Eiszeitalter u. Gegenwart	45	1 — 14 12 fig., 2 tab.	Hannover 1995

Lithostratigraphical studies in the outcrop at Ujście, Toruń-Eberswalde Pradolina, western Poland

MARGOT BÖSE & MARIA GÓRSKA*)

Pleistocene, Weichselian, Saalian, fabric measurement, petrographic analysis, indicator boulder counting, ice flow directions, Toruń-Eberswalde Pradolina, western Poland

Abstract: The outcrop at Ujście is situated at the southern margin of the Toruń-Eberswalde Pradolina, between the Poznań and Pomeranian Phases. Four till beds interbedded with fluvioglacial sands form the approx. 50 m thick sequence. In addition to till fabric measurements, granulometric analyses and the determination of calcium carbonate content, priority has been given to petrographic analysis of the gravel content of the tills in the 4 - 12.5 mm fraction and to indicator boulder counting; both methods will clarify ice flow directions in the continental ice sheet.
The uppermost till (Chodzież subphase) contains a very strong east Baltic group of indicator boulders with Åland granite and many Palaeozoic limestones as well as a relatively great number of Devonian dolomites. In comparison with the uppermost till, the second, Leszno-Poznań till contains less material of east Baltic origin and fewer Palaeozoic limestones. The increasing amount of flint points to a more western provenance. The third till is of Saalian age and its composition, including numerous dolomites, points again to an east Baltic source area, which is typical for tills of the Warthanian phase. The petrographical group of the lowest till represents a northerly provenance, containing material from Dalarna and Småland. This till is probably of Saalian age, too, but an Elsterian age cannot be excluded completely.

[Lithostratigraphische Untersuchungen in dem Aufschluß bei Usch, Thorn-Eberswalder Urstromtal, West-Polen]

Kurzfassung: Der Aufschluß in Usch liegt am Südrand des Thorn-Eberswalder Urstromtales zwischen der Frankfurter Staffel und dem Pommerschen Stadium. Die rund 50 m mächtige Sedimentfolge wird aus vier Geschiebemergelbänken mit zwischengeschalteten glazifluvialen Sanden gebildet. Neben Geschiebeeinregelungsmessungen, granulometrischen Analysen und der Bestimmung des Karbonatgehaltes liegt der Schwerpunkt der Untersuchungen in den petrographischen Analysen der Kiesanteile der Geschiebemergel in der Fraktion 4 - 12,5 mm und in der Leitgeschiebebestimmung. Beide Methoden geben Erkenntnisse über Eisfließrichtungen im Inlandeis.
Der oberste Geschiebemergel (Kolmarer Staffel) enthält viel ostbaltisches Material mit Åland-Graniten, vielen paläozoischen Kalksteinen und relativ vielen devonischen Dolomiten. Der zweite Gechiebemergel (Brandenburger-Frankfurter Stadium) enthält im Vergleich dazu weniger ostbaltisches Material und weniger paläozoische Kalke, dagegen nimmt der Feuerstein-Anteil etwas zu, was ebenfalls auf ein weiter westlich gelegenes Herkunftsgebiet hinweist. Der dritte Geschiebemergel hat saalezeitliches Alter; die zahlreichen Dolomite sowie die sonstige Geschiebezusammensetzung weisen wieder auf ein ostbaltisches Herkunftsgebiet hin, das typisch für warthezeitliche Glazialablagerungen ist. Der unterste Geschiebemergel mit Geschieben aus Dalarna und Småland läßt auf einen Eistransport aus Norden schließen. Diese Moräne ist wahrscheinlich ebenfalls saalezeitlich, ein elsterzeitliches Alter kann jedoch nicht völlig ausgeschlossen werden.

*) Anschriften der Verfasser: Prof. Dr. MARGOT BÖSE, Freie Universität Berlin, Institut für Geographische Wissenschaften, Physische Geographie, Grunewaldstr. 35, D-12165 Berlin. Mgr MARIA GÓRSKA, A. Mickiewicz University, Quaternary Research Institute, Department of Geomorphology, Science Centre PAS, Wieniawskiego 17/19, 61-712 Poznań, Poland.

