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Quaternary glaciations of South Spitsbergen and their correlation with Scandinavian glaciations of Poland

ABSTRACT: The earliest recognizable Quaternary sediments in Spitsbergen, dated by the thermoluminescence method for about 413,000 years BP and composed of marine clays, are ascribed to the Torellkjegla (=Holstein, Mazovian) Interglacial. These clays are overlain by deposits of the Wedel Jarlsberg Land glaciations (=Saalian, Middle-Polish glaciations), dated by the thermoluminescence method for 313,000 to 220,000 years BP. The maximum of the Sörkapp Land (=Weichselian, Vistulian) Glaciation in Spitsbergen was certified for about 45,000 to 40,000 years BP. An attempt of correlation of the Spitsbergen glaciations with Scandinavian glaciations in Poland indicates a distinct convergence in time of the main Quaternary climatic fluctuations in the Arctic and in Central Europe.

INTRODUCTION

A few data only have been collected up to now on the extents and the number of Quaternary glaciations in South Spitsbergen if compared with the other parts of this island (*cf.* Boulton 1979, Salvigsen 1979, Salvigsen & Nydal 1981, Salvigsen & Österholm 1982, Troitsky & *al.* 1979). These data resulted firstly from a few radiocarbon datings of the sediments in this region (*cf.* Blake & *al.* 1965, Birkenmajer & Olsson 1970, Baranowski & Karlén 1976, Mościcki & *al.* 1978, Pękala 1980) and, in major part, from the investigations focused mainly on the morphogenetic and glaciologic aspects.

The recent studies in the Hornsund area (Text-fig. 1) during the Polish Polar Expeditions in 1979 and 1980, organized by the Institute of Geophysics, Polish Academy of Sciences, have resulted in the thermoluminescence datings of some samples (Table 1), done by Dr. J. Butrym in the Thermoluminescence Laboratory (Institute of the Earth Sciences, M. Curie-Skłodowska University at Lublin) and based on the method described earlier (Butrym 1981).

The additional data for a stratigraphic recognition come also from the recent studies on the glacial sediments, glacier scour areas, and raised marine terraces in the Kulmstranda region (Kłysz & Lindner 1981c), Lisbet Valley (Kłysz & Lindner 1981b, Stankowski 1981), Slakli Valley (Kłysz & Lindner 1981a), Rev Valley and Fuglebergsletta (Karczewski & *al.* 1981a), as well as in the forefields of the Vitkovski Glacier (Andrzejewski & Stankowski 1981), Bunge Glacier (Kłysz & Lindner

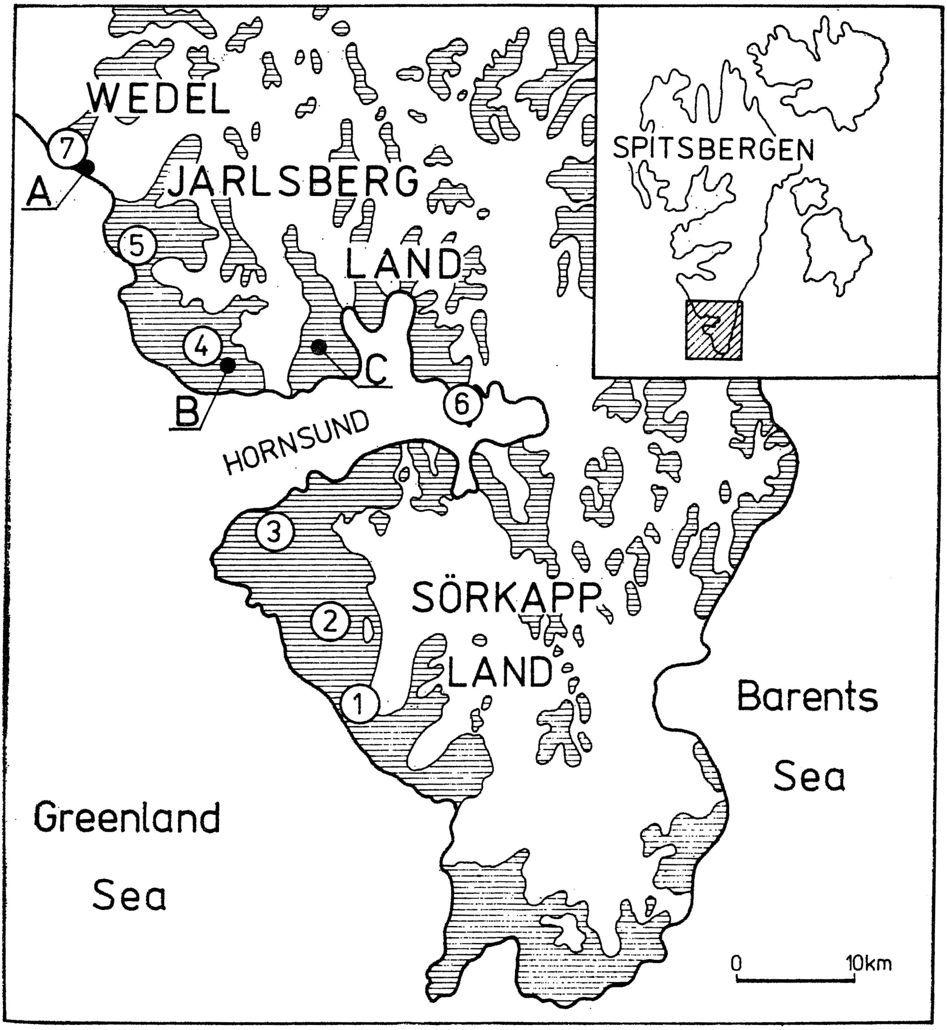

Fig. 1. Location of the investigated areas in the Hornsund region, South Spitsbergen

1 — forefield of the Bunge Glacier (*Bungebreen*) and the southern part of Breinesflya, 2 — Slakli Valley (*Slaklidalen*) area and the northern part of Breinesflya, 3 — Lisbet Valley (*Lisbetdalen*) and Kulmstranda area, 4 — Rev Valley (*Revdalen*) and Fuglebergsletta area, 5 — forefield of the Werenskiold (*Werenskioldbreen*) and Torell (*Torellbreen*) glaciers, 6 — Treskelen Peninsula (*Treskelodden*), 7 — Torellkjegla (*see* Text-fig. 3)

Sites with thermoluminescence datings: **A** — Torellkjegla, **B** — Arie Glacier (*Ariebreen*), **C** — Sofie Glacier (*Sofiebreen*)

1982, Ostaficzuk & *al.* 1982), Gås Glacier (Jania & *al.* 1981), Werenskiold Glacier (Szupryczyński 1963, Baranowski 1977), Torell Glacier (Ostaficzuk & *al.* 1980, Lindner & *al.* 1982), and in the Treskelen Peninsula (Marks 1983).

