and subsequent parallelisation of the cores, a continuous sediment sequence of much higher length than 3 m can be obtained (see station PG1173 in Table 2.1 for example).

2.2.2 Sample storage and transport

Sediments with high consistencies, in most cases terrigeneous sediments with relatively low water contents, could be stored and transported directly in the liner tubes. For that purpose the up to 3 m long PVC tubes were cut into pieces of up to one metre length and closed at both ends, largely air- and waterproof, by suitable plastic caps and flexible tape.

Sediment present in or below the core catcher was recovered, segmented in 1 or 2 cm thick slices, and stored in plastic flasks of 50 ml volume or in plastic bags. The plastic flasks were of known weight and air- and waterproof, enabling determinations of sediment water content and related physical properties. The same style of storage was necessary for sediments with very high water contents because movement and vibration during transport could result in separation of pore water and sediment particles and thus in destruction of sediment stratification and structure. In practice, this was necessary for near-surface sediments and especially in algal mats and moss layers. The sequences were cut into 1 or 2 cm slices by the use of special cutting equipment: a piston to push the sediment from the base of the core tube out its top and a plastic cutter to allow rapid and precise slicing of the core.

All lacustrine and marine sediment samples were stored at slightly positive temperatures. In the field and on the station "Oasis" these were secured with heated, insulated aluminum boxes. During transport on the ship and later during storage at the institute, prior to the start of analytical work, the samples were put into cooling rooms of 0° - 7° C and 4° ± 1° C, respectively.

2.2.3 Sediments in marine basins (epishelf lakes)

Marine basins in East Antarctic oases, also called epishelf lakes or epishelf basins (KOROTKEVICH 1969, SIMONOV & BONCH-OSMOLOVSKAYA 1969), are mostly situated along the seaward shores of the oases and have a hydraulic connection to the open ocean below adjacent ice shelves and glaciers. In Bunger Oasis, the biggest marine basins, Edisto Channel and Kakapon Bay (Fig. 2.4), cover more than half of the total oasis area. Smaller marine basins, such as Transkriptii Bay, occur along the western and southwestern shore, proving floating conditions for large parts of the Apfel and Scott Glaciers (Fig. 2.4).

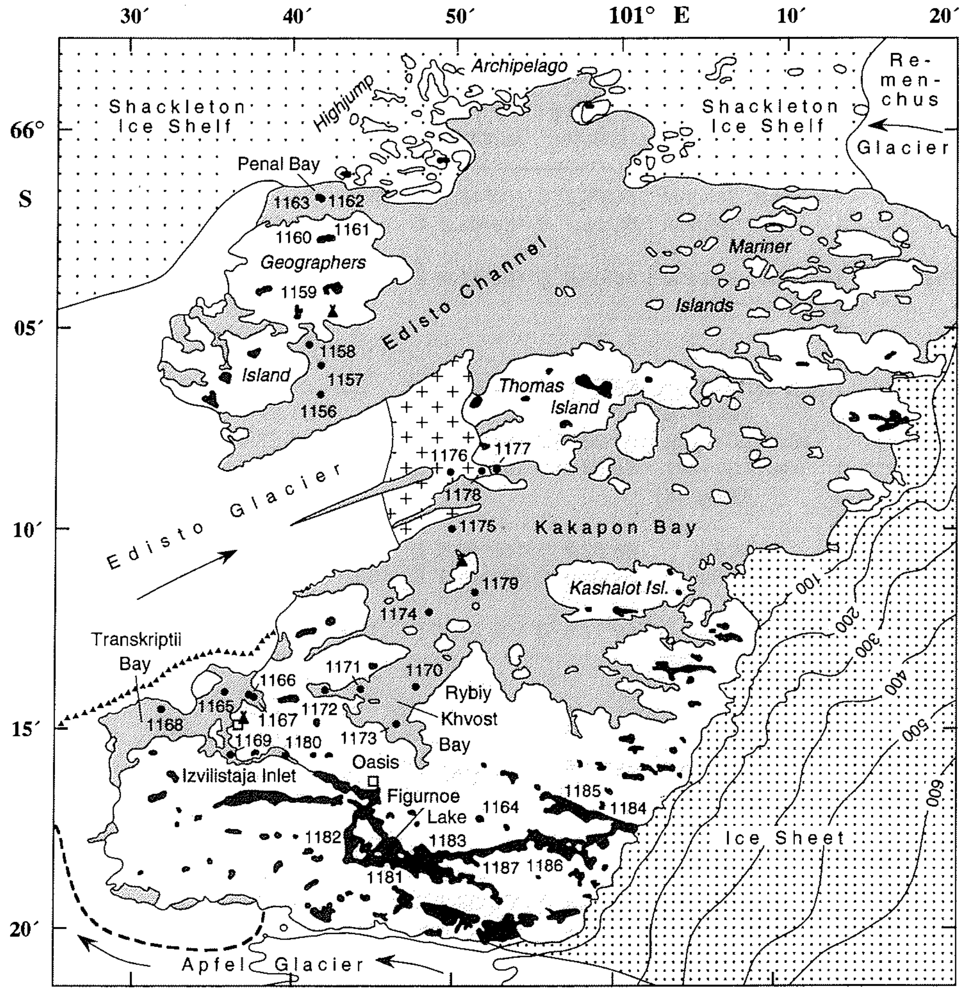


Figure 2.4: Sediment sampling sites in fresh-water lakes and marine basins of the expedition Bunger Oasis 1993/94 (for additional legend see Fig. 2.1)

2.2.3.1 Edisto Channel

In Edisto Channel, sediment coring was carried out for the first time during the Bunger Oasis Expedition 1993/94. Cores were recovered both north and south of Geographers Island (Fig. 2.4, Table 2.1). The sediments are predominantly terrigeneous. A rich marine fauna, including sponges, foraminifera, mussels and sea urchins, and intense bioturbation at least within the near-surface sediments from all sampling locations, reveal fully marine conditions of substantial duration in the Edisto Channel.

In Penal Bay, northwestern Edisto Channel, the longest sediment core recovered has a length of only 70 cm. The sequence consists of sandy, brown

Table 2.1: Sediment cores from fresh-water lakes and marine basins collected during the Bunger Oasis Expedition 1993/94 (abbreviations see end of table)

core no. station-employ	lake/ marine basin	position * latitude	longitude	water depth [m]	date	gear	recovery [cm]
PG1156 - 1	Edisto Channel	66°06.2´ S	100°43.3´ E	249.2	01-23-94	SL	0 - 25
PG1157 - 1	Edisto Channel	66°06.1´ S	100°42.2´ E	117.0	01-24-94	SL	0 - 22
- 2					01-25-94	KOL	112 - 150
PG1158 - 1	Edisto Channel	66°05.8´ S	100°41.6´ E	32.4	01-25-94	SL	0 - 22
- 2					01-25-94	KOL	0 - 229
- 3					01-25-94	KOL	184 - 382
- 4					01-26-94	KOL	172 - 343
PG1159 - 1	lake 8.0 m altitude	66°04.2´ S	100°42.5´ E	2.2	01-26-94	SR	0 - 28
- 2	(Geogr. Isl.)				01-27-94	KOL	0 - 76
PG1160 - 1	lake 17.0 m altit.	66°03.0´ S	100°41.7´ E	6.5	01-27-94	SL	0 - 26
PG1161 - 1	lake 17.0 m altit.	66°03.0´ S	100°41.8´ E	7.1	01-27-94	SL	0 - 25
- 2	(Geogr. Isl.)				01-27-94	KOL	20 - 197
- 3					01-28-94	KOL	0 - 122
PG1162 - 1	Penal Bay	66°02.3´ S	100°40.3´ E	153.3	01-29-94	SL	0 - 21
PG1163 - 1	Penal Bay	66°02.0´ S	100°40.0´ E	155.1	01-29-94	KOL	0 - 70
- 2					01-29-94	SL	0 - 14
PG1164 - 1	lake 8.0 m altitude	66°17.5´ S	100°51.3´ E	12.5	02-05-94	SL	0 - 12
- 2	(South. Hills)				02-05-94	SL	0 - 131
- 3					02-06-94	KOL	0 - 272
- 4					02-07-94	KOL	172 - 383
- 5					02-07-94	KOL	222 - 470
PG1165 - 1	Transkriptii Bay	66°14.6´ S	100°35.7´ E	101.4	02-11-94	SL	0 - 17
- 2					02-11-94	KOL	5 - 99
- 3					02-12-94	KOL	5 - 191
- 4					02-12-94	KOL	91 - 246
- 5					02-12-94	KOL	141 - 325
PG1166 - 1	Transkriptii Bay	66°14.4´ S	100°37.3´ E	51.5	02-13-94	SL	0 - 10
PG1167 - 1	Transkriptii Bay	66°14.4´ S	100°37.4´ E	41.7	02-13-94	KOL	0 - 245
PG1168 - 1	Transkriptii Bay	66°15.0´ S	100°31.4´ E	58.9	02-15-94	SL	0 - 25
PG1169 - 1	Izvilistaja Inlet	66°16.1´ S	100°36.3´ E	11.1	02-15-94	SL	0 - 42
- 2					02-16-94	KOL	30 - 90
- 3					02-16-94	KOL	0 - 190
- 4					02-16-94	KOL	190 - 290
PG1170 - 1	Rybiy Khvost Bay	66°14.3´ S	100°47.3´ E	101.4	02-19-94	SL	0 - 26
- 2					02-19-94	SL	0 - 28
- 3					02-20-94	KOL	10 - 306
- 4					02-20-94	KOL	260 - 396
PG1171 - 1	Rybiy Khvost Bay	66°14.4´ S	100°44.3´ E	35.4	02-20-94	SL	0 - 17
- 2					02-20-94	SL	0 - 15
- 3					02-20-94	KOL	0 - 66
- 4					02-21-94	KOL	0 - 184
PG1172 - 1	Rybiy Khvost Bay	66°14.3´ S	100°41.9´ E	17.2	02-21-94	SL	0 - 18
- 2					02-21-94	SL	0 - 22
- 3					02-21-94	KOL	2 - 265
- 4					02-21-94	KOL	215 - 370
PG1173 - 1	Rybiy Khvost Bay	66°15.2´ S	100°46.5´ E	90.7	02-22-94	SL	0 - 27
- 2					02-22-94	KOL	0 - 292
- 3					02-23-94	KOL	242 - 534
- 4					02-23-94	KOL	484 - 782

Table 2.1: continuation

core no. station-employ	lake/ marine basin	position* latitude	longitude	water depth [m]	date	gear	recovery [cm]
PG1173 - 5	Rybiy Khvost Bay	66°15.2´ S	100°46.5´ E	90.7	02-24-94	KOL	734 - 1028
- 6					02-25-94	KOL	984 - 1278
- 7					02-25-94	KOL	1234 - 1376
PG1174 - 1	Kakapon Bay	66°12.2´ S	100°48.4´ E	102.0	03-01-94	SL	0 - 23
- 2					03-01-94	KOL	2 - 202
- 3					03-01-94	KOL	102 - 287
PG1175 - 1	Kakapon Bay	66°10.2´ S	100°49.6´ E	288.7	03-03-94	SL	0 - 19
PG1176 - 1	Kakapon Bay	66°08.4´ S	100°49.8´ E	274.0	03-03-94	SL	0 - 20
PG1177 - 1	Kakapon Bay	66°08.7´ S	100°52.4´ E	100.0	03-04-94	SL	0 - 2
- 2					03-04-94	KOL	0 - 57
PG1178 - 1	Kakapon Bay	66°08.8´ S	100°51.6´ E	127.0	03-05-94	SL	0 - 1
- 2					03-05-94	KOL	0 - 92
PG1179 - 1	Kakapon Bay	66°11.9´ S	100°51.1´ E	148.7	03-06-94	SL	0 - 11
- 2					03-06-94	KOL	2 - 100
PG1180 - 1	Izvilistaja Inlet	66°15.9´ S	100°39.3´ E	36.9	03-09-94	SL	0 - 43
- 2					03-09-94	KOL	0 - 252
- 3					03-10-94	KOL	202 - 499
- 4					03-10-94	KOL	452 - 748
- 5					03-11-94	KOL	702 - 999
- 6					03-11-94	KOL	952 - 1208
PG1181 - 1	Figurnoe Lake	66°18.6´ S	100°46.8´ E	138.8	03-13-94	SL	0 - 56
- 2					03-13-94	KOL	0 - 214
PG1182 - 1	Figurnoe Lake	66°18.1´ S	100°43.6´ E	61.9	03-15-94	SL	0 - 56
- 2					03-16-94	KOL	0 - 172
PG1183 - 1	Figurnoe Lake	66°18.4´ S	100°49.5´ E	49.7	03-21-94	SL	0 - 22
- 2					03-21-94	KOL	0 - 202
- 3					03-22-94	KOL	150 - 448
- 4					03-23-94	KOL	400 - 680
PG1184 - 1	Figurnoe Lake	66°17.7´ S	101°00.4´ E	68.8	03-26-94	SL	0 - 23
- 2					03-26-94	KOL	0 - 248
- 3					03-28-94	KOL	198 - 359
PG1185 - 1	Figurnoe Lake	66°17.3´ S	100°57.8´ E	116.7	03-28-94	SL	0 - 39
- 2					03-29-94	KOL	0 - 123
PG1186 - 1	Figurnoe Lake	66°18.1´ S	100°56.4´ E	123.1	03-29-94	SL	0 - 32
- 2					03-30-94	KOL	0 - 203
PG1187 - 1	Figurnoe Lake	66°18.1´ S	100°53.3´ E	75.1	03-30-94	SL	0 - 21
- 2					03-30-94	KOL	0 - 92
						sum Σ	107.02 m

SL = ´Schwerelot´ (gravity corer)
SR = ´Stechrohr´ (hand-push corer)
KOL = ´Kolbenlot´ (piston corer)

* after GPS (Global Positioning System)

sediments in the upper part, overlaying fine-grained muds in the middle part, bordered sharply by gray, gravelly sand with stones in the lowermost 3 cm. The very coarse-grained deposits at the core base indicate a strong glacial influence on sediment accumulation. This could be the result of a high proximity to a glacial sediment source or even of coverage by floating or grounded ice. Indications for an ice advance and related erosion or deposition along a west to east trending line comes from the occurrence of moraines along the northern shore of Penal Bay and from bathymetric measurements, which point to a relatively plain basin and a steep southern slope descending to more than 150 m within 500 m distance from the northern shore of Geographers Island.

South of Geographers Island a maximum water depth of about 250 m was measured, much deeper than the 100 to 200 m expected in marine basins of Bunger Oasis by COLHOUN & ADAMSON (1991, 1992). At this location, about half the distance to the Edisto Glacier, only a short sediment core was taken, consisting of brown, predominantly fine-grained sediments.

A much longer sequence (ca. 3.4 m) was recovered from the largest bay on the southern shore of Geographers Island (Fig. 2.4). It comprises a complete glacial and postglacial succession from a poorly sorted, stiff moraine of gray color at the base to sorted, soft glaciomarine sediments of brownish colors up to the surface. The bay is probably separated from the open Edisto Channel by a submarine morainic ridge, which crops out at both sides of the bay entrance. Hence, it is likely that sedimentation in the bay was not interrupted by at least the youngest ice advance through the Edisto Channel.

2.2.3.2 Kakapon Bay

As in Edisto Channel, the near-surface sediments in Kakapon Bay contain a rich marine fauna and are intensely bioturbated. The first cores from northern Kakapon Bay were retrieved during this expedition, at six locations situated between Thomas Island and Southern Hills (Fig. 2.4, Table 2.1). In addition, sediment cores were recovered from four locations in Rybiy Khvost Bay, the largest bay on the northern shore of Southern Hills.