1 Introduction

The investigated outcrop is situated in western Poland, at the southern margin of the Toruń-Eberswalde Pradolina (Fig. 1). The Pradolina consists of three (KRYGOWSKI 1961) or four (KOZARSKI 1962) parts among which the Ujście Basin and the Czarnków part are the central area of this huge ice marginal spillway in the young morainic area (Fig. 2). The morphology of the study area has already attracted the attention of KEILHACK (1897; 1898); MAAS (1904); KORN (1917) and WOLDSTEDT (1932), especially as there are two different ice marginal positions at the southern fringe of this part of the Pradolina, the Czarnków (Scharnikau) and the Chodzież (Kolmar) subphases. Both are younger than the Poznań (Frankfurt) phase and older than the Pomeranian stage. WOLDSTEDT (1932) has attributed the onset of the Pradolina formation to the Chodzież subphase, dated to 17.200 BP by KOZARSKI (1986), when the meltwaters eroded a depression in the hinterland of the Czarnków end moraines. Starting at the latest in the Pomeranian phase, dated to 15.200 BP by KO-

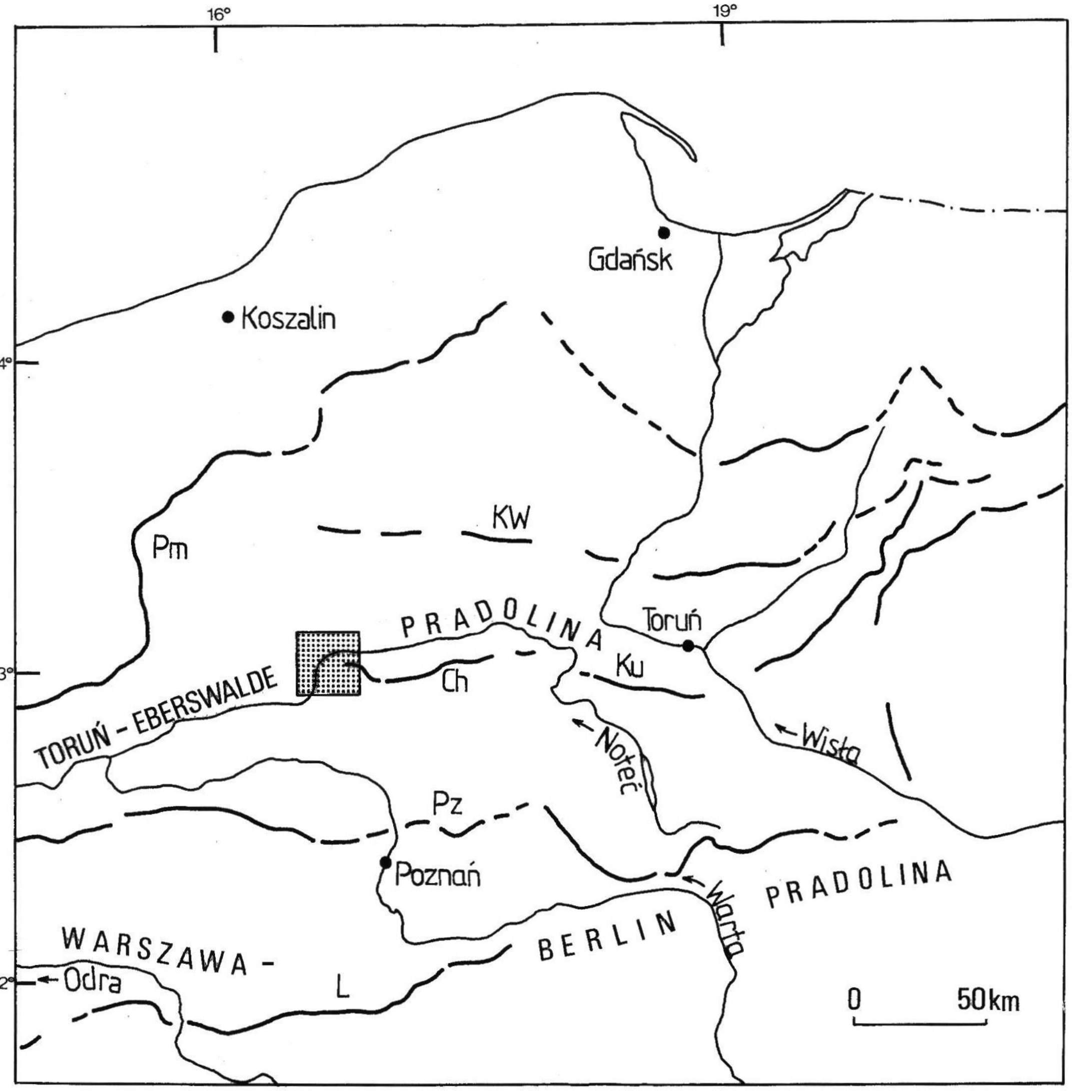

Fig. 1: Location of the study area and the main Weichselian ice margin position in NW Poland (based on NIEWIAROWSKI & WYSOTA 1994). - Pm - Pomeranian Phase, KW - Krajna-Wąbrzeźno Phase, Ch - Chodzież Subphase, Ku - Kujavian Subphase, Pz - Poznań Phase, L - Leszno Phase.