Table 1

Thermoluminescence (*TL*) datings

Location	Laboratory dating No.	Age (*TL* years)	Dated deposits
Ariebreen	*Lub-204*	45,000±4,500	till
Sofiebreen	*Lub-223*	29,500±3,500	till
Sofiebreen	*Lub-224*	43,600±5,200	till
Sofiebreen	*Lub-225*	50,000±6,000	till
Torellkjegla	*Lub-230*	413,000±62,000	marine clay
Torellkjegla	*Lub-231*	313,000±47,000	till
Torellkjegla	*Lub-232*	222,000±40,000	sand
Torellkjegla	*Lub-233*	220,000±33,000	gravel
Torellkjegla	*Lub-234*	229,000±34,000	till

In Poland, the most complete sequence of the Quaternary sediments is exposed at Bełchatów near Piotrków Trybunalski, in a brown-coal open mine (Text-fig. 2). It consists of two main series: the upper one that is not deformed and the lower, glacitectonically deformed one (Haluszczak 1982). Within the lower series, there are 5 till horizons, the three of which are ascribed to the South-Polish (=Mindel) glaciations and the remaining two to the Odranian (=Riss *I*) Glaciation. The deposits of the Middle-Polish (=Riss) glaciations are separated from those of the South-Polish glaciations by the deposits of the Buczyna interglacial lake with a fossil flora corresponding to that of the Ferdynandów site (*cf.* Lindner 1981). The upper series starts with intermorainic deposits of the Lublinian (Riss *I*/Riss *II*) Interglacial, overlain by the two tills of the Wartanian (Riss *II*) Glaciation, organogenic sediments of the Eemian Interglacial, fluvial and aeolian deposits of the Vistulian (Würm) Glaciation, and by the Holocene alluvia of the Widawka River. The sediments of the Bełchatów sequence were dated by the thermoluminescence method by Butrym & *al.* (1982).

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TORELLKJEGLA INTERGLACIAL = MAZOVIAN (HOLSTEIN, MINDEL/RISS) INTERGLACIAL

This period is represented by the earliest recognizable Quaternary sediments in Spitsbergen. They are composed of marine clays, exposed in a cliff of the eastern part of the Torellkjegla seashore (Text-figs 1 and 3). The latter is built of the glaciodislocated median moraine deposits of the Torell Glacier (*Torellbreen*). These clays (layer *1* in Text-fig. 3*A*) form the core of a fold that is overthrust westwards and overlain by a till. Thermoluminescence datings of the clays indicate their deposition about 413,000±62,000 years BP (Laboratory No. *Lub-230*). An occurrence of the marine clays under the glacial sediments suggests them to re-

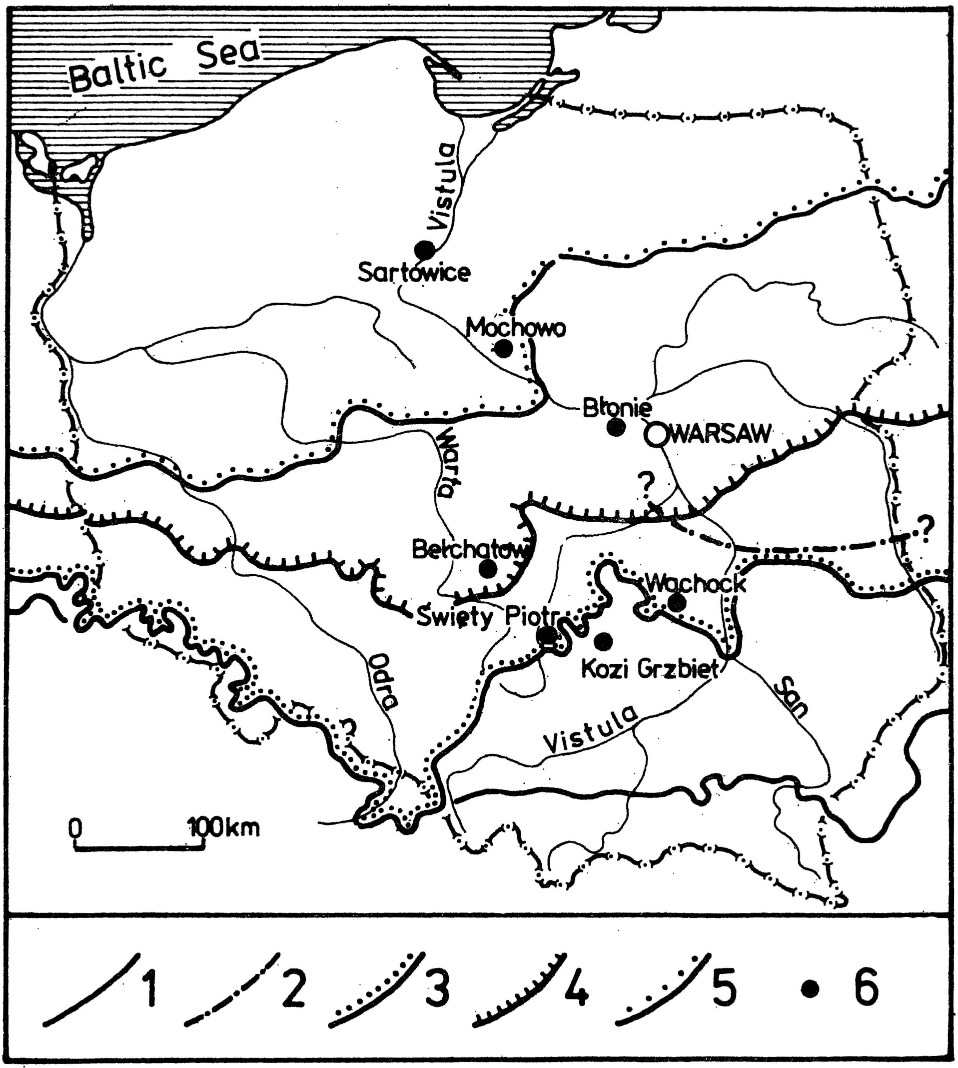


Fig. 2. Location in Poland of Quaternary sediments dated by the thermoluminescence method against the extents of Scandinavian glaciers