Until a calving event in 1991 the Edisto Glacier reached the western shore of Thomas Island (Fig. 2.4). A bathymetric profile, starting below the ancient ice tongue and trending towards the east into the canal southwest of Thomas Island, shows a typical submarine morainic ridge (Table 2.2, Fig. 2.5), which could be related to the youngest (until 1991) glacier advance. The near-surface sediments recovered on three locations along the profile (Fig. 2.5) consist of brown, sandy glaciomarine deposits. At site PG1176 these sediments comprise the whole short sequence recovered by gravity coring. In contrast, at sites PG1178 and PG1177, piston coring supplied longer sequences, where the brown near-surface sediments give way to gray glaciomarine sediments and further to gray, stiff, poorly sorted moraines at the core bases. In spite of restrictions on sediment description due to storage in the plastic

Table 2.2: Echo sounding data collected in addition to those on geological sampling locations (Tab. 2.1) during the Bunger Oasis Expedition 1993/94

sounding no.	position see Figs. 2.4 and 2.5	water depth [m]	sounding no.	position (GPS) latitude; longitude	water depth [m]
1	200 m west of geol. site PG1178	161	12	66°08.8´ S; 100°52.7´ E	93
2	100 m west of geol. site PG1178	147	13	66°08.4´ S; 100°50.2´ E	222
3	100 m east of geol. site PG1178	113	14	66°10.4´ S; 100°49.6´ E	139
4	150 m east of geol. site PG1178	100	15	66°09.9´ S; 100°49.6´ E	> 320
5	200 m east of geol. site PG1178	85	16	66°09.6´ S; 100°49.6´ E	> 320
6	225 m east of geol.site PG1178	80	17	66°09.3´ S; 100°49.6´ E	> 320
7	250 m east of geol. site PG1178	81	18	66°08.9´ S; 100°49.6´ E	> 320
8	275 m east of geol. site PG1178	84	19	66°08.6´ S; 100°49.7´ E	295
9	300 m east of geol. site PG1178	86	20	66°09.2´ S; 100°50.2´ E	> 320
10	400 m east of geol. site PG1178	95	21	66°09.4´ S; 100°51.6´ E	294
11	500 m east of geol. site PG1178	100	22	66°12.2´ S; 100°49.9´ E	116

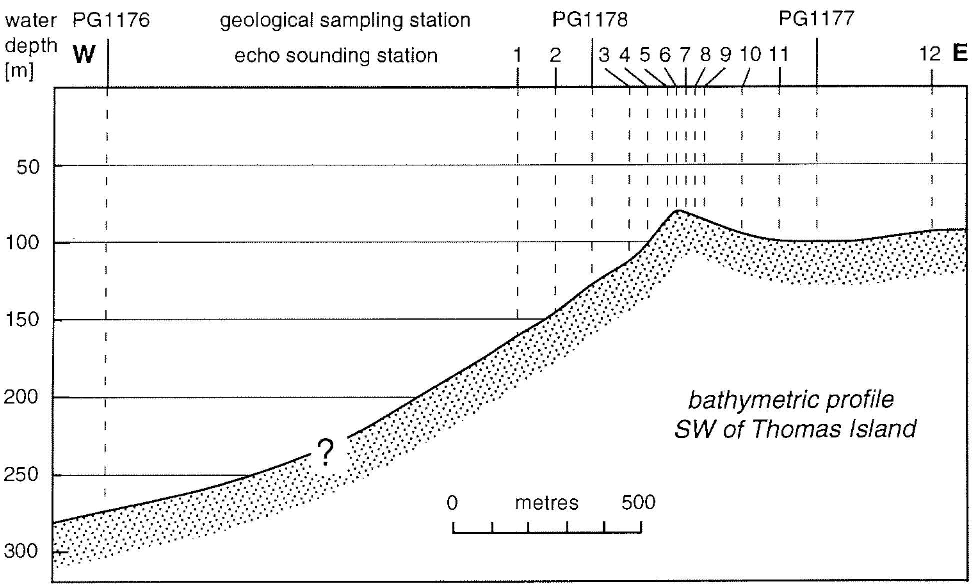


Figure 2.5: Bathymetric profile from below the former Edisto Glacier in the west to the canal southwest of Thomas Island in the east (for location see sediment sampling sites PG1176, PG1178, and PG1177 in Fig. 2.4)

liners, the postglacial sediments on site PG1177 seem to be thicker than those from site PG1178.

A second bathymetric profile was measured across northern Kakapon Bay, along a south to north trending line between Geologists Island and western Thomas Island (Table 2.2). It shows water depths of more than 320 m, the limit for measuring with the echo-sounder used on this expedition, over most parts of the profile. Steep flanks towards both Thomas and Geologists Islands are indicated by water depths of much more than 100 m within a few hundred meters distance from the shores (Table 2.2). Hence, northwestern Kakapon Bay seems to be an overdeepened channel, probably the result of glacial erosion. Similarities in water depths to Edisto Channel suggest that during a late Quaternary ice advance the Edisto Glacier could have been divided into two arms flowing around Thomas Island.

A short gravity core was taken from ca. 290 m water depth north of Geologists Island (Fig. 2.4), consisting of sandy glaciomarine sediments of brown over gray colors. Similar successions in the near-surface sediments were recovered at two sites southwest and southeast of Geologists Island. Piston coring on these sites, however, supplied complete postglacial sequences as well as very stiff, poorly sorted moraines at their bases. Big differences in postglacial sediment thicknesses, ca. 0.9 m at site PG1179 compared to ca. 2.7 m at site PG1174, could be due to differences in deglaciation times but also to a higher proximity of the latter station to the Edisto Glacier, which may have resulted in higher sediment supply by icebergs and meltwater.

Site PG1170 is located in the northeastern, deepest part of Rybiy Khvost Bay (Fig. 2.4). A ca. 4.0 m long sequence was recovered from more than 100 m depth, comprising a succession from a moraine at the base, followed by gray and later olive green glaciomarine sediments and ending with laminated algae mats in the uppermost 2 cm.

The long and narrow inlet extending from western Rybiy Khvost Bay towards Transkriptii Bay, was sampled at two locations (Fig. 2.4). Based on investigations of ancient shore lines, COLHOUN & ADAMSON (1989) concluded that the inlet had been ice-dammed for quite a long time by the Antarctic Ice Sheet during its postglacial retreat. As a consequence, a periglacial fresh-water lake of greater size and depth than the present-day inlet would have existed. BOLSHIYANOV *et al.* (1991) and VERKULICH (1991), in contrast, assumed a marine origin of the shore lines on the basis of geomorphological studies. One objective of the sediment sampling, therefore, was to resolve this contradiction.

At the eastern site, PG1171, a complete sequence down to a moraine was recovered. The overlaying, predominantly fine-grained, postglacial sediments amount to less than two metres. In spite of a much deeper penetration (3.7 m), at site PG1172 the basal moraine was not reached. The postglacial sediments on this location comprise a fining-upward sequence from well sorted, almost pure gravels at the base to sandy muds at the top. From these differences in postglacial sediment compositions and thicknesses, there is no evidence for an ice-damming at the eastern inlet entrance, as assumed by COLHOUN & ADAMSON (1989). More likely is the occurrence of grounded ice masses on the hills west of Rybiy Khvost Bay, supplying high amounts of suspension-loaded meltwater to the western inlet. However, a detailed reconstruction of the postglacial environmental history will only be possible by extensive geological investigations of the sediment cores.

From southern Rybiy Khvost Bay a short (1.2 m) sediment core had been recovered during the SAE 36 (1990/91). Five radiocarbon dates on the organic matter of the sediment pointed to very high sedimentation rates (MELLES *et al.* in press). In order to obtain a very long postglacial sequence with related good time resolution a similar location was sampled during the Bunger Oasis Expedition 1993/94. Coring on this site PG1173 resulted in 13.7 m recovery, which is by far the longest sequence ever obtained from any fresh-water lake or marine basin of Antarctica.

In the uppermost ca. 13.0 m the sequence PG1173 consists of green sapropel, strongly smelling of H_2S. Close to the sediment surface the sapropel exhibits very high water content, resulting in a sediment density close to that of the overlaying bottom water. The sediment is homogeneous down to ca. 1.5 m. In deeper horizons, in contrast, bedding, as well as enclosures of algae layers, are common. A probable fish skeleton and a mussel shell of ca. 5 cm diameter were found at 10.2 and 11.2 m, respectively. The sapropel overlays terrigeneous sediments of gray color, a 0.6 m thick horizon of muds, including sand layers in the lowermost 0.5 m, and a stiff, poorly sorted moraine at the base.

Due to the absence of any indications for sediment erosion or disturbance it is likely that the sequence PG1173 comprises the complete history since the beginning of deglaciation, which is believed to have occurred close to the Pleistocene/Holocene boundary (BOLSHIYANOV *et al.* 1990, ADAMSON & COLHOUN 1992, VERKULICH & HILLER in press). Hence, the time resolution of the sequence probably corresponds to about 10 years per sediment centimetre, a resolution normally reached only by ice cores.

The extraordinary high sedimentation rates have to be explained by a special hydrological situation in southern Rybiy Khvost Bay, resulting in sapropel accumulation, which makes up the major part of the sequence. A hydrological depth profile (BW-29, Fig. 2.6) shows the absence of oxygen in the lowermost 2 to 10 m of the water column. The biogenic components produced in the surface water, therefore, are largely preserved due to the absence of both decomposition by oxidation and feeding by benthic organisms. In spite of the present-day chemocline position very close to the sea floor, this hydrological situation was stable for a considerable time span, as evidenced by the thickness of the sapropel deposits. The occurrence of oxygen in water depths down to 100 m in northeastern Rybiy Khvost Bay (BW-26, Fig. 2.8, Table 2.15) indicates that the hydrological situation at coring location PG1173 is restricted to an isolated depression within the bay, with reduced ventilation by thermohaline currents. A similar setting with related sapropel accumulation was found in Lake Untersee, Wohlthat Massif (MELLES in press).

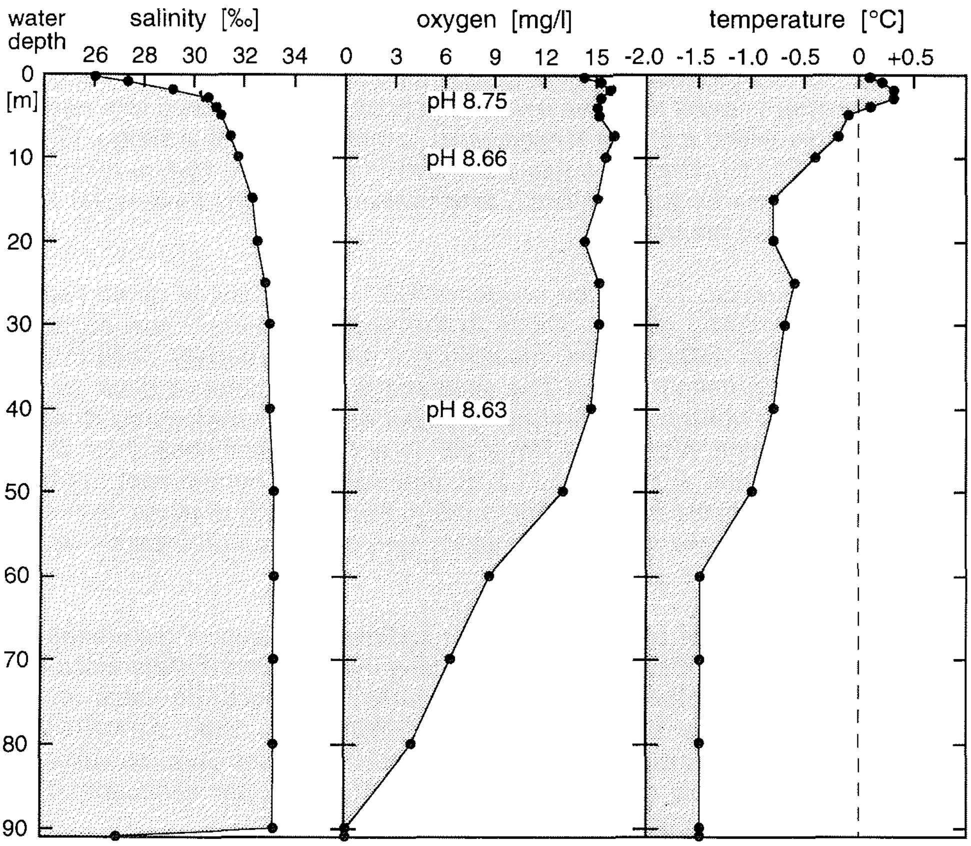


Figure 2.6: Hydrological depth profile at site BW-29 in southern Rybiy Khvost Bay, showing the absence of oxygen and a salinity minimum in the lowermost water column (for location see sediment sampling site PG1173 in Fig. 2.4)

2.2.3.3 Transkriptii Bay

The marine basin (epishelf lake) Transkriptii Bay is situated at the western end of Southern Hills and bordered to the west by the floating Apfel Glacier (Fig. 2.4). In contrast to Edisto Channel and Kakapon Bay, the water column of Transkriptii Bay is composed predominantly of fresh water. Only in the deepest part, below ca. 88 m water depth, a significant salt content and high contents of H_2S and phosphates were determined, as well as an absence of oxygen (KAUP *et al.* 1990, 1993).

This hydrological situation, a stagnant H_2S bearing water body close to the sea floor, is similar to that at coring location PG1173 in southern Rybiy Khvost Bay (see above). The surface sediments at site PG1165, recovered from the deepest part (101 m) of Transkriptii Bay, therefore, also consist of very soft, green sapropels, strongly smelling of H_2S. Their thickness, however, amounts to only 3 cm, indicating that in Transkriptii Bay the formation of an anoxic bottom water occurred more recently. In addition, such a hydrological situation had not existed for a considerable time span after deglaciation, because sapropels are absent in the underlaying sediments, which consist of olive gray, terrigeneous muddy sands, followed by dark gray muds and underlain by a dark gray moraine at the base (3.2 m).

Beside the coring of a complete glacial and postglacial sequence at site PG1165, near-surface sediment sampling was carried out in northeastern and western Transkriptii Bay (Fig. 2.4). In both areas predominantly terrigeneous, sandy sediments were recovered.

As part of Transkriptii Bay, the long and narrow Izvilistaja Inlet extends southeast far into the Southern Hills. The inlet is the pathway for meltwater outflow from Figurnoe Lake to Transkriptii Bay. Sediment coring was carried out at locations in western (PG1169) and eastern (PG1180) Izvilistaja Inlet (Fig. 2.4).

On site PG1169 a ca. 2.9 m long sequence was recovered from 11 m water depth. It consists of multi-colored, partly laminated algae in the uppermost 0.5 m, overlaying greenish fine sands down to 1.6 m, and grayish gravels and sands in the lowermost ca. 1.3 m. The occurence of marine carbonaceous shell fragments at least in three individual sediment horizons (ca. 45, 75, and 190 cm) makes this sequence particularly interesting for reconstructions of Holocene sea-level fluctuations and/or variations of oceanic water penetrations into marine basins. Today, diluted marine waters occur only in the deepest part of Transkriptii Bay, more than 70 m below the water depth at site PG1169.

On site PG1180, eastern Izvilistaja Inlet, a very long sequence of 12.1 m was recovered, starting from a gray moraine at its base. The moraine is overlaid by similarly coloured terrigeneous muds and muddy sands, with occasional algae, moss, and well sorted sand layers of varying thicknesses. Above 10.5 m the entire, predominantly biogenic sediment strongly smelled of H_2S. While the sediment in the uppermost 1.3 m consists of multi-coloured, mostly laminated algae, containing mosses in some horizons, the underlaying sediment has strong similarity with the sapropels sampled in central Transkriptii Bay (see above) or southern Rybiy Khvost Bay (Chapter 2.2.3.2). Hence, at least for a considerable time span within the Holocene, eastern Izvilistaja Inlet was under anoxic conditions.