Abb. 1: Lage des Untersuchungsgebietes und der Haupteisrandlagen in Nordwest-Polen (nach: NIEWIAROWSKI & WYSOTA 1994). Pm - Pommersches Stadium, KW - Krajna-Staffel, Ch - Kolmarer Staffel, Ku - Kujawische Staffel, Pz - Frankfurter (Posener) Stadium, L - Brandenburger (Lissaer) Stadium.

ZARSKI (1986), the meltwaters followed a continuous Pradolina from Toruń to Eberswalde (cf. Fig. 1). Lateral erosion and accumulation phases have left three terraces of Late Pleniglacial and Late Glacial ages. The uppermost terrace is considered by KOZARSKI (1962) to be part of a former outwash plain that has been dissected later. The flood plain is covered by Holocene organic sediments (cf. Fig. 2).

The most recent investigations in this area were conducted in the outcrop west of Ujście and are related to the lithostratigraphy and kinetostratigraphy of the Weichselian tills (KOZARSKI & NOWACZYK 1985; KASPRZAK & KOZARSKI 1985; KOZARSKI 1991). The analyses of direction elements in sediments of the Chodzież subphase and underlying fluvioglacial material indicate the transgressive character of this ice advance (KASPRZAK & KOZARSKI 1985).

2 The outcrop

The outcrop at the southern bank of the Noteć (Netze) is situated almost opposite the mouth of the tributary river Gwda (Küddow) and the Noteć is forced