1 — extent of the Sanian (Mindel *II*) Glaciation, 2 — extent of the Wilgian Glaciation (*after* Mojski 1982), 3 — extent of the Odranian (Riss *I*) Glaciation, 4 — extent of the Wartanian (Riss *II*) Glaciation, 5 — extent of the Vistulian (Würm) Glaciation, 6 — sites with thermoluminescence-dated sediments (*see* Text-fig. 6)

present a time when Spitsbergen glaciers were at their recession of an interglacial rank, named herein *the Torellkjegla Interglacial*.

The presented dating indicates that the deposition of the marine clays is contemporaneous with the transgression of the Holstein (Alexandrian) Sea in Europe. The latter is to be correlated with the Likhvin Interglacial, dated by the thermoluminescence method for 459,000±56,000 to 318,000±33,000 years BP (Sudakova & Aleshinskaya 1974, Lindner 1981), and the Mazovian Interglacial with its climatic optimum placed between 456,000 and 389,700 years BP (Lindner & Grzybowski 1982), separated from the Ferdynandów climatic optimum (Janczyk-Kopikowa 1980) by the Wilga Glaciation (Mojski 1982; called *the Wilgian* in Text-fig. 5). In Central Poland this interglacial is known to yield organogenic sediments (Różycki 1964, 1972; Rühle 1973) which offer their type sections at Barkowice Mokre, Olszewice, and Krępiec (Sobolewska 1952, 1956; Marciniak 1980, Janczyk-Kopikowa 1981). The contemporaneous warming in the Black Sea basin is named the Tobechikian (Zubakov & *al.* 1982).

WEDEL JARLSBERG LAND GLACIATIONS = MIDDLE-POLISH GLACIATIONS (SAALIAN, RISS)

This period is represented by glaciodislocated, bipartite glacial deposits that overlie the interglacial marine clays in the Torellkjegla section. These sediments are composed of the two till layers (*2* and *5* in Text-fig. 3*A*), separated by an older (layers *3* and *4*) and overlain by a younger (layers *6* and *7*) sandy-gravel series. These sediments are overturned what is evidenced by their datings (Table 1 and Text-fig. 3*A*) and are overlain by gravels (layer *8*) and a till (layer *9*) of the Würm Glaciation. The overturned sediments represent two glacial episodes in Spitsbergen, lasting since about 313,000±47,000 years BP (*Lub-231*) to about 220,000±33,000 years BP (*Lub-233*), and named herein as *the Wedel Jarlsberg Land glaciations*. These are the earliest glaciations recognizable in Spitsbergen.

Consequently, the till in Central Spitsbergen (Billefjorden section), dated by the thermoluminescence method for 116,000 years BP (*Tln-TL-32*) and correlated with the Riss Glaciation (Troitsky & *al.* 1979), seems (*cf.* Różycki 1980, Wysoczański-Minkowicz 1982) to have been deposited during the earliest part of the Würm (Vistulian) Glaciation, *i.e.* the Vistula *1*. During the contemporaneous Kap Mackenzie Stadial, the Greenland glaciers were in advance (Hjort 1981).

The datings of the Wedel Jarlsberg Land glaciations enable their correlation with the Middle-Polish glaciations (Odranian, Wartanian; Text-fig. 5). A deposition of the older till in the Torellkjegla section

(313,000±47,000 years BP) corresponded to the maximum extent of the Odranian Glaciation between 352,000 and 245,000±45,000 years BP (Lindner & Prószyński 1979), to the Geroevskian 2 cooling (Zubakov & *al.* 1982), and to the Dnieper Glaciation in the Soviet Union, the latter lasting since 306,000±34,000 to 252,000±29,000 years BP (Sudakova & Aleshinskaya 1974, Lindner & Grzybowski 1982). In the Bełchatów section, the maximum of the Odranian Glaciation occurred before 264,000 years BP (Butrym & *al.* 1982).

A deposition of the younger till in the Torellkjegla secthion (229,000±±34,000 years BP) is to be correlated with the beginning of the Wartanian Glaciation (Text-fig. 5) that starts in the Bełchatów section with sub-till ice-dam sediments dated for about 183,000 years BP (Butrym & *al.* 1982). In the Soviet Union, this interval is defined as the Moscow Glaciation and lasted since about 215,000±24,000 years BP to about 152,000±16,000 years BP (Sudakova & Aleshinskaya 1974, Lindner 1981).