2.2.4 Sediments in fresh-water lakes

Many fresh-water lakes fill the valleys and bedrock depressions in the Southern Hills as well as on the islands in the northern part of Bunger Oasis. Additionally, saline lakes of mostly smaller size (one of the largest being Polest Lake, Fig. 2.2) are widely distributed especially along the northern shore of Southern Hills (KAUP *et al.* 1993). During the Bunger Oasis Expedition 1993/94, lake sediment sampling was carried out exclusively on fresh-water lakes.

2.2.4.1 Lakes on Geographers Island

On Geographers Island two unnamed fresh-water lakes, at altitudes of 8 m and 17 m, were sampled. The objective was to extend the sample set recovered in Edisto Channel both north and south of Geographers Island (Chapter 2.2.3.1). This is particularly important with respect to stratigraphic information, because lake sediments more often enable radiocarbon dating due to higher organic carbon contents than sediments from marine basins (VERKULICH & MELLES 1992).

The ´8 m Lake´, located close to the southeastern shore of Geographers Island (Fig. 2.4), is very shallow, reaching only 2.2 m water depth in its deepest part. Coring revealed a 0.8 m long sediment sequence, consisting of brown and gray, laminated algae mats in the uppermost 8 cm, and underlaying stiff, laminated algae clods. The high consistency of the latter sediment type, and their separation into individual clods, indicates that they represent former laminated algae mats, compacted and broken into pieces by ice load due to complete freezing of the lake water body.

The ´17 m Lake´ is located close to the northern shore of Geographers Island (Fig. 2.4). From the deepest part of the lake (7.1 m) a 1.2 m long sequence was recovered, comprising a succession from a probable moraine at the base, followed by terrigeneous sediments, stiff algae clods, and soft, laminated algae mats up to the sediment surface. In similarity to ´8 m Lake´ (see above), the occurrence of the stiff algae clods indicates that also this lake was completely frozen at least once within its postglacial history. This could be due to either a colder climate than that of today or a lowered lake level.

2.2.4.2 Lakes in Southern Hills

In Southern Hills, extensive sediment sampling was carried out on Figurnoe Lake, the biggest fresh-water lake in Bunger-Oasis, covering an area of 14.3 km^2 (KAUP *et al.* 1993). In addition, one location was sampled in a small, unnamed lake of 8 m altitude north of Figurnoe Lake (Fig. 2.4).

The ´8 m Lake´ in Southern Hills is located in a trough-like depression, surrounded by steep slopes with altitudes more than 40 m above the lake level (Fig. 2.2). As a consequence, the lake has a restricted catchment area and no surface water outflows; the water balance, therefore, is controlled predominantly by precipitation and evaporation. Under these conditions, it is expected that changes in sediment composition in the lake reflect regional climatic variations rather than local environmental changes such as ice movement or relative sea-level fluctuations.

Sediment coring at site PG1164 in the deepest part of the lake (12.5 m) resulted in 4.7 m recovery. The sequence consists of a gray, very stiff, poorly sorted moraine at the base, and overlaying stratified, soft, heterogeneous sediments with varying contents of multi-colored algae, brown and black mosses, gray muds, and white, possibly carbonaceous aggregates. The mosses are concentrated in thin (up to 2 cm) layers, whose distribution shows only minor variations throughout the postglacial sequence. Both the algae and the white aggregates are most frequent in the upper part of the sequence, whereas the number and thickness of the mud layers increases towards the lower part.

The ca. 15 km long, up to ca. 140 m deep Figurnoe Lake (Fig. 2.4) is subdivided morphologically in several depressions, separated by underwater ridges of only a few metres water depth. Sediment coring was carried out at seven locations, situated in the main depressions and widely distributed in the lake. Together with the cores from Transkriptii Bay and Izvilistaja Inlet (see Chapter 2.2.3.3), and some short cores recovered from Figurnoe Lake by earlier russian expeditions (e.g. VERKULICH & MELLES 1992), these samples complete a detailed profile crossing the entire Southern Hills from the Apfel Glacier in the west to the Antarctic Ice Sheet in the east.

From the macroscopic sediment description the Figurnoe Lake can be divided into two areas of characteristic sedimentary successions, probably representing different paleoenvironmental settings. The first area covers the western part of the lake, sampled at sites PG1181, PG1182, PG1183, and PG1187 (Fig. 2.4). One similarity of these locations is the occurrence of gray, stiff, poorly sorted basal moraines, which were recovered at sites PG1182 and PG1183 and probably occur also at site PG1187, where similar morainic material was found stuck to the corer wall but lost in the tube during recovery. At site PG1181, in the deepest depression (140 m), further coring was prevented by big stones; their difference in petrologies to those of the surrounding rocks also suggests a glacial transport and deposition. The overlaying postglacial sediments differ in thickness at all four sites, ranging from ca. 1 m to 6.5 m, but show considerable similarities in composition. In each case, postglacial sedimentation started with terrigeneous, well sorted, mostly stratified deposits, which pass over into predominantly biogenic sediments with different compositions of algae and moss layers.

In eastern Figurnoe Lake, close to the ice sheet edge, sediment sampling was carried out for the first time during the Bunger Oasis Expedition 1993/94. At all three sampling locations from this area (PG1186, PG1185, and PG1184; Fig. 2.4) a basal moraine was recovered. It differs in composition from those in western Figurnoe Lake, as well as from all other lakes and marine basins, by a higher sand content and a brown instead of gray color. These differences probably reflect a different source area, with an unique petrological composition of basement rock. The proximity of the sampling locations to the Antarctic Ice Sheet indicates a deposition of the moraines by a late Quaternary ice sheet advance. Their restricted range, however, argues against a north-westward expansion over the entire Bunger Oasis, as proposed by ADAMSON & COLHOUN (1992). It is more likely, therefore, that the main oasis area was covered by ice streams from a western direction. Mineralogical and geochemical investigations of the entire morainic material recovered during the expedition (see also Chapters 2.3.1. and 2.6), however, expect a much better distinguishing of ice streams and related source areas.

The postglacial sediments from eastern Figurnoe Lake differ to those from the western lake part by a predominance of terrigeneous sediment particles and a brown color. The postglacial sequence from site PG1185 is very homogeneous without distinct differences in sediment composition. In contrast, sites PG1184, about 400 m in front of the present-day ice sheet edge, and PG1185 in Apendiksi Bay show fining-upward sequences from well sorted, sandy gravels close to the basal moraine to muds at the sediment surface. These successions may represent a more or less continuous retreat of the Antarctic Ice Sheet towards the east, resulting in increasing distances of the sampling sites from the glacial sediment source.

2.3 OTHER TERRESTRIAL SEDIMENTS

Beside the marine and lacustrine sediment cores, smaller amounts of other terrestrial deposits were sampled during the expedition (Fig. 2.7, Table 2.3). This material was taken with the objective of supplementing the palaeoenvironmental reconstruction expected from the sediment core investigations.

2.3.1 Morainic deposits

From the quite complicated glaciological surroundings of the Bunger Oasis - the ice sheet to the southeast, outlet glaciers to the south, west, and east, and the ice shelf to the north (Fig. 2.7) - different source areas of the ice masses and thus of ice-rafted debris are expected. Differences in petrological compositions of the source rocks would be reflected also in the compositions of moraines deposited from ice masses during the last glacial maximum or during postglacial ice advances. Hence, from mineralogical and geochemical investigations of morainic deposits, information can be obtained concerning the sources and limits of ice advances.

In order to enlarge the sample set of moraines recovered at the bases of several marine and lacustrine sediment cores, 6 samples were taken from morainic deposits above the present-day sea level (Fig. 2.7, Table 2.3). The sampling locations are situated adjacent to the Shackleton Ice Shelf (906, 908, 910), the Apfel Glacier (922) and the Antarctic Ice Sheet (934, 935).

2.3.2 Snow petrel stomach oil (mumiyo)

Breeding colonies of snow petrels (*Pagodroma nivea*) are wide-spread all over Bunger Oasis. Predominantly for defence against skuas, the snow petrels regurgitate stomach oil, which accumulates in front of their nesting sites together with varying amounts of egg shells, feathers, bones (sometimes even complete carcasses), guano, and terrigeneous sediments. These stomach oil

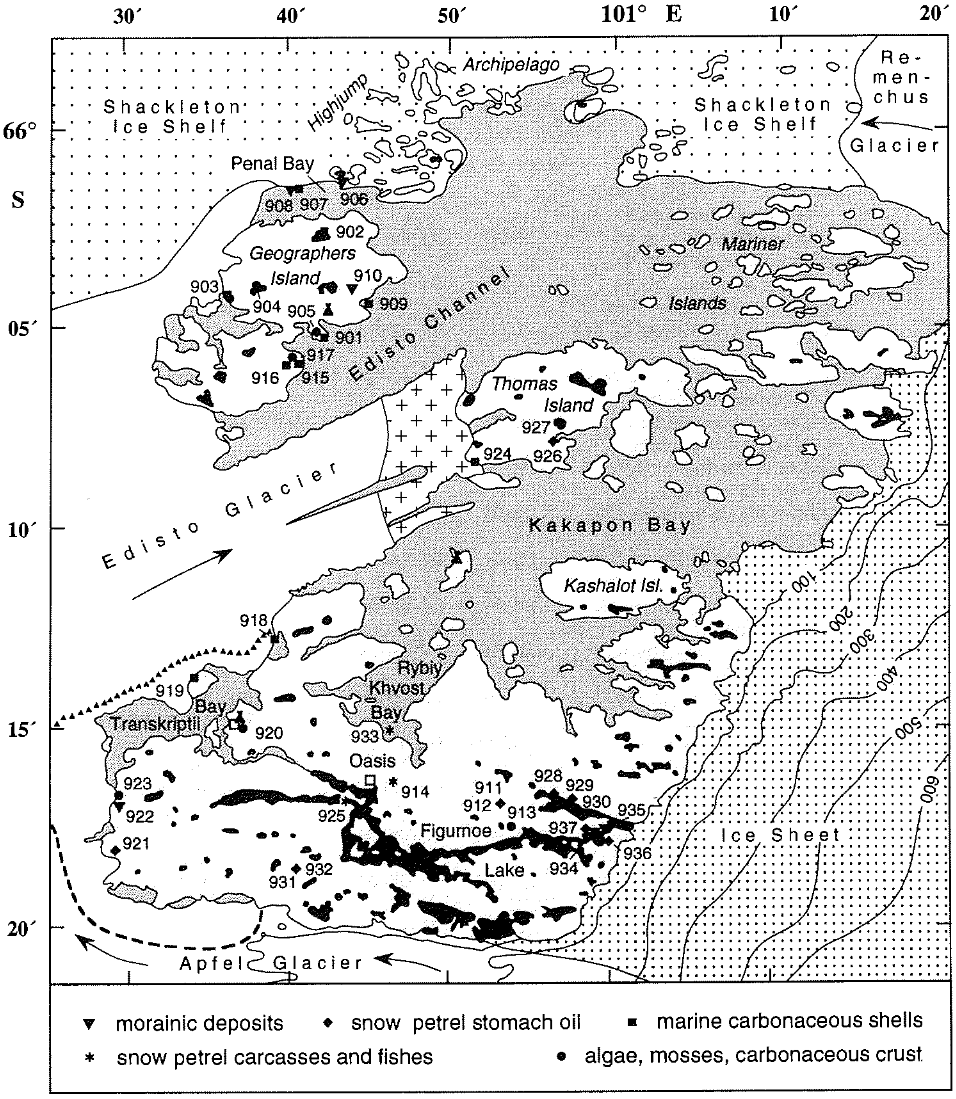


Figure 2.7: Locations of terrestrial sediment samples collected during the expedition Bunger Oasis 1993/94 in addition to the marine and lacustrine sediment cores presented in Fig. 2.3 (for additional legend see Fig. 2.1)

deposits (also called "mumiyo" in russian literature) are more or less distinctly layered and, after long settlement periods, may reach thicknesses of several decimeters.

First radiocarbon datings on snow petrel stomach oil were carried out by HILLER *et al.* (1988) on deposits from Dronning Maud Land, Antarctica. They have shown that information can be obtained concerning the time periods in which the nesting sites had been settled, and thus, during which they had been free of ice or water. The dating of the basal layers, therefore, may reveal

Table 2.3: Terrestrial sediments collected during the Bunger Oasis Expedition 1993/94 in addition to the marine and lacustrine sediment cores presented in Table 2.1

sample no. / subsample	location	altitude [m a.s.l.]	date	material
901	peninsula on southeastern Geographers Island	3	01-24-94	marine fossils (carbonaceous shells, sponge spiculae)
902 / 1	lake of altitude 17.0 m, northern Geographers Island	22-25	01-27-94	marine fossils (carbonaceous shells, sponge spiculae)
902 / 2	lake of altitude 17.0 m, northern Geographers Island	22-25	01-27-94	mosses and sponge spiculae from lake shore
903	western shore of Geographers Island	10	01-28-94	mosses and sponge spiculae
904	lake of altitude 16.0 m, central Geographers Island	16	01-28-94	living algae and mosses from lake shore
905	lake on southeastern Geographers Island	ca. 7	01-28-94	living algae from lake shore
906	moraine on northern shore of Penal Bay	ca. 3	01-29-94	clastic sediments (gravel, sand, silt, clay) from slope of ice cored moraine
907	northern shore of Penal Bay	ca. 4	01-29-94	fragments of reworked marine fossils from morainic ridge
908	northern shore of Penal Bay	ca. 4	01-29-94	clastic sediments (gravel, sand, clay) from slope of morainic ridge
909	small island in bay east of Geographers Island	ca. 8	01-30-94	marine fossils (carbonaceous shells, sponge spiculae)
910	northeastern Geographers Island	ca. 20	01-30-94	clastic sediments (sand, clay) from surface of moraine
911	110.0 m hill north of Figurnoe Lake	ca. 85-90	02-06-94	snow petrel stomach oil deposit, 2.5 - 3.0 cm thick
912	110.0 m hill north of Figurnoe Lake	ca. 85-90	02-06-94	snow petrel stomach oil deposit, surface
912 / 1	110.0 m hill north of Figurnoe Lake	ca. 85-90	02-06-94	snow petrel stomach oil deposit, 6.5 - 7.5 cm depth
913	between 110.0 m hill and north. shore of Figurnoe Lake	ca. 50-60	02-06-94	carbonaceous (?) crust between basic rocks
914	about 1 km east of station "Oasis"	ca. 25	02-06-94	wings of dead snow petrel
915	51 m hill, southeastern Geographers Island	ca. 25	01-30-94	marine carbonaceous shells
916	51 m hill, southeastern Geographers Island	ca. 42	01-30-94	marine carbonaceous shells
917	51 m hill, southeastern Geographers Island	ca. 25	01-30-94	living mosses
918	between western shore of Vertoletny Penins. and Edisto Gl.	ca. 7	01-12-94	marine carbonaceous shells (in moraine and ice core of moraine)
919	between Krainiy Island and Edisto Glacier	ca. 5	02-14-94	marine shell fragments, reworked, from morainic ridge
920	small fresh water lake at station "David Edgeworth"	ca. 3	02-12-94	living algae from lake shore
921	southwestern end of Bunger Oasis	ca. 130	02-17-94	snow petrel stomach oil deposit (not populated nest), surface
921 / 1	southwestern end of Bunger Oasis	ca. 130	02-17-94	snow petrel stomach oil deposit (not populated nest), 12.5-13 cm depth
922	southwestern end of Bunger Oasis	ca. 10	02-17-94	clay with gravel and sand from morainic ridge
923	southwestern end of Bunger Oasis	ca. 10	02-17-94	living mosses from morainic ridge
924	southwestern shore of Thomas Island	0 - 5	02-26-94	mussel shells and serpel from fresh morainic wall
925	between western shore of Figurnoe Lake and Dolgoe L.	ca. 50	02-27-94	body of dead snow petrel from a nest
926	southwestern Thomas Island	ca. 30	03-05-94	snow petrel stomach oil deposit, 2.5 - 3.5 cm depth