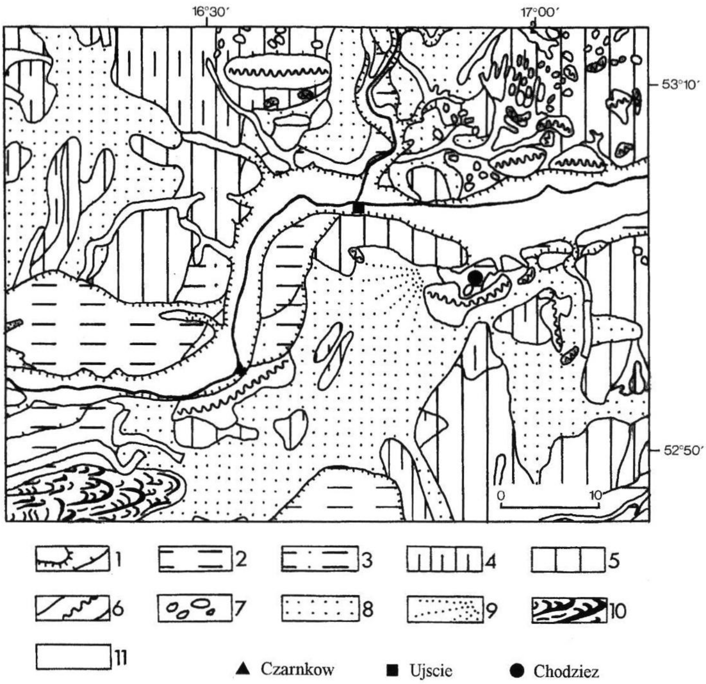

Fig. 2: Geomorphology of the surrounding area (based on Przeglądowa Mapa Geomorfologiczna Polski). - 1 - fluvial erosional edges, 2 - Weichselian terraces of the Toruń-Eberswalde pradolina, 3 - Weichselian terraces of the Toruń-Eberswalde pradolina; outwash plain younger than Chodzież subphase (after KOZARSKI 1962), 4 - undulated till plain, 5 - flat till plain, 6 - thrust end moraine, 7 - depositional end moraine, 8 - outwash plain, 9 - outwash fan, 10 - dunes, 11 - flat surface with Holocene organic material.

Abb. 2: Die Geomorphologie der Umgebung (nach: Przeglądowa Mapa Geomorfologiczna Polski). 1 - fluviale Erosionskanten, 2 - weichselzeitliche Terrassen des Thorn-Eberswalder Urstromtales, 3 - weichselzeitliche Terrasse des Thorn-Eberswalder Urstromtales; Sander, jünger als die Kolmarer Staffel (nach KOZARSKI 1962), 4 - wellige Grundmoränenplatte, 5 - ebene Grundmoränenplatte, 6 - Stauchendmoräne, 7 - Satzendmoräne, 8 - Sanderfläche, 9 - Sanderkegel, 10 - Dünen, 11 - Talboden mit holozänen organischen Ablagerungen.

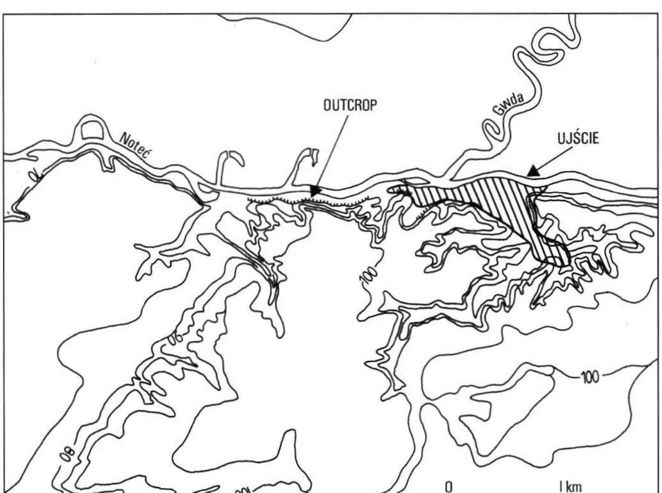

Fig. 3: Location of the outcrop in Ujście.

Abb. 3: Lage des Aufschlusses in Usch.

to the very southern edge of the valley so that all terraces have been destroyed and the morainic plateau forms a cliff to the flood plain. The outcrop has existed at least since the beginning of this century and belongs to a glass factory (Fig. 3). The outcrop was investigated in 1990, 1991, 1992 and 1994. It had an average depth of about 50 m. Three tills had been described previously (KOZARSKI & NOWACZYK 1985; KASPRZAK & KOZARSKI 1985; KOZARSKI & KASPRZAK 1987), but in 1990 and 1991 a fourth till was revealed in some parts as the pit was excavated at lower levels than before (Fig. 4). The uppermost till (till A) is only partly preserved; it is calcareous and medium brown in colour. Till A is separated from the underlying till B by a thin sandy layer only a few centimetres thick, characterized by a mylonitization zone (KOZARSKI & KASPRZAK 1992) (Fig. 5). This till is of a slightly darker brown colour and shows a sandy facies also including more gravels.

In the eastern part of the investigated site this till is directly underlain by a light greyish till (till C) with a friable structure due to a great number of small joints. To the west, this till dips downward and glaciofluvial sands several metres thick are intercalated between the overlying till and this greyish one.