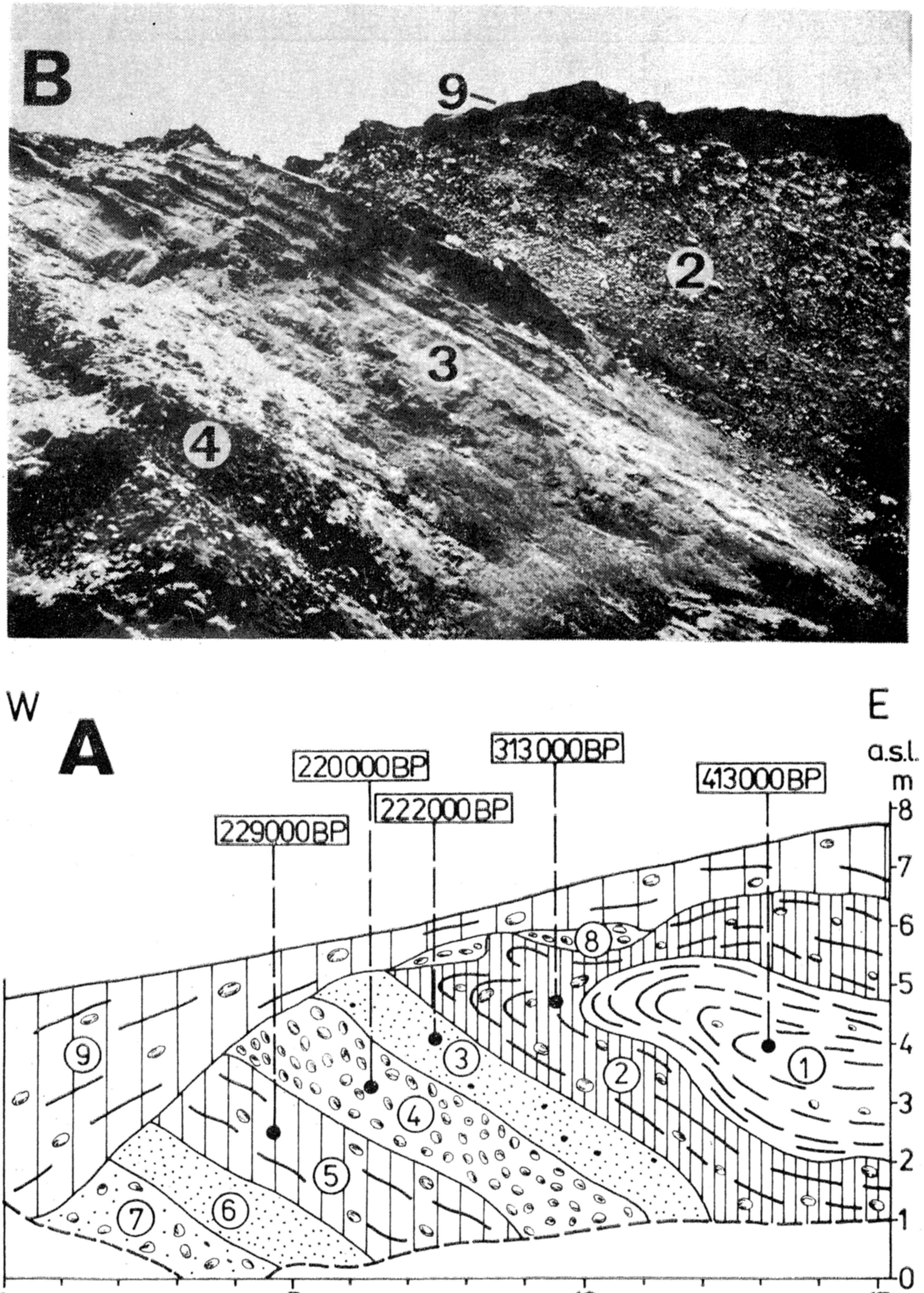
EEMIAN INTERGLACIAL

In South Spitsbergen, no sediments of the Eemian Interglacial have been noted until now. The marine sediments from the Billefjorden section dated for 70,000 years BP (*Tln-TL-21*), as well as from the Bröggerhalvöya section dated for 97,000 years BP (*Tln-TL-19*) and 83,000 years BP (*Tln-TL-13*), both considered as of the Eemian Interglacial age by Troitsky & *al.* (1979), should be related (*cf.* Różycki 1980, Wysoczański-Minkowicz 1982) to the Brörup Interstadial in Europe, and to the Hochstetter Interstadial in East Greenland (Hjort 1981). In deep-sea cores (Shackleton & Opdyke 1973), this warming is correlated with the O^{18} stage *5a* (Bowen 1978).

SÖRKAPP LAND GLACIATION = VISTULIAN (WEICHSELIAN, WÜRM) GLACIATNON

The evidence for a glaciation of South Spitsbergen in that time comes from the Hornsund area (Text-fig. 1).

In south-western Wedel Jarlsberg Land, this glaciation is evidenced by the thermoluminescence datings of the older lateral moraine of the Arie Glacier (45,000±4,500 years BP, *Lub-204*), and the oldest (50,000±±6,000 years BP, *Lub-225*; 43,600±5,200 years BP, *Lub-224*) and older (29,500±3,500 years BP, *Lub-223*) end moraines of the Sofie Glacier (Table 1, Text-fig. 1 and Pl. 1, Figs 1—2). The other data come from the paleogeomorphologic analysis of glacial landforms and sediments and their relation to marine landforms and sediments in the Revdalen-Fugle-



Torellkjegla, an exposure with the glaciodislocated deposits of a median moraine of the Torell Glacier (Torellbreen); marked are sampling sites of thermoluminescence-dated sediments by Dr. J. Butrym

A — geological section of the exposed sequence; B — close-up view of the exposure, photo taken in August 1980

TORELLKJEGLA INTERGLACIAL: 1 — marine clays; WEDEL JARLSBERG LAND GLACIATIONS: 2 — till, 3 — fine-grained and medium-grained sands, 4 — gravels, 5 — till, 6 — stratified sands, 7 — stratified gravels and coarse-grained sands; SÖRKAPP LAND GLACIATION: 8 — gravels, 9 — till

Fig. 4. Glacier extents in the Hornsund area during the Würm and the Holocene, based on the reference data (Birkenmajer 1959; Karczewski & *al.* 1981*a*; Kłysz & Lindner 1981*a*, *b*, *c*; Lindner & *al.* 1982; Marks 1983; Ostaficzuk & *al.* 1982; Norge, Topografisk Kart over Svalbard... 1948, 1953), with marked present-day system of sea currents in the adjacent part of the Greenland Sea (*after* Węsławski 1981)
1 — maximum extent of the Würm glaciers, 2 — glacier extents during the maxiumm of the Holocene glaciation (3,500—2,000 years BP), 3 — glacier extents during the maximum of the Little Ice Age, 4 — glaciers in 1980, 5 — Atlantic (West Spitsbergen) Stream, 6 — Sörkapp (East Spitsbergen) Stream, 7 — mountain massifs, 8 — present-day coastline