Table 2.3: continuation

sample no. / subsample	location	altitude [m a.s.l.]	date	material
927	southwestern Thomas Island, lake of 12.0 m altitude	12.0	03-05-94	living algae from lake shore
928	north of Apendiksi Bay, eastern Figurnoe Lake	ca. 35	03-11-94	snow petrel stomach oil deposit, 6.0 - 7.5 cm depth
929	north of Apendiksi Bay, eastern Figurnoe Lake	ca. 120	03-11-94	snow petrel stomach oil deposit, 4.5 - 6.0 cm depth
930	north of Apendiksi Bay, eastern Figurnoe Lake	ca. 120	03-11-94	snow petrel stomach oil deposit, 3.0 - 4.0 cm depth
931	between southwestern Figurnoe Lake and ice sheet	ca. 120	03-15-94	snow petrel stomach oil deposit, 11.5 - 12.5 cm depth
932	between southwestern Figurnoe Lake and ice sheet	ca. 120	03-15-94	snow petrel stomach oil deposit, 10.0 - 11.0 cm depth
933	southern Rybiy Khvost Bay	-	03-20-94	fresh fishes
934	nothern shore of eastern Figurnoe Lake	ca. 13	03-29-94	morainic deposits
935	nothern shore of eastern Figurnoe Lake	ca. 25	03-30-94	morainic deposits
936	southern shore of eastern Figurnoe Lake	ca. 75	03-30-94	snow petrel stomach oil deposit, 6.0 - 7.0 cm thick
937	south of Apendiksi Bay, eastern Figurnoe Lake	ca. 90	03-30-94	snow petrel stomach oil deposit, ca. 7.0 cm thick

information concerning minimum ages of deglaciation, marine regression, or lake-level fall. From Bunger Oasis, several snow petrel stomach oil samples were taken on earlier expeditions and dated by VERKULICH & HILLER (in press). During the summer season of 1993/94 the sample net was extended, especially in the southeastern oasis, close to the edge of the Antarctic Ice Sheet (Fig. 2.7, Table 2.3).

2.3.3 Marine carbonaceous shells

In recent years, radiocarbon datings on marine carbonaceous shells found above the present-day sea level contributed much to knowledge about the Holocene environmental evolution of the Bunger Oasis. From datings of carbonaceous shells collected from marine beaches less than 10 m a.s.l., VERKULICH (1991) and COLHOUN & ADAMSON (1991, 1992) concluded early- to mid-Holocene transgressions into the oasis. Maximum ages of Holocene advances of the Edisto Glacier were determined by ADAMSON & COLHOUN (1992) by datings of marine shells from morainic deposits.

During the 1993/94 expedition, the first marine carbonaceous shell samples were obtained from Geographers Island (Fig. 2.7, Table 2.3). The range of altitudes between 3 m and 42 m of these 5 samples suggest new information concerning the relative sea-level changes in the northernmost part of the oasis. From moraines, 4 new marine shell samples were taken, adding to the sample set from the Edisto Glacier moraines, and for the first time will probably enable datings of Apfel Glacier and Shackleton Ice Shelf advances.

2.3.4 Snow petrel carcasses and fishes

Radiocarbon datings on both snow petrel stomach oil (Chapter 2.3.2.) and marine carbonaceous shells (Chapter 2.3.3.) are influenced by the Antarctic Marine Reservoir Effect via the consumption of marine organisms and life in the marine environment, respectively. This effect results in much older radiocarbon ages of biogenic components than the real age of their production. For example, in Vestfold Oasis, about 1000 km west of Bunger Oasis, the Antarctic Marine Reservoir Effect amounts to 1300 years (ADAMSON & PICKARD 1986).

This value was used for reservoir corrections on radiocarbon ages from Bunger Oasis; however, the Antarctic Marine Reservoir Effect varies significantly within antarctic coastal waters. From datings of the organic matter in near-surface sediments, MELLES *et al.* (in press) recently estimated for Bunger Oasis a reservoir effect of more than 1000 years. In order to obtain a more accurate determination, samples were taken from two snow petrel carcasses (a wing-pair remained from a skua meal and a complete body from a collapsed nest cave) and from some fresh fish (Fig. 2.7, Table 2.3).

2.3.5 Algae, mosses and a carbonaceous crust

From Schirmacher and Untersee Oases, Dronning Maud Land, a high number of algae and moss samples was taken in summer season 1991/92 (WAND & SCHWARZ in press) and during earlier expeditions. Algae species determinations were carried out by PANKOW *et al.* (1990) and stable carbon isotope ratios ($\delta\,^{13}C$) were measured by WAND & MÜHLE (1990). In order to compare the results from different antarctic oases, some algae and moss samples were also taken from the Bunger Oases (Fig. 2.7, Table 2.3).

In addition, measurements of the stable carbon, hydrogen and nitrogen isotope ratios in the algae and moss samples shall be carried out for comparison to the respective results from the organic matter in the marine and lacustrine sediment cores. From this, a better understanding of the sources and possible transport processes of the organic material is expected. For the same objective, a carbonaceous crust was sampled (Fig. 2.7, Table 2.3).

2.4 HYDROLOGY OF LAKES AND MARINE BASINS

Investigations of the hydrological settings of lake water bodies contribute to the understanding of the present-day sediment formation, and may reveal information concerning the lake history and evolution. During the expedition Bunger Oasis 1993/94 in situ hydrological measurements were carried out as well as water samplings for hydrochemical and isotopic hydrological ana-

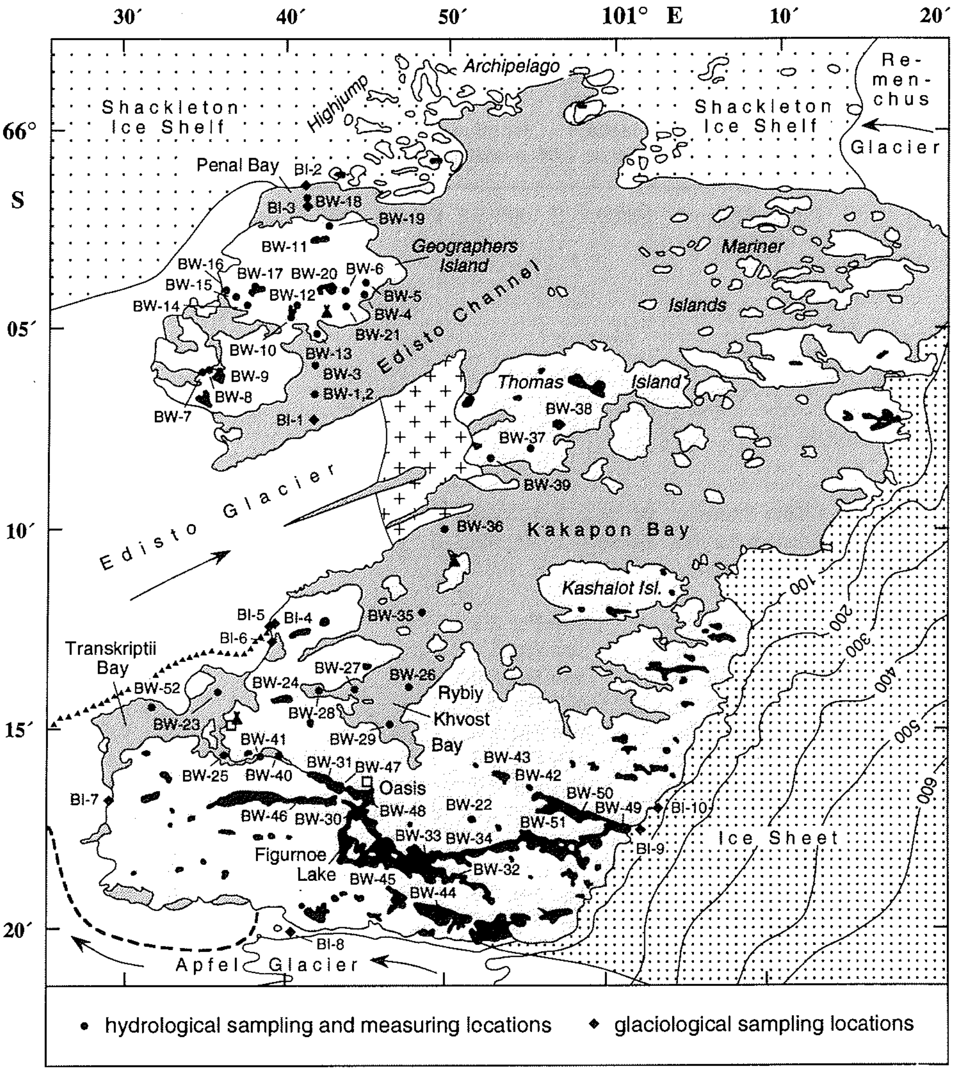


Figure 2.8: Locations of water and ice sampling and hydrological measuring sites of the expedition Bunger Oasis 1993/94 (for additional legend see Fig. 2.1)

lyses. The hydrological measuring and sampling locations are presented in Fig. 2.8 and Table 2.4)

2.4.1 Hydrological measurements

First systematic hydrological measurements on lakes and marine basins of Bunger Oasis were carried out by KAUP *et al.* (1990, 1993). One objective of the expedition in 1993/94 was to supplement the datum set, especially in the northern, hydrologically unexplored oasis area. In addition, a special interest

Table 2.4: Hydrological measurements and samplings carried out during the Bunger Oasis Expedition 1993/94 (sample volumes are 0.5 l)

hydrol. station no.	position: lake/ marine basin	position: latitude	position: longitude (where GPS available)	measurements: depth profile [m]	pH	oxyg.	sal./cond.	temp.	samples: depth [m]	samples: date of recovery
BW - 1	Edisto Channel	66°06.2′ S	100°43.3′ E	0.5 - 250.0	x	x	x	x	2.0	01-23-94
									10.0	01-23-94
									20.0	01-23-94
									30.0	01-23-94
									40.0	01-23-94
									50.0	01-23-94
									75.0	01-23-94
									100.0	01-23-94
									150.0	01-23-94
									200.0	01-23-94
									250.0	01-23-94
BW - 2	Edisto Channel	66°06.2′ S	100°43.3′ E						249.2	01-23-94
BW - 3	Edisto Channel	66°06.1′ S	100°42.2′ E	0.5 - 100.0	x	x	x	x	2.0	01-24-94
									50.0	01-24-94
									95.0	01-24-94
BW - 4	lake on Geogr. Isl.	see Fig. 2.8							0.0	01-25-94
BW - 5	lake on Geogr. Isl.	see Fig. 2.8							0.0	01-25-94
BW - 6	lake on Geogr. Isl.	see Fig. 2.8							0.0	01-25-94
BW - 7	lake on Geogr. Isl.	see Fig. 2.8							0.0	01-25-94
BW - 8	lake on Geogr. Isl.	see Fig. 2.8							0.0	01-25-94
BW - 9	lake on Geogr. Isl.	see Fig. 2.8							0.0	01-25-94
BW - 10	lake on Geogr. Isl.	see Fig. 2.8							0.0	01-25-94
BW - 11	lake on Geogr. Isl.	66°03.0′ S	100°41.7′ E	0.0 - 6.0	x	x	x	x	0.0	01-27-94
									3.2	01-27-94
									5.0	01-27-94
BW - 12	lake on Geogr. Isl.	see Fig. 2.8							0.0	01-28-94
BW - 13	lake on Geogr. Isl.	see Fig. 2.8							0.0	01-28-94
BW - 14	lake on Geogr. Isl.	see Fig. 2.8							0.0	01-28-94
BW - 15	lake on Geogr. Isl.	see Fig. 2.8							0.0	01-28-94
BW - 16	lake on Geogr. Isl.	see Fig. 2.8							0.0	01-28-94
BW - 17	lake on Geogr. Isl.	see Fig. 2.8							0.0	01-28-94
BW - 18	Penal Bay	66°02.1′ S	100°40.2′ E	0.5 - 145.0	x	x	x	x	4.0	01-29-94
									125.0	01-29-94
									145.0	01-29-94
BW - 19	lake on Geogr. Isl.	see Fig. 2.8							0.0	01-29-94
BW - 20	lake on Geogr. Isl.	see Fig. 2.8							0.0	01-30-94
BW - 21	lake on Geogr. Isl.	see Fig. 2.8							0.0	01-30-94
BW - 22	lake 8.0 m altitude	66°17.5′ S	100°51.3′ E	0.5 - 12.5	x	x	x	x	1.0	02-05-94
	(Southern Hills)								6.0	02-05-94
									12.0	02-05-94
BW - 23	Transkriptii Bay	66°14.6′ S	100°35.7′ E	1.0 - 80.0		x	x	x	3.0	02-11-94
									5.0	02-11-94
									10.0	02-11-94
									20.0	02-11-94
									30.0	02-11-94
									50.0	02-11-94
									70.0	02-11-94
									80.0	02-11-94

Table 2.4: continuation

hydrol. station no.	position: lake/ marine basin	latitude	longitude (where GPS available)	measurements: depth profile [m]	pH sal./cond. oxyg. temp.	samples: depth [m]	date of recovery
						85.0	02-11-94
						90.0	02-11-94
						100.0	02-11-94
						101.0	02-11-94
BW - 24	Polest Lake	see Fig. 2.8			x x	0.0	02-12-94
	(Southern Hills)					1.0	02-12-94
						2.0	02-12-94
						3.0	02-12-94
						4.0	02-12-94
						5.0	02-12-94
BW - 25	Izvilistaja Inlet	66°16.1′ S	100°36.3′ E	0.5 - 11.0	x x x x	2.0	02-16-94
						10.0	02-16-94
BW - 26	Rybiy Khvost Bay	66°14.3′ S	100°47.3′ E	0.5 - 100.0	x x x	0.5	02-19-94
						10.0	02-19-94
						50.0	02-19-94
						70.0	02-19-94
						90.0	02-19-94
						100.0	02-19-94
						101.7	02-19-94
BW - 27	Rybiy Khvost Bay	66°14.4′ S	100°44.3′ E	0.5 - 35.4	x x x x	3.0	02-21-94
						20.0	02-21-94
BW - 28	Rybiy Khvost Bay	66°14.3′ S	100°41.9′ E	0.5 - 17.2	x x x	3.0	02-21-94
						17.2	02-21-94
BW - 29	Rybiy Khvost Bay	66°15.2′ S	100°46.5′ E	0.5 - 91.0	x x x x	3.0	02-23-94
						10.0	02-23-94
						45.0	02-23-94
						91.0	02-23-94
						91.0	02-23-94
BW - 30	Figurnoe Lake	see Fig. 2.8				0.0	02-23-94
						7.5	02-23-94
						15.0	02-23-94
BW - 31	Figurnoe Lake	see Fig. 2.8				0.0	02-23-94
						10.0	02-23-94
						15.0	02-23-94
						30.0	02-23-94
BW - 32	Figurnoe Lake	see Fig. 2.8				0.0	02-26-94
BW - 33	Figurnoe Lake	see Fig. 2.8				0.0	02-26-94
						25.0	02-26-94
						52.0	02-26-94
BW - 34	Figurnoe Lake	see Fig. 2.8				0.0	02-26-94
BW - 35	Kakapon Bay	66°12.2′ S	100°48.4′ E	0.5 - 100.0	x x x	102.0	02-26-94
BW - 36	Kakapon Bay	66°10.2′ S	100°49.6′ E	0.5 - 288.8	x x	10.0	03-02-94
						100.0	03-02-94
						200.0	03-02-94
						288.5	03-03-94
BW - 37	lake on Thomas Isl.	see Fig. 2.8				0.0	03-05-94
BW - 38	lake on Thomas Isl.	see Fig. 2.8				0.0	03-05-94
BW - 39	lake on Thomas Isl.	see Fig. 2.8				0.0	03-05-94