The lowest till (till D) is separated from the overlying till by layered sands of questionable Holsteinian age; they have been studied using palaeomagnetic analyses (AUSTIN 1988), and results point to the Brunhes epoch. This lowest till in the outcrop is dark greyish (D_1), with very dark brown parts mainly at the bottom parts (D_2) (Fig. 4) but no intermediate layer. The differentiation of colour is probably related to weathering processes, the lowermost part contains more sand.

3 Methods Used

Various methods were applied to obtain sedimentological and stratigraphical data.

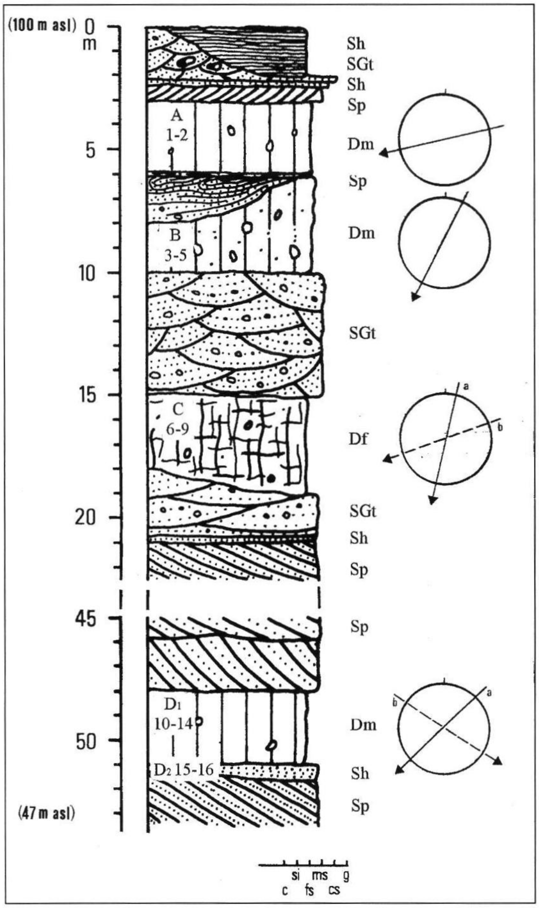

Fig. 4: Local summary sequence and the till fabric in the outcrop in Ujście. - Sh - horizontally stratified sand, Sp - planar cross-stratified sand, SGt - gravelly sand of trough cross-stratification, Dm - massive glacial diamicton (glacial till), Df - glacial diamicton of friable structure; a - layer top, b - layer bottom.

Abb. 4: Zusammenfassende Darstellung der Sedimentfolge mit Einregelungsmessungen im Aufschluß in Usch. - Sh - horizontal geschichtete Sande, Sp - schräggeschichtete Sande, SGt - kiesiger Sand in Gerinne-Füllungen, Dm - massiver Geschiebemergel, Df - Geschiebemergel mit bröckeliger Struktur; a - oberer Bereich, b - unterer Bereich.