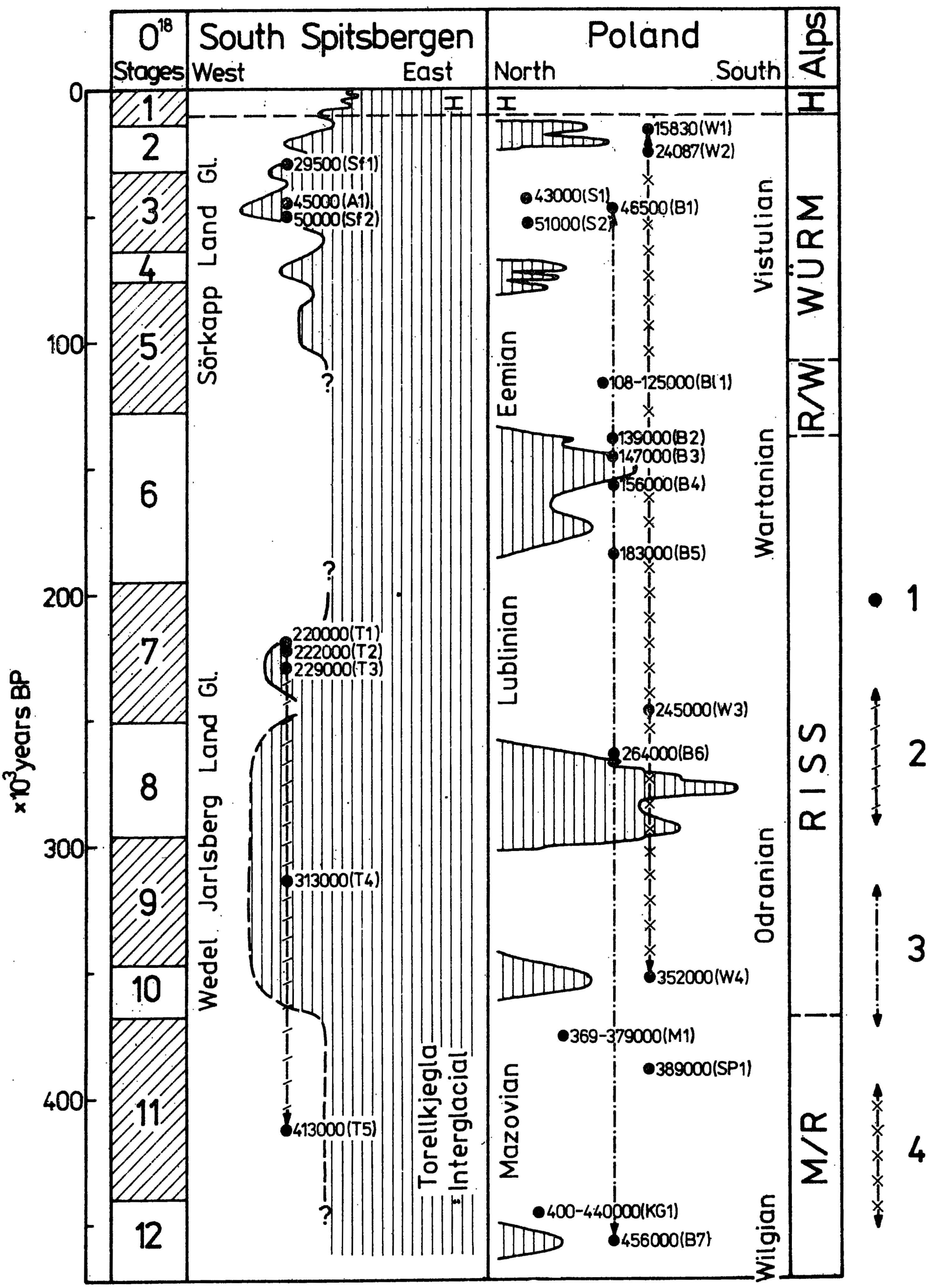


Fig. 5. Chronostratigraphic scheme of the Quaternary in South Spitsbergen and in Poland (areas vertically hachured mark the glacial episodes), refered to the O[18] stages (*after* Shackleton & Opdyke 1973) and to the glaciations in the Alps

1 — thermoluminescence dated sites (*cf.* Text-figs 1—2 and Table 1): Sf1, Sf2 — Sofie Glacier; A1 — Arie Glacier; T1, T2, T3, T4, T5 — Torellkjegla; W1, W2, W3, W4 — Wąchock (*after* Lindner & Prószyński 1979); B1, B2, B3, B4, B5, B6,

bergsletta area, the forefield of the Werenskiold and Torell glaciers, the Treskelen Peninsula, and the Torellkjegla seashore (Text-fig. 1). In the latter area, the thermoluminescence datings of the youngest till (layer 9 in Text-fig. 3A) prove a glacitectonic push of the exposed deposits at about 73,137±9,500 to 54,000±7,000 years BP. The presented datings of the oldest and older moraines situated to the north of Hornsund, as well as of the glaciodislocations support the Boulton's (1979) opinion on the maximum extent of the Würm glaciers in Spitsbergen at about 45,000 to 40,000 years BP.

In north-western Sörkapp Land, the data on the number and extents of glacier advances during the Würm were collected in southern Breinesflya (forefield of the Bunge Glacier), northern Breinesflya (Slakli Valley), and Kulmstranda (Lisbet Valley). The authors name this glaciation *the Sörkapp Land Glaciation.*

A maximum development of the glaciers during the Sörkapp Land Glaciation is marked, among others, by highly located bottoms of glacial valleys. In the Slakli Valley, the fragments of the oldest glacial valley bottoms occur (Kłysz & Lindner 1981*a*) at 182—185 m a.s.l. in its up--stream part (Pl. 3, Fig. 2), and at 140—150 m a.s.l. in its outlet. They correspond to the maximum of the Sörkapp Land Glaciation, *i.e.* the period from 45,000 to 40,000 years BP. Instead, the lower valley bottom, at 130 m a.s.l. up-stream (Pl. 3, Fig. 2) and at 95—100 m a.s.l. in the valley outlet, records probably the glacier advance about 33,000 to 25,000 years BP (Kłysz & Lindner 1981*a*). During the Middle as well as during the Late Sörkapp Land Glaciation, the glaciers filled the whole Slakli Valley and entered its foreland (northern Breinesflya) as indicated also by their ground moraine overlain in Breinesflya by gravels of the Late Würm and the Holocene marine terraces. The ground moraine of this age is also exposed in the present-day cliff of Kulmstranda, in the down--stream part of the Lisbet Valley (Kłysz & Lindner 1981*b*, *c*), and in the forefield of the Bunge Glacier (Kłysz & Lindner 1982). Almost the whole north-western Sörkapp Land was covered, therefore, by glaciers during the maximum of the Sörkapp Land Glaciation (Text-fig. 4).