Table 2.4: continuation

hydrol. station no.	position: lake/ marine basin	latitude	longitude (where GPS available)	measurements: depth profile [m]	pH	oxyg.	sal./cond.	temp.	samples: depth [m]	date of recovery
BW - 40	Izvilistaja Inlet	66°15.9´ S	100°39.3´ E	0.5 - 38.5	x		x	x	36.9	03-09-94
									1.0	03-10-94
									10.0	03-10-94
									25.0	03-10-94
									38.5	03-10-94
									36.9	03-11-94
BW - 41	Izvilistaja Inlet	see Fig. 2.8			x		x	x	0.0	03-10-94
BW - 42	Dolinnoye Lake	see Fig. 2.8			x		x	x	0.0	03-11-94
BW - 43	Dolinnoye Lake	see Fig. 2.8							0.0	03-11-94
									3.0	03-11-94
									10.0	03-11-94
									16.5	03-11-94
BW - 44	Ptichje Lake	see Fig. 2.8							0.0	03-14-94
									7.5	03-14-94
									37.0	03-14-94
BW - 45	Figurnoe Lake	66°18.6´ S	100°46.8´ E	0.5 - 140.0	x		x	x	5.0	03-13-94
									50.0	03-13-94
									100.0	03-13-94
BW - 46	Dolgoe Lake	see Fig. 2.8							0.5	03-23-94
									15.0	03-23-94
									33.5	03-23-94
BW - 47	Figurnoe Lake	see Fig. 2.8			x		x	x	0.5	03-24-94
									15.0	03-24-94
									30.5	03-24-94
BW - 48	Figurnoe Lake	see Fig. 2.8			x		x	x	0.5	03-24-94
									10.0	03-24-94
									19.5	03-24-94
BW - 49	Figurnoe Lake	66°17.7´ S	101°00.4´ E		x		x	x	1.0	03-24-94
									35.0	03-24-94
									68.8	03-24-94
BW - 50	Figurnoe Lake	see Fig. 2.8			x		x	x	0.5	03-24-94
									35.0	03-24-94
BW - 51	Figurnoe Lake	66°17.3´ S	100°57.8´ E						116.7	03-28-94
BW - 52	Transkriptii Bay	66°15.0´ S	100°31.4´ E	0.5 57.5		x	x	x	---	02-15-94

was to determine the present-day hydrological setting at the sediment coring sites, to get an impression of the hydrological influence on the surface sediment formation.

Three WTW (Wissenschaftlich-Technische Werkstätten GmbH, Weilheim) instruments were used to measure pH, oxygen content, salinity/conductivity and the temperature of the water column at all sediment coring sites and for other lakes, both freshwater and saline, in the Southern Hills. The pH electrode underwent a two-point calibration using pH 7.00 and 4.01 solutions prior to every water column measurement, and the oximeter was calibrated using the WTW supplied electrode calibration sheath. Frequent problems were encountered with calibration of the pH and oximeters. Table 2.4 indicates which measurements were performed at each location, Fig. 2.8 shows the measuring locations, and Tables 2.5 - 2.27 present the results.

Saline waters were found in the Edisto Channel (BW-1 to BW-3), Penal (BW-18), Kakapon (BW-35, BW-36), and Rybiy Khvost (BW-26 to BW-29) Bays and in Transkriptskii Bay (BW-23) below a chemocline at a depth of 88 m; these water bodies exhibited tidal behaviour. All measured lakes were freshwater, except for Lake Polest (BW24) with a salinity of 86.1 ‰ at 5 m depth. Mean conductivities of the measured freshwater lakes ranged between 62.5 and 2430 µS/cm, the former value at Lake Figurnoe's deepest point and the latter found at ´8 m Lake´, Southern Hills.

Oxidizing conditions were found throughout every horizon where oxygen was measured except at depth in Transkriptskii Bay and in the southern part of Rybiy Khvost Bay, where both waters and sediments smelled strongly of H_2S.

Mean temperatures found in the marine basins lay between -1.6 and 1.4 °C, tending to decrease with depth after an initial increase in the uppermost portion where ice formation was occurring. Freshwater bodies were between 0.7 and 5.3 °C, with similar tendencies. In two of the marine basins, a colder (ca. -1.4 °C) saline horizon was overlain by a warmer (-1.0 °C for BW-1, +0.3 °C for BW-23) freshwater layer. Also of particular interest was the shallow Lake Polest, with temperatures up to 7.5 °C at a depth of 5 m. Mean temperature values for the Lake Figurnoe profiles lay between 1.7, proximal to the ice sheet, and 3.3 °C, at the lake's deepest point.

Table 2.5: Hydrological measurements carried out on sites BW-1 and BW-2 (for location see Fig. 2.8; water depths 100.0, 150.0, and 200.0 m were measured in the bathometer immediately after recovery)

water depth [m]	oxygen [%]	oxygen [mg/l]	salinity [‰]	conductivity [µS/cm]	pH	temperature [°C]		
0.5	88	---	0.3	---	5.87	0.1	0.0	0.0
2.0	8	---	3.4	---	7.79	-1.2	-1.5	-2.0
10.0	194	---	3.4	---	8.05	-1.4	-1.5	-2.0
20.0	594	---	34.0	---	8.06	-1.5	-1.5	-2.0
30.0	465	---	34.0	---	8.07	-1.5	-1.6	-2.0
40.0	122	---	34.1	---	8.08	-1.5	-1.5	-2.0
50.0	124	---	34.1	---	8.09	-1.5	-1.5	-2.0
60.0	125	---	34.1	---	8.09	-1.5	-1.5	-2.0
75.0	108	---	34.2	---	8.09	-1.5	-1.5	-2.0
100.0	100	---	34.2	---	8.09	-1.5	-1.5	-2.0
150.0	94	---	34.1	---	8.08	-1.3	-0.8	-1.0
200.0	81	---	33.8	---	8.09	-1.1	-1.3	-1.0
250.0	84	---	34.2	---	8.02	-1.3	-1.2	-1.0

Table 2.6: Hydrological measurements carried out on site BW-3 (for location see Fig. 2.8; oximeter measurements were switched to mg/l below 15 m water depth; bottom was reached at 100 m)

water depth [m]	oxygen [%]	oxygen [mg/l]	salinity [‰]	conductivity [µS/cm]	pH	temperature [°C]		
0.5	77	---	0.4	---	6.96	0.0	0.0	1.2
1.0	83	---	0.9	---	7.36	0.0	-0.1	1.0
2.0	88	---	32.7	---	8.21	-1.5	-1.6	-1.0
3.0	120	---	32.8	---	8.25	-1.5	-1.6	-1.0
4.0	207	---	32.8	---	8.26	-1.5	-1.6	-1.0
5.0	101	---	32.8	---	8.30	-1.5	-1.6	-1.0
10.0	241	---	32.8	---	8.29	-1.5	-1.6	-1.0
15.0	362	---	32.9	---	8.29	-1.5	-1.6	-1.0
20.0	---	11.6	33.1	---	8.32	-1.5	-1.6	-1.0
30.0	---	11.1	33.1	---	8.31	-1.5	-1.6	-1.0
40.0	---	10.8	33.2	---	8.32	-1.5	-1.6	-1.0
50.0	---	10.6	33.2	---	8.31	-1.5	-1.5	-1.0
60.0	---	10.4	33.2	---	8.31	-1.5	-1.5	-1.0
70.0	---	10.3	33.2	---	8.31	-1.5	-1.5	-1.0
80.0	---	10.2	33.2	---	8.31	-1.5	-1.5	-1.0
90.0	---	10.1	33.3	---	8.31	-1.5	-1.5	-1.0
100.0	---	9.9	31.3	---	8.18	-1.5	-1.6	-1.0

Table 2.7: Hydrological measurements carried out on site BW-11 (for location see Fig. 2.8; water depth 1.5 m was remeasured after water column)

water depth [m]	oxygen [%]	oxygen [mg/l]	salinity [‰]	conductivity [µS/cm]	pH	temperature [°C]		
0.0	10	1.4	---	301	7.52	0.0	0.0	0.1
1.0	9	1.2	---	328	7.55	0.0	0.0	0.1
1.5	145	18.8	---	798	7.82	4.6	4.6	4.7
2.0	159	19.6	---	805	7.68	4.5	4.8	4.6
3.0	161	19.8	---	797	7.82	4.7	4.8	4.9
4.0	179	21.6	---	860	7.81	5.4	5.5	5.5
5.0	182	21.9	---	861	7.82	5.6	5.5	5.7
6.0	185	22.2	---	861	7.83	5.6	5.5	5.7

Table 2.8: Hydrological measurements carried out on site BW-18 (for location see Fig. 2.8)

water depth [m]	oxygen [%]	[mg/l]	salinity [‰]	conductivity [µS/cm]	pH	temperature [°C]		
0.5	---	15.9	0.2	---	6.82	0.1	0.0	0.3
1.0	---	16.2	0.2	---	6.84	0.1	0.0	0.3
2.0	---	16.1	0.2	---	6.84	0.0	0.0	0.3
3.0	---	16.1	0.3	---	6.87	0.0	0.0	0.2
4.0	---	12.9	22.0	---	8.04	-1.4	-1.6	-1.0
5.0	---	12.9	33.9	---	8.02	-1.5	-1.6	-1.0
6.0	---	13.0	33.9	---	8.03	-1.5	-1.6	-1.0
7.0	---	13.0	33.9	---	8.04	-1.5	-1.6	-1.0
8.0	---	12.9	33.9	---	8.04	-1.5	-1.6	-1.0
9.0	---	12.9	33.9	---	8.04	-1.5	-1.6	-1.0
10.0	---	12.9	33.9	---	8.05	-1.5	-1.6	-1.0
20.0	---	12.5	33.9	---	8.05	-1.5	-1.6	-1.0
30.0	---	12.4	33.9	---	8.05	-1.5	-1.6	-1.0
40.0	---	12.2	33.9	---	8.04	-1.5	-1.6	-1.0
50.0	---	12.1	33.9	---	8.04	-1.5	-1.6	-1.0
75.0	---	11.9	34.1	---	8.03	-1.5	-1.7	-2.0
100.0	---	11.8	34.0	---	8.03	-1.5	-1.6	-2.0
125.0	---	15.5	33.7	---	7.91	-1.3	-1.4	-1.0
145.0	---	13.5	33.7	---	7.98	-1.3	-1.5	-1.0

Table 2.9: Hydrological measurements carried out on site BW-22 (for location see Fig. 2.8; bottom was reached at 12.5 m)

water depth [m]	oxygen [%]	[mg/l]	salinity [‰]	conductivity [µS/cm]	pH	temperature [°C]		
0.5	110	13.4	---	2430	8.75	3.8	3.7	3.7
1.0	104	13.4	---	2430	8.75	3.8	3.7	3.7
2.0	104	13.5	---	2420	8.74	3.8	3.7	3.7
3.0	109	13.6	---	2420	8.73	3.8	3.7	3.8
4.0	108	13.4	---	2430	8.73	3.9	3.7	3.8
5.0	109	13.6	---	2430	8.73	3.8	3.7	3.8
6.0	108	13.6	---	2430	8.72	3.8	3.7	3.8
7.0	108	13.7	---	2400	8.71	3.9	3.7	3.8
8.0	108	13.7	---	2420	8.71	3.9	3.7	3.8
9.0	108	13.7	---	2420	8.70	3.9	3.7	3.8
10.0	108	13.7	---	2420	8.70	3.9	3.8	3.8
11.0	108	13.7	---	2420	8.71	3.9	3.7	3.8
12.0	108	13.7	---	2420	8.70	3.9	3.8	3.8
12.5	42	5.0	---	2950	7.52	4.4	4.5	4.3

Table 2.10: Hydrological measurements carried out on site BW-23 (for location see Fig. 2.8; data were collected by S. Maksuta, AARI)

water depth [m]	oxygen [%]	oxygen [mg/l]	salinity [‰]	conductivity [µS/cm]	pH	temperature [°C]		
1.0	---	---	0.3	---	---	0.0	---	---
2.0	---	14.1	0.3	---	---	0.0	---	---
3.0	---	14.6	0.7	---	---	1.0	---	---
4.0	---	15.0	0.7	---	---	0.2	---	---
5.0	---	15.5	0.7	---	---	0.3	---	---
7.5	---	15.8	0.7	---	---	0.3	---	---
10.0	---	16.0	0.7	---	---	0.4	---	---
15.0	---	16.1	0.7	---	---	0.4	---	---
20.0	---	16.1	0.7	---	---	0.5	---	---
25.0	---	16.2	0.7	---	---	0.6	---	---
30.0	---	16.4	0.7	---	---	0.7	---	---
40.0	---	16.4	0.9	---	---	0.3	---	---
50.0	---	16.0	1.0	---	---	0.1	---	---
60.0	---	15.8	1.0	---	---	0.0	---	---
70.0	---	15.5	1.0	---	---	0.0	---	---
80.0	---	15.0	1.2	---	---	0.0	---	---

Table 2.11: Hydrological measurements carried out on site BW-24 (for location see Fig. 2.8)

water depth [m]	oxygen [%]	oxygen [mg/l]	salinity [‰]	conductivity [µS/cm]	pH	temperature [°C]		
0.0	33.2	---	---	86600	---	-0.4	---	---
1.0	40.0	---	---	---	---	-0.3	---	---
2.0	81.2	---	---	---	---	5.7	---	---
3.0	82.5	---	---	---	---	7.0	---	---
4.0	83.1	---	---	---	---	7.3	---	---
5.0	86.1	---	---	---	---	7.5	---	---
5.5	60.0	---	---	---	---	7.3	---	---

Table 2.12: Hydrological measurements carried out on site BW-25 (for location see Fig. 2.8; pH values were measured with a KNICK in the bathometer immediately after recovery; bottom was reached at 11.0 m)

water depth [m]	oxygen [%]	oxygen [mg/l]	salinity [‰]	conductivity [µS/cm]	pH	temperature [°C]		
0.5	36	5.0	---	92	---	0.1	0.2	---
1.0	36	4.9	---	187	-	0.1	0.1	---
2.0	102	14.2	---	1970	7.48	0.7	0.6	---
3.0	106	14.6	---	1995	---	0.8	0.7	---
4.0	108	15.1	---	2000	---	0.8	0.7	---
5.0	108	15.1	---	2010	---	0.8	0.7	---
6.0	115	15.9	---	2060	---	0.6	0.6	---
7.0	119	16.4	---	2070	---	0.5	0.6	---
8.0	119	16.5	---	2080	---	0.5	0.6	---
9.0	120	16.8	---	2080	---	0.5	0.6	---
10.0	120	16.7	---	2070	8.90	0.6	0.7	---
11.0	123	17.1	---	2010	---	1.3	1.5	---