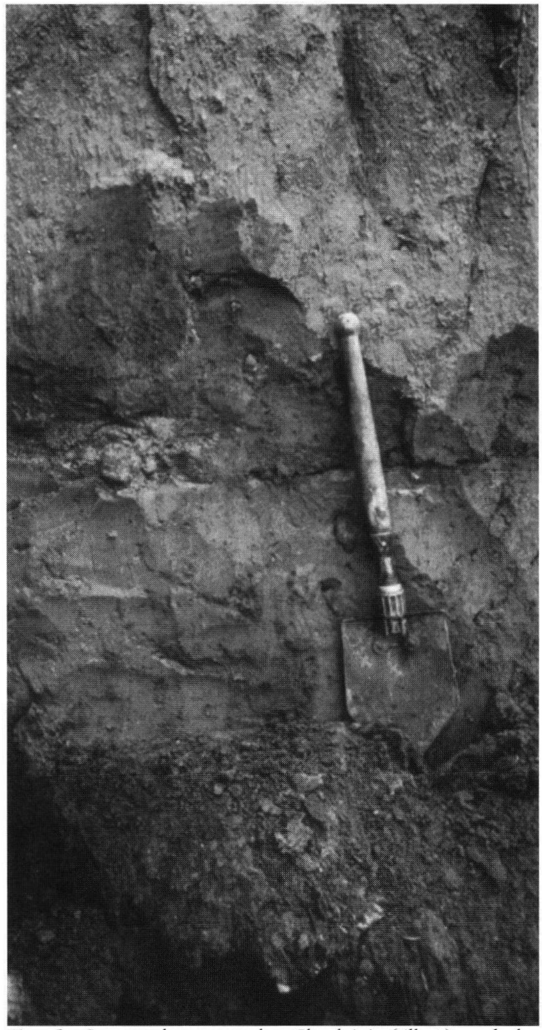

Fig. 5: Contact between the Chodzież (till A) and the Leszno-Poznań (till B) tills with horizontal wedge, developed in the stoss of a stone (Photo: BÖSE, 21/6/90).

Abb. 5: Kontakt zwischen Kolmarer Geschiebemergel (A) und Brandenburg-Frankfurter Geschiebemergel (B) mit horizontaler Sandeinschaltung an der Luvseite eines Steines (Foto: BÖSE, 21.6.90).

- Grain size distribution was established by sieve analysis and CASAGRANDE's gravitational silt (< 0.1 mm) analysis in PRÓSZYNSKI's modification (LITYŃSKI 1972).
- The calcium carbonate content was determined according to SCHEIBLER.
- Petrographic gravel analysis of the 4 - 12.5 mm particle size was undertaken to facilitate stratigraphical interpretation. Ten components were distinguished megascopically or by using magnifying lenses: K-crystalline rocks, S-sandstone and quartzite, TU-Palaeozoic shale and siltstone, F-flint, KK-Cretaceous chalk, PK-Palaeozoic limestone, D-Devonian dolomite, L-lydite, Q-quartz, WQ-white quartz; the sum of all particles of one sample equals 100%, other components such as concretions or Tertiary material were counted separately. The source areas of Palaeozoic, Devonian and Cretaceous sedimentary rocks are marked in Fig. 6. To facilitate comparison, compositional properties were then characterized by coefficients. Lydite and white quartz are considered to be southern fluvial components incorporated in the tills.
- Indicator boulder countings and evaluation by the TGZ (Theoretisches Geschiebezentrum) method were carried out according to LÜTTIG (1958).
- As they represent local ice-flow directions, till fabric measurements are considered to be more useful