During the younger part of this glaciation, a system of glacier scour limits was formed at slopes of mountain massifs north of Hornsund. They are the best preserved at about 300 m a.s.l. at the southern and eastern slopes of Fugleberget (Pl. 3, Fig. 1), at 400 m a.s.l. in the Rev Valley, and at 500 m a.s.l. in the Skålfjell Valley. These glacier scour limits are younger than the oldest and older moraines of the Arie and

B7 — Bełchatów (*after* Butrym & *al.* 1982); S1, S2 — Sartowice (*after* Drozdowski 1980); B11 — Błonie (*after* Karaszewski 1974); M1 — Mochowo (*after* Lamparski 1981); SP1 — Święty Piotr and KG1 — Kozi Grzbiet (*after* Lindner & Grzybowski 1982); 2 — Torellkjegla section; 3 — Bełchatów section; 4 — Wąchock section

Sofie glaciers and presumably mark the glacial erosion of the glaciers being in advance about 18,000 years BP (Lindner & Marks 1983).

A correlation of these three advances of the Spitsbergen glaciers during the Sörkapp Land Glaciation (about 45,000—40,000, 33,000—25,000 and 18,000 years BP) with the extents of the Scandinavian icesheets during the Vistulian Glaciation in Poland, shows certain differences (Text-fig. 5). In South Spitsbergen, the maximum of this glaciation occurred at 45,000—40,000 years BP, whereas in Poland (Kozarski 1980, Galon 1982) and German Democratic Republic (Cepek 1965) it is dated for about 20,000 years BP. This diachronism resulted probably from varying positions of cyclones in mid and high latitudes of the northern hemisphere, due to displacements of the earth magnetic poles (Bucha 1977). At first, the cyclones moved northwards over the Atlantic Ocean and when a glacial cover, and the resulting stable high-pressure area developed there, they passed further to the east and fed Scandinavia with snowfalls (*cf.* Jahn 1981, Olausson 1982).

HOLOCENE

In South Spitsbergen the traces of the Holocene first glacier advance are the best preserved in the Slakli Valley (Kłysz & Lindner 1981*a*). At a half-length of the valley, an extent of this advance is marked by an older lateral moraine (Pl. 4, Fig. 2), corresponding in the down-stream valley fragment and in northern Breinesflya to the higher extramorainal outwash. In northern Breinesflya, the sediments of this outwash are cut in the marine terrace 20—26 m a.s.l. and cover the terrace 15—18 m a.s.l. Taking into account these data as well as the known age of marine terraces in South Spitsbergen (Jahn 1959*a*, *b*; Birkenmajer 1960, Birkenmajer & Olsson 1970, Szupryczyński 1968, Karczewski & *al.* 1981*b*, Kłysz & Lindner 1981*a*, *b*, *c*; Stankowski 1981), the outwash and the lateral moraine are found to delimit the maximum glacier extent about 11,000—10,000 years BP (*cf.* Boulton 1979).

The second advance of the Holocene glaciers is, among others, recorded in the Rev Valley by a ground moraine, roches moutonnées and outwash deposits cut in the marine terraces 22—30 and 8—18 m a.s.l. (Karczewski & *al.* 1981*a*). A lower glacier scour limit formed in that time occurs at the Rev Valley slopes from 150 m a.s.l. up-stream to 60 m a.s.l. down-stream (Pl. 2, Fig. 1), at the southern and eastern slopes of Fugleberget at 120 m a.s.l. (Pl. 2, Fig. 2), and in Gangpasset at 320—330 m a.s.l. The lower ground moraine in the forefield of the Werenskiold Glacier is also of the same age (Baranowski 1977), as well as the morainic ridges up-stream the Slakli Valley (Pl. 4, Fig. 1; Kłysz & Lindner 1981*a*). The Holocene second glacier advance occurred about

3,500—2,000 years BP in South Spitsbergen (Szupryczyński 1968, Baranowski 1977, Karczewski & *al.* 1981*a*, Punning & *al.* 1982).

The third advance of the Holocene glaciers, defined as the Little Ice Age, took part during the last 600 years. In South Spitsbergen, there appear numerous and distinct traces of the maximum extent and of the retreat of these glaciers (Text-fig. 4); the latter started to retreat at the beginning of this century. The last deglaciation is to be studied especially in the intramorainal zone of the Werenskiold (Szupryczyński 1963, Baranowski 1977), Torell and Nann (Szupryczyński 1963, Karczewski & Wiśniewski 1975, 1977; Ostaficzuk & *al.* 1980, Lindner & *al.* 1982), Vitkovski (Andrzejewski & Stankowski 1981), Bunge (Kłysz & Lindner 1982, Ostaficzuk & *al.* 1982, Lindner & *al.* 1983) glaciers, in the Treskelen Peninsula (Marks 1983), and at numerous nunataks in the Wedel Jarlsberg Land (Pękala 1980). A considerably slower deglaciation rate, in comparison with the areas at the western seaside of South Spitsbergen, is noted for the inner Hornsund.

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CZWARTORZĘDOWE ZLODOWACENIA POŁUDNIOWEGO SPITSBERGENU ORAZ ICH KORELACJA ZE ZLODOWACENIAMI SKANDYNAWSKIMI W POLSCE

(Streszczenie)

W rejonie Hornsundu rozpoznano, w oparciu o datowanie metodą termoluminescencji (tabela 1), obecność najstarszych na Spitsbergenie osadów czwartorzędowych. Reprezentowane są one przez iły morskie interglacjału Torellkjegla (= Holstein, Mazovian) datowane na około 413 000 lat BP, oraz przez osady zlodowaceń Wedel Jarlsberg Land (=Saalian, zlodowacenia środkowopolskie) datowane na 313 000 — 220 000 lat BP (fig. 1 i 3). Określono wiek maksimum zlodowacenia Sörkapp Land (=Weichselian, Vistulian) na 45 000 — 40 000 lat BP oraz wyznaczono maksymalny zasięg lodowców spitsbergeńskich w tym okresie, jak również podczas zlodowaceń holoceńskich (*patrz* fig. 4 i pl. 1—4). W oparciu o stanowiska osadów datowanych metodą termoluminescencji (fig. 2 i 5) przeprowadzono korelację zlodowaceń południowego Spitsbergenu ze zlodowaceniami skandynawskimi w Polsce *.