Table 2.13: Hydrological measurements carried out on site BW-26 (for location see Fig. 2.8)

water depth [m]	oxygen [%]	oxygen [mg/l]	salinity [‰]	conductivity [µS/cm]	pH	temperature [°C]		
0.5	---	20.3	20.7	---	---	0.2	---	---
1.0	---	22.0	26.2	---	---	0.3	---	---
2.0	---	25.0	30.9	---	---	0.3	---	---
3.0	---	21.1	31.4	---	---	-0.2	---	---
4.0	---	22.0	31.8	---	---	-0.4	---	---
5.0	---	21.0	32.1	---	---	-0.5	---	---
10.0	---	20.4	32.8	---	---	-0.7	---	---
15.0	---	20.9	33.3	---	---	-0.7	---	---
20.0	---	19.1	33.6	---	---	-1.0	---	---
25.0	---	19.8	33.9	---	---	-0.9	---	---
30.0	---	20.3	33.9	---	---	-0.8	---	---
40.0	---	20.0	34.0	---	---	-1.0	---	---
50.0	---	17.6	34.1	---	---	-1.2	---	---
60.0	---	13.0	34.2	---	---	-1.5	---	---
70.0	---	10.3	34.2	---	---	-1.5	---	---
80.0	---	8.0	34.2	---	---	-1.5	---	---
90.0	---	6.7	34.2	---	---	-1.5	---	---
100.0	---	4.0	34.2	---	---	-1.5	---	---

Table 2.14: Hydrological measurements carried out on site BW-27 (for location see Fig. 2.8; pH values were measured with a KNICK in the bathometer immediately after recovery)

water depth [m]	oxygen [%]	oxygen [mg/l]	salinity [‰]	conductivity [µS/cm]	pH	temperature [°C]		
0.5	---	16.7	18.0	---	---	-0.2	---	---
1.0	---	17.3	22.0	---	---	-0.6	---	---
2.0	---	17.4	31.4	---	---	0.1	---	---
3.0	---	16.2	31.7	---	8.74	0.0	---	---
4.0	---	15.9	32.0	---	---	-0.1	---	---
5.0	---	15.7	32.1	---	---	-0.2	---	---
7.5	---	15.3	32.6	---	---	-0.3	---	---
10.0	---	14.7	32.8	---	---	-0.5	---	---
15.0	---	16.4	33.6	---	---	-0.2	---	---
20.0	---	15.1	33.7	---	8.43	-0.6	---	---
25.0	---	13.8	33.9	---	---	-0.8	---	---
30.0	---	14.5	34.2	---	---	-0.8	---	---
35.4	---	8.7	34.3	---	---	-1.4	---	---

Table 2.15: Hydrological measurements carried out on site BW-28 (for location see Fig. 2.8)

water depth [m]	oxygen [%]	oxygen [mg/l]	salinity [‰]	conductivity [µS/cm]	pH	temperature [°C]		
0.5	---	15.1	8.6	---	---	-0.3	---	---
1.0	---	15.3	9.9	---	---	-0.3	---	---
2.0	---	16.9	29.2	---	---	0.1	---	---
3.0	---	16.3	29.6	---	---	0.3	---	---
4.0	---	16.3	30.1	---	---	0.2	---	---
5.0	---	15.9	30.4	---	---	0.1	---	---
7.5	---	15.1	30.6	---	---	0.0	---	---
10.0	---	15.0	31.2	---	---	0.0	---	---
12.5	---	17.0	32.5	---	---	-0.1	---	---
15.0	---	13.0	32.5	---	---	-0.8	---	---
17.2	---	10.5	32.6	---	---	-1.1	---	---

Table 2.16: Hydrological measurements carried out on site BW-29 (for location see Fig. 2.8; pH values were measured with a KNICK in the bathometer immediately after recovery)

water depth [m]	oxygen [%]	oxygen [mg/l]	salinity [‰]	conductivity [µS/cm]	pH	temperature [°C]		
0.5	---	14.3	26.0	---	---	0.1	---	---
1.0	---	15.2	27.3	---	---	0.2	---	---
2.0	---	15.8	29.1	---	---	0.3	---	---
3.0	---	15.2	30.5	---	8.75	0.3	---	---
4.0	---	15.0	30.8	---	---	0.1	---	---
5.0	---	15.1	31.0	---	---	-0.1	---	---
7.5	---	16.0	31.4	---	---	-0.2	---	---
10.0	---	15.5	31.7	---	8.66	-0.4	---	---
15.0	---	15.0	32.3	---	---	-0.8	---	---
20.0	---	14.3	32.5	---	---	-0.8	---	---
25.0	---	15.1	32.8	---	---	-0.6	---	---
30.0	---	15.1	33.0	---	---	-0.7	---	---
40.0	---	14.7	33.0	---	---	-0.8	---	---
45.0	---	---	---	---	8.63	---	---	---
50.0	---	13.0	33.2	---	---	-1.0	---	---
60.0	---	8.6	33.2	---	---	-1.5	---	---
70.0	---	6.3	33.2	---	---	-1.5	---	---
80.0	---	4.0	33.2	---	---	-1.5	---	---
90.0	---	0.0	33.2	---	---	-1.5	---	---
91.0	---	0.0	27.0	---	---	-1.5	---	---

Table 2.17: Hydrological measurements carried out on site BW-35 (for location see Fig. 2.8)

water depth [m]	oxygen [%]	oxygen [mg/l]	salinity [‰]	conductivity [µS/cm]	pH	temperature [°C]		
0.5	---	5.5	224.6	---	---	-1.2	---	---
1.0	---	9.4	26.4	---	---	-1.3	---	---
2.0	---	14.3	29.2	---	---	-0.2	---	---
3.0	---	14.9	29.5	---	---	-0.2	---	---
4.0	---	15.6	29.7	---	---	-0.4	---	---
5.0	---	15.6	29.8	---	---	-0.6	---	---
7.5	---	14.7	30.3	---	---	-1.0	---	---
10.0	---	14.2	30.4	---	---	-1.0	---	---
15.0	---	14.2	30.6	---	---	-1.2	---	---
20.0	---	13.6	30.8	---	---	-1.3	---	---
25.0	---	13.5	30.9	---	---	-1.3	---	---
30.0	---	13.3	31.0	---	---	-1.4	---	---
40.0	---	12.7	31.0	---	---	-1.4	---	---
50.0	---	12.9	31.0	---	---	-1.3	---	---
75.0	---	12.6	31.1	---	---	-1.4	---	---
100.0	---	11.6	30.9	---	---	-1.4	---	---

Table 2.18: Hydrological measurements carried out on site BW-36 (for location see Fig. 2.8; water depths 200.0 and 288.8 m were measured in the bathymeter immediately after recovery)

water depth [m]	oxygen [%]	[mg/l]	salinity [‰]	conductivity [µS/cm]	pH	temperature [°C]		
0.5	---	---	2.9	---	---	1.4	---	---
1.0	---	---	9.0	---	---	0.3	---	---
2.0	---	---	30.9	---	---	0.5	---	---
3.0	---	---	31.1	---	---	0.6	---	---
4.0	---	---	31.3	---	---	0.4	---	---
5.0	---	---	31.4	---	---	0.4	---	---
7.5	---	---	31.5	---	---	0.4	---	---
10.0	---	---	31.7	---	---	0.3	---	---
25.0	---	---	32.1	---	---	0.1	---	---
40.0	---	---	32.2	---	---	0.0	---	---
50.0	---	---	32.3	---	---	0.0	---	---
75.0	---	---	32.4	---	---	-0.1	---	---
100.0	---	---	32.5	---	---	-0.1	---	---
200.0	---	---	32.3	---	---	0.1	---	---
288.8	---	---	27.5	---	---	5.7	---	---

Table 2.19: Hydrological measurements carried out on site BW-40 (for location see Fig. 2.8; water depths 0.5, 1.0, and 2.0 m were remeasured after water column; bottom was reached at 38.5 m)

water depth [m]	oxygen [%]	[mg/l]	salinity [‰]	conductivity [µS/cm]	pH	temperature [°C]		
0.5	---	---	---	756	7.03	0.7	1.2	---
1.0	---	---	---	1239	7.37	1.0	1.5	---
2.0	---	---	---	1818	7.35	1.5	1.9	---
3.0	---	---	---	1701	7.07	2.3	3.0	---
4.0	---	---	---	1816	7.04	1.5	2.0	---
5.0	---	---	---	1796	7.11	1.7	2.3	---
7.5	---	---	---	1787	7.15	1.8	2.4	---
10.0	---	---	---	1778	7.17	2.1	2.6	---
12.5	---	---	---	1779	7.19	2.2	2.7	---
15.0	---	---	---	1757	7.21	2.6	2.9	---
20.0	---	---	---	1740	7.21	2.9	3.2	---
25.0	---	---	---	1734	7.24	3.1	3.3	---
30.0	---	---	---	1728	7.27	3.2	3.4	---
38.5	---	---	---	8450	7.30	2.6	3.3	---

Table 2.20: Hydrological measurements carried out on site BW-41 (for location see Fig. 2.8; data were collected by S. Maksuta, AARI)

water depth [m]	oxygen [%]	oxygen [mg/l]	salinity [‰]	conductivity [µS/cm]	pH	temperature [°C]		
0.5	---	---	---	310	8.03	2.1	---	---
1.0	---	---	---	302	7.99	2.5	---	---
2.0	---	---	---	293	8.02	3.1	---	---
3.0	---	---	---	292	8.08	3.2	---	---
4.0	---	---	---	292	8.10	3.2	---	---
5.0	---	---	---	292	8.00	3.3	---	---
7.5	---	---	---	291	8.11	3.3	---	---
10.0	---	---	---	291	8.11	3.3	---	---
12.5	---	---	---	291	8.11	3.4	---	---
15.0	---	---	---	290	8.11	3.4	---	---
20.0	---	---	---	290	8.09	3.4	---	---
25.0	---	---	---	289	8.07	3.6	---	---
30.0	---	---	---	288	8.09	3.7	---	---
33.3	---	---	---	287	8.10	3.7	---	---

Table 2.21: Hydrological measurements carried out on site BW-42 (for location see Fig. 2.8; data were collected by S. Maksuta, AARI)

water depth [m]	oxygen [%]	oxygen [mg/l]	salinity [‰]	conductivity [µS/cm]	pH	temperature [°C]		
0.5	---	---	0.4	---	8.74	2.3	---	---
1.0	---	---	0.5	---	8.71	2.8	---	---
2.0	---	---	0.5	---	8.66	4.3	---	---
3.0	---	---	0.5	---	8.63	5.2	---	---
4.0	---	---	0.5	---	8.62	5.4	---	---
5.0	---	---	0.5	---	8.61	5.3	---	---
7.5	---	---	0.5	---	8.61	5.3	---	---
10.0	---	---	0.5	---	8.60	5.4	---	---
12.5	---	---	0.5	---	8.59	5.5	---	---
15.0	---	---	0.5	---	8.58	5.6	---	---
20.0	---	---	0.5	---	8.57	5.8	---	---
25.0	---	---	0.5	---	8.56	6.6	---	---
30.0	---	---	0.5	---	8.53	6.5	---	---
35.0	---	---	0.5	---	8.55	6.4	---	---
38.5	---	---	0.5	---	8.55	6.4	---	---

Table 2.22: Hydrological measurements carried out on site BW-45 (for location see Fig. 2.8)

water depth [m]	oxygen [%]	oxygen [mg/l]	salinity [‰]	conductivity [µS/cm]	pH	temperature [°C]		
0.5	---	---	---	13.5	7.12	0.7	---	---
1.0	---	---	---	21.0	7.20	0.7	---	---
2.0	---	---	---	67.0	7.25	2.3	---	---
3.0	---	---	---	70.6	7.33	2.5	---	---
4.0	---	---	---	69.5	7.35	3.1	---	---
5.0	---	---	---	69.9	7.40	3.3	---	---
7.5	---	---	---	68.8	7.43	3.5	---	---
10.0	---	---	---	68.6	7.44	3.6	---	---
15.0	---	---	---	67.4	7.43	3.7	---	---
20.0	---	---	---	67.1	7.45	3.8	---	---
30.0	---	---	---	66.8	7.44	3.8	---	---
40.0	---	---	---	66.8	7.45	3.8	---	---
50.0	---	---	---	66.6	7.44	3.9	---	---
60.0	---	---	---	66.4	7.43	4.0	---	---
70.0	---	---	---	66.5	7.41	4.1	---	---
80.0	---	---	---	66.4	7.40	4.1	---	---
90.0	---	---	---	66.6	7.42	4.1	---	---
100.0	---	---	---	66.9	7.43	4.1	---	---
140.0	---	---	---	71.1	8.12	3.8	---	---

Table 2.23: Hydrological measurements carried out on site BW-47 (for location see Fig. 2.8)

water depth [m]	oxygen [%]	oxygen [mg/l]	salinity [‰]	conductivity [µS/cm]	pH	temperature [°C]		
0.5	---	---	---	89.0	7.60	2.3	---	---
1.0	---	---	---	89.0	7.60	2.5	---	---
2.0	---	---	---	86.6	7.62	2.7	---	---
3.0	---	---	---	85.8	7.61	2.7	---	---
4.0	---	---	---	84.9	7.61	2.8	---	---
5.0	---	---	---	84.5	7.61	2.7	---	---
7.5	---	---	---	84.1	7.59	2.7	---	---
10.0	---	---	---	83.7	7.59	2.7	---	---
12.5	---	---	---	83.1	7.59	2.7	---	---
15.0	---	---	---	82.6	7.59	2.7	---	---
17.5	---	---	---	82.1	7.60	2.7	---	---
20.0	---	---	---	81.8	7.60	2.8	---	---
25.0	---	---	---	81.0	7.61	3.0	---	---
30.0	---	---	---	80.0	7.65	3.2	---	---
30.5	---	---	---	116.9	6.89	3.5	---	---

Table 2.24: Hydrological measurements carried out on site BW-48 (for location see Fig. 2.8)

water depth [m]	oxygen [%]	[mg/l]	salinity [‰]	conductivity [µS/cm]	pH	temperature [°C]		
0.5	---	---	---	84.2	7.65	2.2	---	---
1.0	---	---	---	83.2	7.72	2.1	---	---
2.0	---	---	---	82.0	7.67	2.0	---	---
3.0	---	---	---	81.9	7.60	2.0	---	---
4.0	---	---	---	80.8	7.62	2.2	---	---
5.0	---	---	---	80.5	7.65	2.3	---	---
7.5	---	---	---	79.5	7.62	2.4	---	---
10.0	---	---	---	78.2	7.61	2.7	---	---
12.5	---	---	---	77.3	7.60	2.8	---	---
15.0	---	---	---	76.6	7.60	2.9	---	---
17.5	---	---	---	76.3	7.59	2.9	---	---
19.0	---	---	---	76.2	7.62	2.9	---	---
19.5	---	---	---	75.8	7.61	3.0	---	---

Table 2.25: Hydrological measurements carried out on site BW-49 (for location see Fig. 2.8; bottom was reached at 69.0 m)

water depth [m]	oxygen [%]	[mg/l]	salinity [‰]	conductivity [µS/cm]	pH	temperature [°C]		
0.5	---	---	---	75.2	7.75	1.4	---	---
1.0	---	---	---	75.6	7.74	1.6	---	---
2.0	---	---	---	76.0	7.72	1.8	---	---
3.0	---	---	---	75.7	7.73	1.8	---	---
4.0	---	---	---	75.3	7.72	1.8	---	---
5.0	---	---	---	75.0	7.69	1.8	---	---
7.5	---	---	---	74.2	7.67	1.8	---	---
10.0	---	---	---	73.7	7.64	1.8	---	---
15.0	---	---	---	72.9	7.62	1.8	---	---
20.0	---	---	---	72.1	7.59	1.9	---	---
25.0	---	---	---	71.8	7.57	1.9	---	---
30.0	---	---	---	71.6	7.55	1.9	---	---
40.0	---	---	---	71.1	7.54	2.0	---	---
50.0	---	---	---	70.9	7.54	2.0	---	---
60.0	---	---	---	72.3	7.53	1.2	---	---
69.0	---	---	---	111.1	7.45	1.1	---	---