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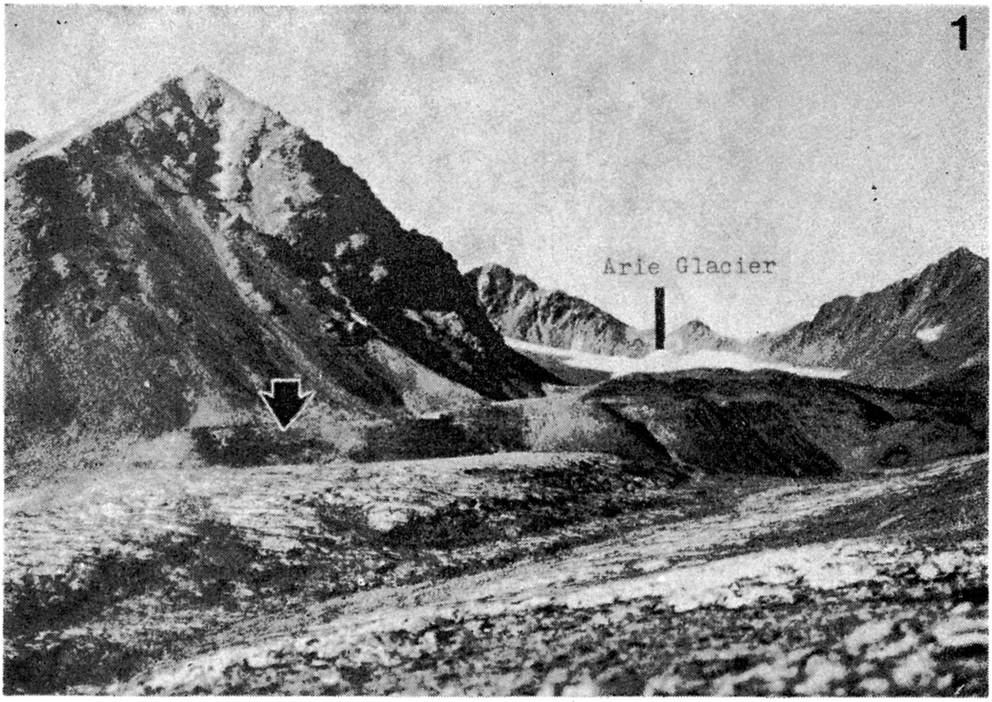
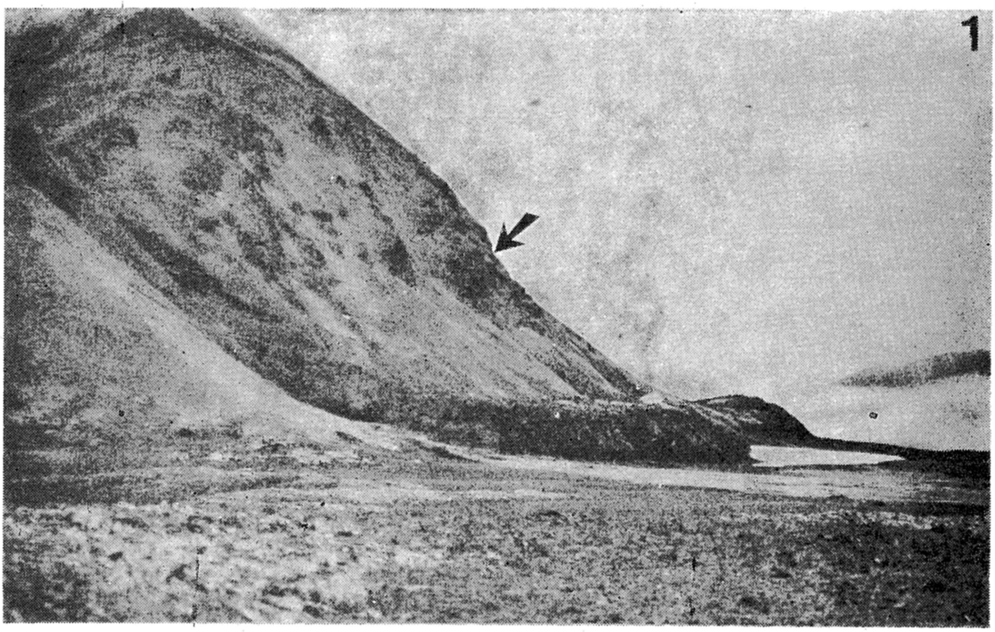
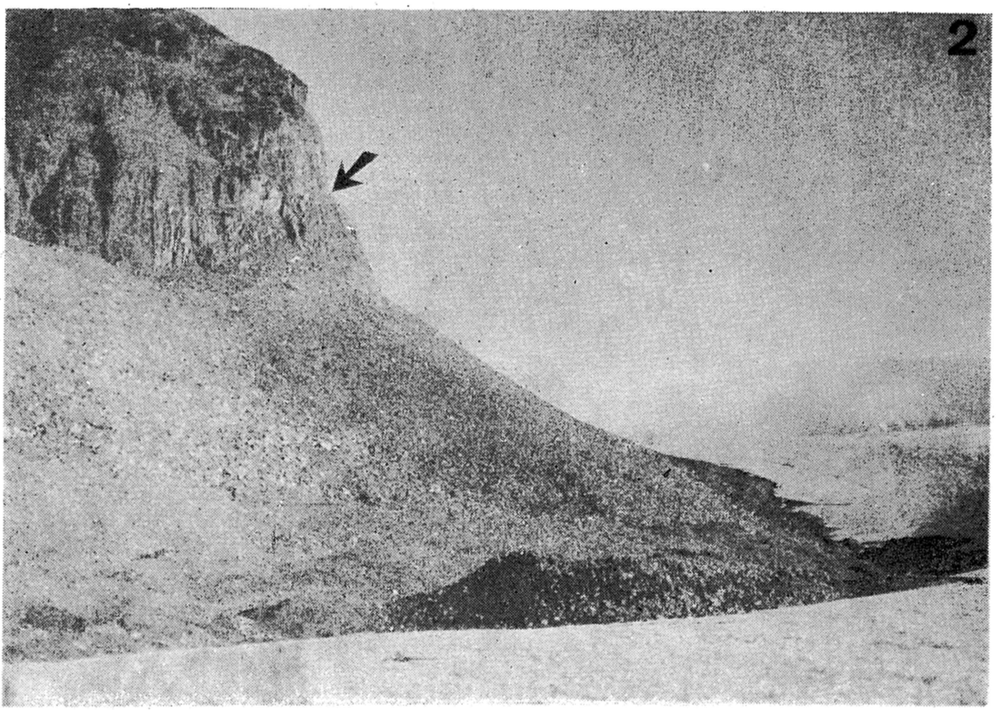
* Praca wykonana w ramach problemu międzyresortowego *MR.I.29*.