Table 2.26: Hydrological measurements carried out on site BW-50 (for location see Fig. 2.8)

water depth [m]	oxygen [%]	oxygen [mg/l]	salinity [‰]	conductivity [µS/cm]	pH	temperature [°C]		
1.0	---	---	---	77.4	7.36	0.1	---	---
2.0	---	---	---	79.1	7.39	0.8	---	---
3.0	---	---	---	75.9	7.38	2.3	---	---
4.0	---	---	---	75.0	7.38	2.5	---	---
5.0	---	---	---	74.8	7.36	2.5	---	---
7.5	---	---	---	74.1	7.36	2.5	---	---
10.0	---	---	---	73.8	7.36	2.5	---	---
15.0	---	---	---	73.0	7.35	2.5	---	---
20.0	---	---	---	72.6	7.35	2.6	---	---
25.0	---	---	---	72.2	7.35	2.6	---	---
30.0	---	---	---	71.9	7.35	2.6	---	---
40.0	---	---	---	71.6	7.34	2.6	---	---
50.0	---	---	---	71.4	7.34	2.6	---	---
60.0	---	---	---	71.4	7.33	2.6	---	---
69.0	---	---	---	71.4	7.33	2.6	---	---

Table 2.27: Hydrological measurements carried out on site BW-52 (for location see Fig. 2.8; data were collected by S. Maksuta, AARI)

water depth [m]	oxygen [%]	oxygen [mg/l]	salinity [‰]	conductivity [µS/cm]	pH	temperature [°C]		
0.5	---	12.4	0.4	---	---	0.1	---	---
1.0	---	12.3	0.6	---	---	0.0	---	---
2.0	---	12.9	0.6	---	---	0.0	---	---
3.0	---	13.3	0.8	---	---	0.0	---	---
4.0	---	13.4	0.8	---	---	0.1	---	---
5.0	---	13.5	0.8	---	---	0.1	---	---
7.5	---	13.7	0.8	---	---	0.1	---	---
10.0	---	13.9	0.8	---	---	0.2	---	---
15.0	---	14.2	0.8	---	---	0.3	---	---
20.0	---	14.2	0.8	---	---	0.4	---	---
25.0	---	14.2	0.8	---	---	0.6	---	---
30.0	---	14.3	0.8	---	---	0.6	---	---
40.0	---	14.4	0.9	---	---	0.2	---	---
50.0	---	14.2	1.1	---	---	0.0	---	---
57.5	---	14.1	0.5	---	---	-0.1	---	---

2.4.2 Water sampling

Hydrochemical (main cations and anions) and isotopic hydrological ($\delta\ ^{2}H$, ■ ^{18}O, and $\delta\ ^{34}S$) investigations on water samples may supply information concerning the evolution and history of water bodies and may contribute to the understanding of the present-day sedimentation in lakes and marine basins (e.g. HERMICHEN *et al.* 1985, WAND *et al.* 1985, HÄNDEL & KAUP 1986, KAUP *et al.* 1990).

The water column at all study sites was sampled; in addition, samples were taken at other freshwater and saline lakes in the Southern Hills and on Geographers Island, and at points in Lake Figurnoe and Izvilistaja Inlet where no sediment cores were taken (Fig. 2.8, Table 2.4). A total of 130 samples were collected over 52 sampling points. Sampling depth in the water column was determined by the presence of horizons, and by the total depth. An UWITEC 5 l bathymeter was employed to collect 500 ml of each sample, in a pre-rinsed polyethylene bottle. Samples were kept between 0 and 7 °C during storage and transport.

2.4 GROUNDWATER HYDROLOGY

Few studies of the importance of groundwater contributions to antarctic lakes exist; however, for lakes such as ´8 m Lake´ in Southern Hills (Fig. 2.2), without either surface inflows or outflows, in environments where the potential yearly evaporation is greater than the precipitation, groundwater flow through the active layer plays a significant role in determining lake chemistry.

2.5.1 Description of study site

´8 m Lake´ (66° 17.5' S, 100° 51.3' E) is located in the southeast corner of the Bunger Oasis, at a distance of 6.3 km from the nearest edge of the Antarctic Ice Sheet and an altitude of 8 m a.s.l. The lake is oblong, running roughly east-west, and 400 m long. The surface area is approximately 4.5 x 10^{4} m^{2}, comprising 4.1 % of the total catchment area of 1.101 x 10^{6} m^{2}.

The catchment is in places covered by a layer of glacial till of greater than 1 m thickness; for the most part this till forms the active layer in the catchment, which, at the onset of sampling, was between 30 cm and 100 cm deep. Frost sorted polygons are evident in every catchment. Numerous outcrops of bedrock form the peaks and steepest slopes of the catchment. Relative to the lake surface, the highest peak within the catchment reaches an altitude of between 100 and 110 m; the lake is 12 m deep at its deepest point.

Due to a cold summer, described by one expedition member as extraordinary, snow banks lying in the windshadow afforded by slopes with a western aspect persisted throughout the summer and provided a steady source of meltwater until temperatures fell. The lake began to freeze over in the last week of

February; this ice was removed entirely by storm between March 14 and 16 and the lake was completely frozen at most 10 days later.

2.5.2 Method

The role of groundwater in the catchment hydrology was ascertained using principally minipiezometers. Constructed after LEE & CHERRY (1978), the minipiezometers are polyethylene tubes, screened over ten centimeters with Nytex™, and driven into the active layer with a piece of steel tubing, which is removed.

Properly installed, piezometers yield information concerning ground saturation, the vertical pressure gradient of groundwater and the hydraulic conductivity of the active layer sediments, as well as allowing sampling of the groundwater at depth in the active layer. The water level in minipiezometers installed in the littoral zone of the lake relative to lake level indicates the relative hydraulic pressure at the depth of the minipiezometer's screened portion. A positive relative pressure is evidence for an upward component of groundwater flow in the active layer, and the measured ´head´ or difference in water levels is an indication of the magnitude of the pressure. This pressure head is measured after flushing the piezometer tube, and allowing it to achieve equilibrium. The hydraulic conductivity of the saturated sediments can be measured using slug and bail tests (FREEZE & CHERRY 1979). Samples of groundwater are then obtained, after flushing the minipiezometer, by withdrawing water from the tube.

The catchment area was separated into 5 distinct subcatchments. In three of the subcatchments, where there was evidence of significant groundwater flow (saturated soils, surface waters, snow fields distanced from the lake), transects of snow and of surface- and groundwater sampling were established radial to the lake. The lake water column including porewater was sampled, as was the lake water in the littoral zone of each subcatchment. The bulk of the sampling was performed over a 6 day period from Feb. 2 until Feb. 7. All samples were filtered at 45 µm, collected in triple rinsed bottles and stored between 0 and 7 °C for later major ion analyses. Snowbank, fresh snow and lake samples were also taken for $\delta^{18}O$ analyses, in gastight bottles (sample list presented in Table 2.28). A floating evapometer was installed in the eastern end of the lake from which only two samples could be recovered.

2.5.3 Preliminary results

The conductivity, pH, oxygen content and temperature of ´8 m Lake´ were measured at its deepest point, yielding representative values of 2430 µS/cm, 8.72, 13.6 mg/l and 3.8 °C at 6 m depth, respectively.

Minipiezometers installed in the littoral zone of each subcatchment indicated a positive pressure at depth in the active layer, suggesting that groundwater

Table 2.28: Snow and water samples collected from 8 m Lake catchment during the Bunger Oasis Expedition 1993/94

sample no.	sample name	nature	volume anion	cation	conductivity	pH	date
100	southshore	snowmelt	x	x	-	6,6	02-01-94
101	P8	piezometer	x	x	-	7,8	02-02-94
102	P9	piezometer	x	x	-	7,6	02-02-94
103	boike bay	stream	x	x	-	7,7	02-02-94
104	P7	soilpit	x	x	-	8,6	02-03-94
105	P7	piezometer	x	x	-	9,4	02-03-94
106	P5	piezometer	x	x	x	8,3	02-03-94
107	P4	piezometer	x	x	x	7,7	02-03-94
108	P4/P5	stream	x	x	-	9,9	02-03-94
109	P6	piezometer	x	x	x	9,0	02-03-94
110	P6	stream	x	x	-	8,8	02-03-94
111	snowfield	snowmelt	x	x	-	-	02-03-94
112	westend	snowmelt	x	x	x	9,5	02-05-94
113	westend	stream	x	x	x	9,2	02-05-94
114	westend	soilpit	x	x	x	9,2	02-05-94
115	westend	surface	x	x	x	9,2	02-05-94
116	above P7	stream	x	x	x	9,0	02-05-94
117	P1	stream	x	x	x	8,2	02-05-94
118	P1	piezometer	x	x	x	7,8	02-05-94
119	P2	piezometer	x	x	x	9,3	02-05-94
119a	P3	piezometer	x	x	x	9,7	02-05-94
120	little rock	lakewater	x	x	x	9,9	02-05-94
121	P13	piezometer	x	x	x	8,9	02-05-94
122	P11	piezometer	x	x	x	9,0	02-05-94
123	P12	piezometer	x	x	x	8,4	02-05-94
124	P12	stream	x	x	x	8,2	02-05-94
125	12 m	lakewater	x	x	-	-	02-04-94
126	6 m	lakewater	x	x	-	8,8	02-04-94
127	1 m	lakewater	x	x	-	10,0	02-04-94
128	fatboy snowfield	stream	x	x	x	6,7	02-06-94
129	fatboy snowfield	snow	x	x	x	6,4	02-06-94
131	P7 snowfield	snow	x	x	x	5,9	02-07-94
132	P17	piezo	x	x	x	7,8	02-07-94
133	lake	porewater	x	x	x	7,4	02-07-94
134	at P15	lakewater	x	x	x	8,3	02-06-94
135	P15	piezometer	-	-	x	-	02-06-94
136	P16	piezometer	x	x	x	8,1	02-06-94
137	boike bay	lakewater	x	x	x	8,5	-
138	at P14	lakewater	x	x	x	8,4	-
139	at westend	lakewater	x	x	x	8,5	-
140	boike bay snow	snow	x	x	x	8,6	02-08-94
141		evapometer	x	x	-	-	02-06-94
142		evapometer	x	x	-	-	02-08-94
143	P14	piezometer	x	x	x	-	03-01-94
144	P17	piezometer	x	x	x	-	03-01-94
145	P7	soilpit	x	x	x	-	03-01-94
146	P18	piezometer	x	x	x	-	03-01-94
147		evapometer	x	x	-	-	03-01-94
148		fresh snow	x	x	x	-	03-03-94

was entering the lake through the littoral active layer. A total of 13 minipiezometers were located in the lake, 10 in the littoral zone and 3 in deeper locations. Pressure heads between -1 and +14 mm were recorded for the former. None of the deeper piezometer´s heads were measured. Further pressure head measurements were obtained from the 7 minipiezometers located in surface waters located upslope in 4 of the catchments. These values varied from -8 mm to -7.5 cm relative to the surface water. The negative values indicate areas downslope from melting snowfields where the water is entering the active layer to flow at subsurface depths into the lake or to downslope surface waters. Taken together, the set of pressure head measurements present a clear indication of active layer transport of snowfield meltwater into the lake, particularly in two subcatchments whose major snowfields lay at the catchment head and whose lakeshores were not covered by snowfields. Piezometers dried up as temperatures fell to sufficiently decrease the snowmelt.

Slug and bail tests were performed for some of the littoral zone piezometers to give some indication of the hydraulic conductivities of the saturated active layer sediments. In total, 14 tests were performed on 7 of the littoral zone piezometers.

Groundwater samples had pH values between 7.7 and 9.7 (average: 8.6 ± 0.7). Snow samples tended to be basic with an average value of 6.6.

It was noted that algae, normally found only at depths greater than 4 m, grew substantially up to the lakeshore of two of the subcatchments, where snowfields at the catchment head provided a steady source of meltwater. This, coupled with evidence for the efflux of concentrated groundwaters into the lake, may suggest that nutrient supply provided through groundwater flow plays a role in determining littoral zone algal distribution.

2.6 GLACIOLOGY

The isotopic composition ($\delta\ ^{2}H$, $\delta\ ^{18}O$) of the present-day glacier ice reveals information concerning the source areas of the ice and the average annual temperatures during the snow accumulation (e.g. HERMICHEN & KOWSKI 1988). For a better understanding of the complicated glaciological setting in the glacial surroundings of Bunger Oasis, therefore, ice samples were taken from the Edisto Glacier (BI-1, BI-5, BI-6), from the Apfel Glacier (BI-7, BI-8) and from the Antarctic Ice Sheet (BI-9; Fig. 2.8, Table 2.29).

Palaeoglaciological information can be obtained by stable isotope analyses ($\delta\ ^{2}H$, $\delta\ ^{18}O$) of ice from ice-cored moraines, which were deposited during late Quaternary ice advances (e.g. HERMICHEN *et al.* 1991). Ice-cored moraines were sampled close to the Shackleton Ice Shelf (BI-2), the Edisto Glacier (BI-4), and the Antarctic Ice Sheet (BI-10; Fig. 2.8, Table 2.29). The terrigeneous morainic material contained in these samples will later be isolated and included in the sample set of morainic deposits above the present-day sea level (see Chapter 2.3.1).

Table 2.29: Ice samples collected during the Bunger Oasis Expedition 1993/94 (for locations see Fig. 2.8

sample no.	date	volume [l]	sampled material	location
BI - 1	01-30-94	0.5	iceberg from Edisto Glacier	Edisto Channel (66°06.9´ S; 100°43.0´ E)
BI - 2	01-30-94	1.0	ice cored moraine	morainic island north of Geographers Isl.
BI - 3	01-30-94	1.5	sea ice (3.9 m thick)	Penal Bay (66°02.3´ S; 100°40.3´ E)
BI - 4	02-12-94	1.5	ice cored moraine	western Vertalotny Peninsula
BI - 5	02-12-94	1.5	Edisto Glacier (bubble-rich ice)	west of Vertalotny Peninsula
BI - 6	02-12-94	1.0	Edisto Glacier (clear ice)	west of Vertalotny Peninsula
BI - 7	02-17-94	1.0	Apfel Glacier	southwest of Transkriptii Bay
BI - 8a	03-15-94	1.5	Apfel Glacier (0.2 m depth)	south of Bunger Oasis
BI - 8b	03-15-94	1.5	Apfel Glacier (1,5 m depth)	south of Bunger Oasis
BI - 9a	03-26-94	1.0	ice sheet (0.2 m depth)	east of Figurnoe Lake
BI - 9b	03-15-94	1.0	ice sheet (1.0 m depth)	east of Figurnoe Lake
BI - 10	03-26-94	1.0	ice cored moraine	east of Figurnoe Lake

Both the glacier ice and the ice-cored moraines are sources for melt-water flows into the deglaciated Bunger Oasis. Hence, the isotopic analyses may, in addition to the hydrological and hydrochemical measurements on water samples (Chapter 2.4.2), contribute to the understanding of the isotopic composition and thus of the evolution of the lakes and marine basins.

The sample BI-3 was taken from the sea ice of Penal Bay. On this location the ice contained high amounts of terrigeneous sediment particles of probably aeolian origin. Main objectives of this sampling, therefore, are mineralogical and geochemical analyses on the clastics in order to obtain information concerning the amount and composition of the aeolian sediment supply to the marine sediments.

2.7 GEOMORPHOLOGY

Geomorphological studies had been major objectives of the soviet/russian and australian expeditions carried out within the last few years in the Bunger Oasis (BOLSHIYANOV 1990, VERKULICH 1991, ADAMSON & COLHOUN 1992). The studies supplied important information concerning the general processes and history of the relief formation in the oasis. During the expedition in 1993/94 geomorphological field work was concentrated on those areas, which were still widely unexplored (Geographers Island) or especially promising for reconstructions of the deglaciation history (Thomas Island, eastern Southern Hills, Fig. 2.2).

2.7.1 Geographers Island

As being assumed for other parts of Bunger Oasis (BOLSHIYANOV 1990), the present-day relief on Geographers Island is a result of denudation processes in dependence from the geological structures, which mainly were formed before the onset of antarctic glaciation. The northern and southeastern island is more shallow than its southeastern part, where the hills reach altitudes of up to 126 m. However, compared to most of the oasis areas, the relief on Geographers Island is relatively smooth. This is a consequence of both the structural geological features and the extensive perennial snow cover, which fills most of the depressions.

Glacial erosion and deposition played a minor role in the relief formation on Geographers Island. Although till deposits, composed of sands and muddy sands with boulders, cover almost the entire island, their thickness is mostly less than 1 m and probably does not exceed 4 m. The thickest deposits were found in the northern, southwestern and especially northwestern island parts, where they cover low rocky hills and form small morainic ridges. Because no striae on rock outcrops were found on the entire island, the only information about ice flow directions during former glaciations comes from the form and orientation of these morainic ridges. They indicate an ice advance from western directions, which is, however, in contradiction to conclusions made by ADAMSON & COLHOUN (1992).

Many fragments of probably old marine abrasion terraces were found in altitudes between ca. 15 and 40 m a.s.l. They are covered by thin till deposits. In altitudes up to about 8 m a.s.l., in contrast, more younger beaches occur on the eastern, western, and northern coasts of Geographers Island. They show a thin coverage of sorted sandy to gravelly deposits. The beaches presumably were formed during a transgression which has followed the deglaciation of the oasis (VERKULICH 1991). The location and extend of the beaches indicate more ice-free conditions than those of today.

2.7.2 Thomas Island

The western part of Thomas Island was visited only during a one-day field trip. In similarity to Geographers Island, the major relief features were formed by denudation processes in dependence from the geological structures. On southwestern Thomas Island low hills, ridges, rock outcrops, and ice-scored valleys are oriented in general from west to east. The valleys and lower slopes are covered by a till layer of mostly less than 1 m thickness, being composed of boulders in a matrix of muddy sands.

In the northwestern island part, the till coverage differs to that of the southwestern part. Its thickness probably reach more than 6 metres at some locations, which is one of the highest within the Bunger Oasis (BOLSHIYANOV 1990), and decreases rapidly towards the east. In addition, the till shows a distinctly higher content of boulders. The relief on northwestern Thomas Island is relatively smooth, altitudes reach up to 100 m. The surface microrelief exhibits small holes, lake basins, and boulder ridges, which were probably formed during deglaciation.

Thomas Island differs to Geographers Island and other areas of Bunger Oasis in the fact that most of the lakes are saline. In addition, spots and thin crusts of salt are common on the ground.

2.7.3 Southern Hills

The eastern part of Southern Hills is characterized by a low but rugget, tectonically predicted relief. Deep valleys and lake basins are incised with steep slopes into rock outcrops. Many of the depressions are ice-scored, indicating an intensive glacial erosion during the last glaciation. Glacial deposition, in contrast, was low. Till deposits, composed of a muddy and sandy matrix and a high amount of boulders, are thin and confined to the valley floors.

Several lakes in eastern Southern Hills are dammed each from another by perennial snow banks, forming a complicated system of water basins, which probably is characterized by meltwater outflow events during worm summer seasons.

At the northwestern shore of Apendiksi Bay, in the valley towards Dolinnoye Lake (Fig. 2.2), terraces are incised into the slope, representing ancient beaches. Their deposits are composed of sorted sands and gravels with low amounts of boulders. The beaches occur in altidudes of 20 to 40 m a.s.l., almost 30 metres above the present-day lake level. The occurence of a much higher lake water level of Apendiksi Bay can best be explaned by ice-damming of the bay by the Antarctic Ice Sheet, which could have separated Apendiksi Bay from Figurnoe Lake during its postglacial retreat. Similar well sorted deposits, but more strongly reworked by erosional and cryogenic processes, were found on the western shore of ´8 m Lake´ (Fig. 2.2).

2.8 ACKNOWLEDGEMENTS

We like to thank the russian expedition members Vladimir Savin (hydrologist), Alexander Maksuta (hydrologist), Oleg Klementiev (glaciologist), Alexander Mankovsky (radio operator and cook), Alexey Melnikov (physician and cook), Vladimir Hudiakov (mechanic) and Yurii Michailov (mechanic) for the pleasant atmosphere during the expedition and for their support of the field work. Special thanks to Artur Zielke for his excellent technical assistance. Some financial support was provided by the Deutsche Forschungsgemeinschaft (Grant Me 1169/2-2).

2.9 REFERENCES

ADAMSON, D.A. & PICKARD, J. (1986): Cainozoic history of the Vestfold Hills. - In: PICKARD, J. (Ed.), *Antarctic Oasis*, Academic Press, Sydney: 63-98.

ADAMSON, D. A. & COLHOUN, E.A. (1992): Late Quaternary glaciation and deglaciation of the Bunger Hills, Antarctica. - *Antarctic Science,* 4 (4): 435-446.

BIRD, M.I., CHICAS, A.R., RADNELL, C.J. & BURTON, H.R. (1991): Sedimentological and stable-isotope evolution of lakes in Vestfold Hills, Antarctica. - *Palaeogeography, Palaeoclimatology, Palaeoecology,* 84: 109-130.

BJÖRCK, S., HAKANSSON, H., ZALE, R., KARLEN, W. & JÖNSSON, B. L. (1991): A late Holocene lake sediment sequence from Livingston Island, South Shetland Islands, with paleoclimatic implications. - *Antarctic Science*, 3: 61-72.

BOLSHIYANOV, D.Y (1990): Osnovnye cherty geomorfologicheskogo stroeniya Oazisa Bangera (Vostochnaya Antarktida). [in Russian, transl.: General features of the geomorphological situation in the Bunger Oasis (East Antarctica)]. - *Information Bulletin Soviet Antarctic Expedition*, 113: 79-90, Leningrad.

BOLSHIYANOV, D.Y, VERKULICH, S.R., KLOKOV, V. & ARSLANOV, H. (1990): Radiocarbon datings of sediments from the Bunger Oasis (East Antarctica).- In: U. WAND & G. STRAUCH (Eds.), *Proc. 5th Working Meeting Isotopes in Nature*, Leipzig, Sept. 1989, 47-52, Leipzig.

BOLSHIYANOV, D.Y., VERKULICH, S.R., PUSHINA, Z. & KIRIENCO, E. (1991): Some features of the Late Pleistocene and Holocene history of the Bunger Hills (East Antarctica). - *Proc. Sixth Intern. Symp. Antarctic Earth Sciences*, Tokyo, Sept. 1991, Abstract, 66-71, Tokyo.

COLHOUN, E.A. & ADAMSON, D.D. (1989): Former glacial lakes of the Bunger Hills, Antarctica. - *Australian Geographer*, 20 (2): 125-136.

COLHOUN, E.A. & ADAMSON, D.A. (1991): Raised beaches of the Bunger Hills, Antarctica. - In: D. GILLIESON & S. FITZSIMONS (Eds.), *Quaternary Research in Antarctica: Future Directions*, Special Publication No. 3, Dept. of Geogr. and Oceanogr., Univ. Coll., Austral. Def. Force Acad., 79-83, Canberra.

COLHOUN, E.A. & ADAMSON, D.A. (1992): Raised beaches of the Bunger Hills, Antarctica. - *ANARE Reports* ,136: 45 pp.

DORAN, P.T., WHARTON Jr., R.A. & LYONS, W.B. (1994): Paleolimnology of the McMurdo Dry Valleys, Antarctica. - *Journal of Paleolimnology*, 10: 85-114.

FREEZE, R.A. & CHERRY, J.A. (1979): Groundwater. - Englewood Cliffs, N.J.: Prentice Hall, 558 pp.

HÄNDEL, D. & KAUP, E. (1986): Hydrochemische Untersuchungen im Unterseegebiet im Zentralen Wohlthatmassiv (Ostantarktika).- *Geodät. Geophys. Veröff., Reihe I*, Heft 13: 72-92.

HERMICHEN, W.-D. & KOWSKI, P. (1988): Stable isotope composition and regional climatic features - a comparative study of the East Antarctic ice sheet surface. - *ZFI-Mitteilungen*, 143: 33-53.

HERMICHEN, W.-D., KOWSKI, P., HAHNE, K. & VAIKMÄE, R. (1991): On the late Quaternary glacio-climatic history of an East Antarctic ice sheet margin: indications from ice-cored moraines in Central Queen Maud Land. - *IAHS Publication*, 208: 285-289.

HERMICHEN, W.-D., KOWSKI, P. & WAND, U. (1985): Lake Untersee, a first isotope study of the largest freshwater lake in the interior of East Antarctica. - *Nature*, 315: 131-133.

HILLER, A., WAND, U., KÄMPF, H. & STACKEBRANDT, W. (1988): Occupation of the Antarctic continent by petrels during the past 35000 years: inferences from a ^{14}C-study of stomach oil deposits. - *Polar Biology,* 9: 69-77.

KAUP, E., HÄNDEL, D. & VAIKMÄE, R. (1993): Limnological features of the saline lakes of the Bunger Hills (Wilkes Land, Antarctica). - *Antarctic Science*, 5 (1): 41-50.

KAUP, E., KLOKOV, V., VAIKMÄE, R., HÄNDEL, D. & ZIERATH, R. (1990): Hydrochemical and isotope hydrological investigations in the Bunger Oasis. - In: H.-J. PAECH & D. FRITZSCHE (Eds.), *Geod. Geophys. Veröff., Reihe C*, Heft 16: 345-360, Berlin.

KOROTKEVICH, Y.S. (1969): Oazisy. [in Russian, transl: Oases]. - In: Y. TOLSTIKOV *et al.* (Eds.), *Atlas Antarktiki, tom II [Atlas of Antarctica, Volume II]*, 563-578, Gidrometeoizdat, Leningrad.

LEE, D.R. & CHERRY, J.A. (1978): A field exercise on groundwater flow using seepage meters and mini-piezometers. - *Journal of Glaciological Education*, 27: 6-10.

MÄUSBACHER, R., MÜLLER, J., MUNNICH, M. & SCHMIDT, R. (1989): Evolution of postglacial sedimentation in Antarctic lakes (King George Island). - *Z. Geomorphologie, N.F.,* 33: 219-234.

MATTHIES, D., MÄUSBACHER, R. & STORZER, D. (1990): Deception Island tephra: a stratigraphical marker for limnic and marine sediments in Bransfield Strait area, Antarctica. - *Zentralbl. Geol. Paläontol., Teil 1*, No. 1/2: 153-165.

MELLES, M., VERKULICH, S.R. & HERMICHEN, W.-D. (in press): Radiocarbon dating of lacustrine and marine sediments from the Bunger Hills, East Antarctica. - *Antarctic Science*, 6 (3).

MELLES, M. (in press): Seesedimente. - In: H. MILLER (Ed.), Die Expedition ANTARKTIS-X mit F.S. "Polarstern", *Berichte zur Polarforschung*

MILLER, H. (in press): Die Expedition ANTARKTIS-X mit F.S. "Polarstern". - *Berichte zur Polarforschung.*

PANKOW, H., HÄNDEL, D. & RICHTER, W. (1990): The freshwater algae of the Schirmacher Oasis, Queen Maud Land. - *Geodät. Geophys. Veröff., Reihe I*, Heft 16: 459-470.

RUSIN, N.P. (1961): Meteorologichesky i radiocionny rezhim Antarktidy. [in Russian, transl.: The meteorological and radiation regime of the Antarctic].- L., Gidrometeoizdat, 447 pp.

SCHMIDT, R. MÄUSBACHER, R. & MÜLLER, J. (1990): Holocene diatom flora and stratigraphy from sediment cores of two Antarctic lakes (King George Island). - *J. Paleolimnolology*, 3: 55-90.

SIMONOV, I.M. & BONCH-OSMOLOVSKAYA, K.S. (1969): K voprosu o khimizme vod, l´da i snega oazisa Shirmakhera. [in Russian, transl.: To the question about the chemisty of water, ice and snow in Schirmacher Oasis]. - *Information Bulletin of the Soviet Antarctic Expedition*, 72: 41-48.

TATUR, A. & DEL VALLE, R. (1986): Badania paleolimnologicne i geomorfologicne na wyspie krola jerzego-Antarktyka zachodnia (1984-1986). [in Polish, transl.: Paleolimnological and geomorphological investigations on King George Island - West Antarctica]. - *Preglad Geologiczny,* 11: 621-626.

VERKULICH, S.R. (1991): Osobennosti morfologii i formirovania morkih terras na poberezhiah zalivov Oazisa Bangera (Vostochnaya Antarktida). [in Russian, transl.: The features of morphology and genesis of marine terraces on the coasts of the Bunger Oasis (East Antarctica)]. - *Information Bulletin Soviet Antarctic Expedition,* 115: 9-14, Leningrad.

VERKULICH, S.R., BOLSHIYANOV, D.Y., PUSHINA, Z.V., KIRIENKO, E.A. (1990): Nekotorye osobennosti vliyaniya morya na razvitiye oazisa Bangera (Vostochnaya Antarktida) v golotsene. [in Russian, transl.: Some features of marine influence on the Holocene evolution of the Bunger Oasis (East Antarctica)]. - In: *Okeanologicheskiye issledovaniya Yuzhnogo Okeana [Oceanologic investigations of the Southern Ocean],* 128-134. Leningrad State University, Leningrad.

VERKULICH, S.R. & HILLER, A. (in press): The Holocene deglaciation history of the Bunger Oasis derived from ^{14}C measurements on stomach oil deposits in snow petrel colonies. - *Antarctic Science.*

VERKULICH, S.R. & MELLES, M. (1992): Composition and paleoenvironmental implications of sediments in a fresh water lake and in marine basins of Bunger Hills, East Antarctica. - *Polarforschung,* 60 (3): 169-180

VOLKMAN, J.K., BURTON, H.R., EVERITT, D.A. & ALLAN, D.I. (1988): Pigment and lipid compositions of algal and bacterial communities in Ace Lake, Vestfold Hills. - *Org. Geochemistry,* 10: 671-681.

WAND, U., HERMICHEN, W.-D., PARTISCH, M. & ZIERATH, R. (1985): Hydrogeochemische Untersuchungen an Seen und Niederschlägen in der Schirmacher-Oase, Königin-Maud-Land, Ostantarktika. - *Geodät. Geophys. Veröff., Reihe I,* Heft 12: 35-56.

WAND, U. & MÜHLE, K. (1990): Extremely ^{13}C-enriched biomass in a freshwater environment: examples from Antarctic lakes. - *Geodät. Geophys. Veröff., Reihe I,* Heft 16: 361-366.

WAND, U. & SCHWARZ, G. (in press): Hydrologie/Hydrogeochemie der Seen. - In: H. MILLER (Ed.), Die Expedition ANTARKTIS-X mit F.S. "Polarstern", *Berichte zur Polarforschung.*

WHARTON jr., R.A., PARKER, B.C. & SIMMONS jr., G.M. (1983): Distribution, species composition and morphology of algal mats in Antarctic Dry Valley lakes. - *Phycologia,* 22: 355-365.