1 — Arie Valley: end moraine of the Arie Glacier, contacting by the mountain slope with an ancient lateral moraine dated by the thermoluminescence method for 45, 000±4, 500 years BP (sampling site arrowed); August 1979

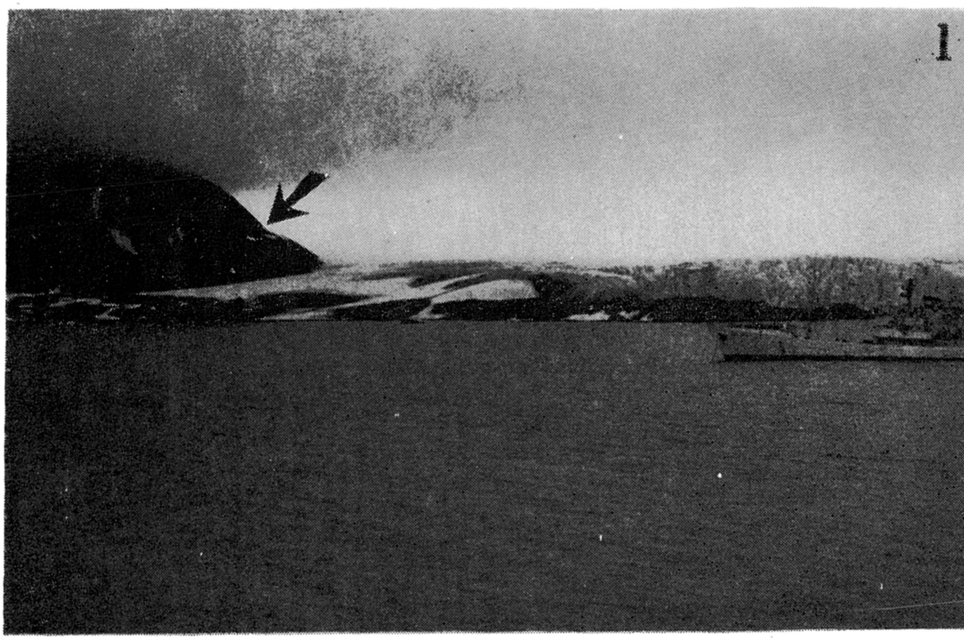
2 — Outlet of the Arie Valley: end and anccient lateral moraines of the Arie Glacier (sampling site arrowed); at the backgrounds — the Revelva mouth in Hornsund; August 1980





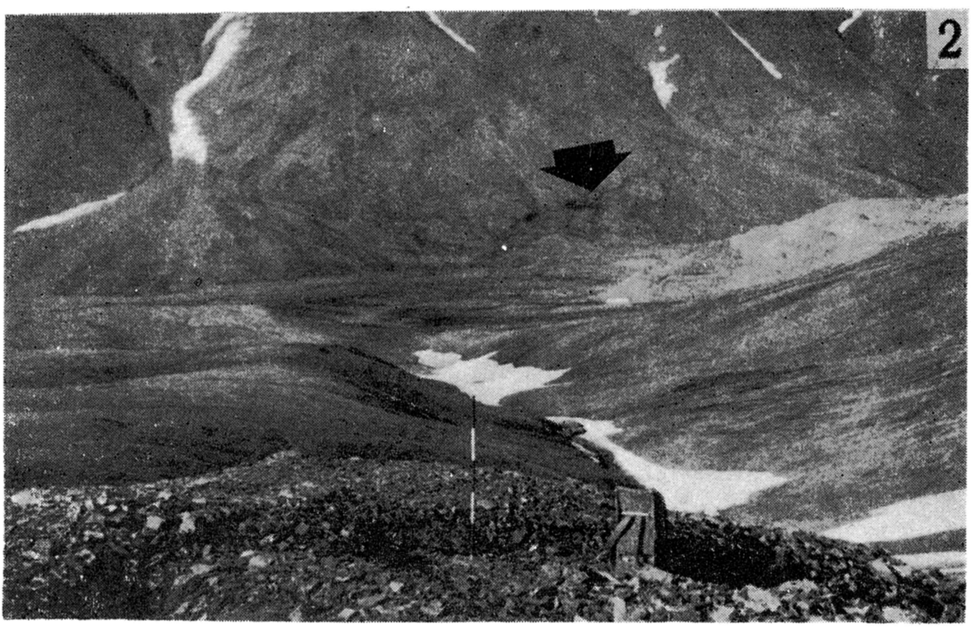
1 — Entry of the Rev Valley: a glacier scour limit (*arrowed*) formed 3,500 — 2,000 years BP at the eastern slope of Rotjesfjellet; nival moraine is visible at the foot of the latter; August 1979

2 — Eastern slope of Fugleberget by the flank of the Hans Glacier, with a distinct glacier scour limit (*arrowed*) formed 3,500 — 2,000 years BP; September 1979



1 — Ice cliff of the Hans Glacier in Hornsund and the eastern slope of Fugleberget, with a distinct glacier scour limit (*arrowed*) formed about 18,000 years BP; July 1980

2 — Fragments of ancient valley bottoms in the up-stream part of the Slakli Valley: **A** — at 182—185 m a.s.l., **B** — at 130 m a.s.l.; July 1980



1 — Fragments of lateral moraines (*arrowed*) in the up-stream part of the Slakli Valley formed 3,500 — 2,000 years BP; July 1980

2 — Ancient lateral moraine (*arrowed*) at the northern slope of the Slakli Valley formed 11,000 — 10,000 years BP; July 1980