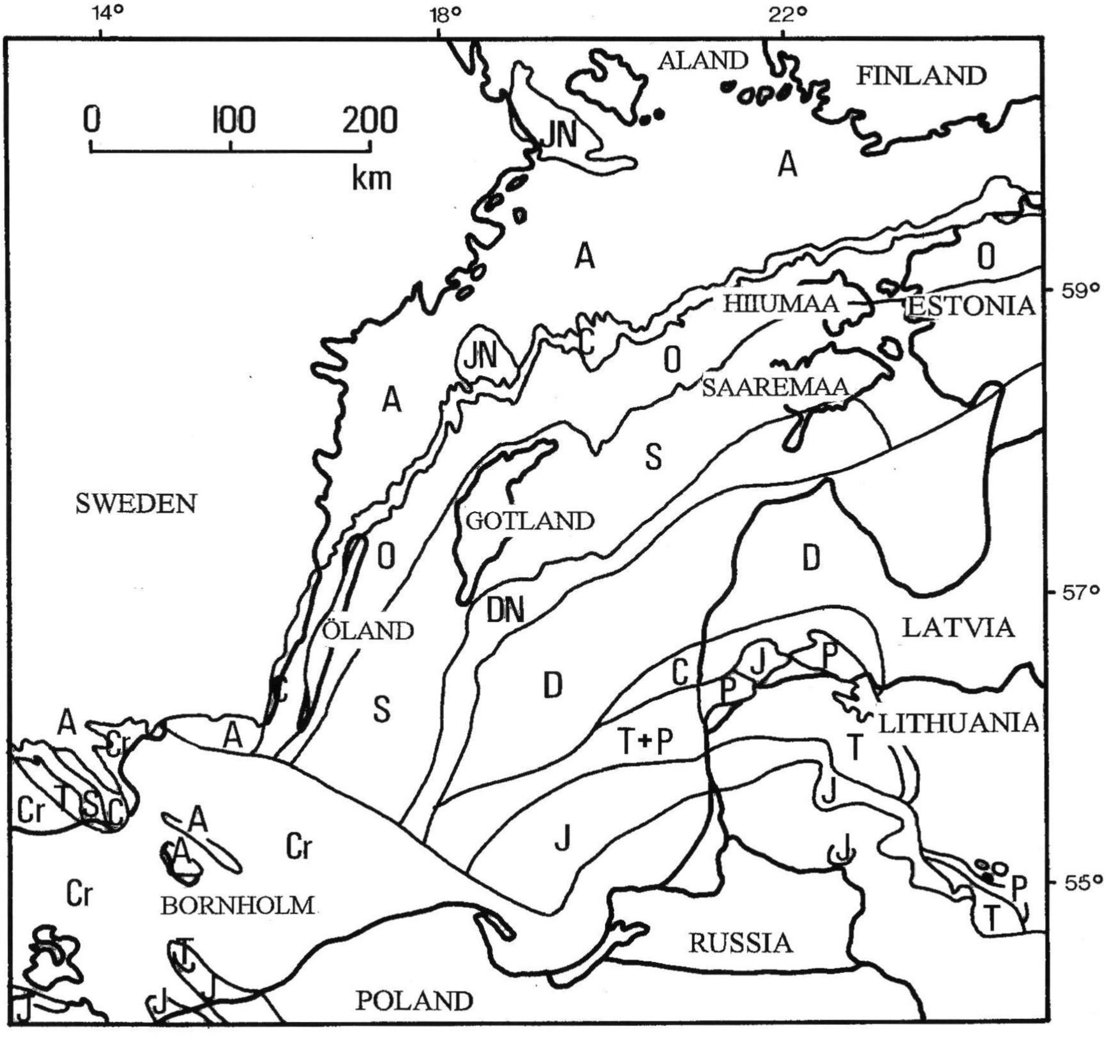

Fig. 6: Distribution of pre-Quaternary layers in the Baltic depression (from FLODEN after MEYER 1991). A - pre-Cambrian (mainly crystalline), JN - pre-Cambrian, Jotnian sandstone, Cm - Cambrian, O - Ordovician, S - Silurian, DN - Downton, D - Devonian, C - Carboniferous, P - Permian, T - Triassic, J - Jurassic, Cr - Cretaceous.

Abb. 6: Verteilung der präquartären Ablagerungen im Ostseebereich (nach: FLODEN in MEYER 1991). A - Präkambrium (hauptsächlich Kristallin), JN - Präkambrium, Jotnischer Sandstein, Cm - Kambrium, O - Ordovizium, S - Silur, DN - Downton, D - Devon, C - Karbon, P - Perm, T - Trias, J - Jura, Cr - Kreide.

for a palaeogeographical interpretation of the study area than for stratigraphical purposes.

4 Properties of the tills

4.1 Till A

The uppermost till was investigated using two samples with very different granulometric compositions. Sample 1 contains an unusually high quantity of clay, whereas sample 2 represents the "normal" sandy till (Fig. 7). The fine-grained material probably corresponds to a sediment called "lehmiger bis toniger Sand mit undurchlässigem Tonmergel - und tieferem Geschiebemergel-Untergrund" mapped as top layer on parts of the till plain by KORN (1907) on the adjacent geological map sheet "Scharnikau". The calcium carbonate content varies from 26% in the clay-rich part, which is definitely the highest value of all samples, to about 10% in the "normal" till (Fig. 8). Till fabric measurements by KASPRZAK & KOZARSKI (1985) show an ice flow from ENE for the upper till which is mainly due to the fact that the outcrop is located in the western part of the ice tongue which shaped the end moraine of the Chodzież subphase (Fig. 4).

The gravel content (4 - 12.5 mm) shows significantly little crystalline (~ 37%), and the Palaeozoic limestone

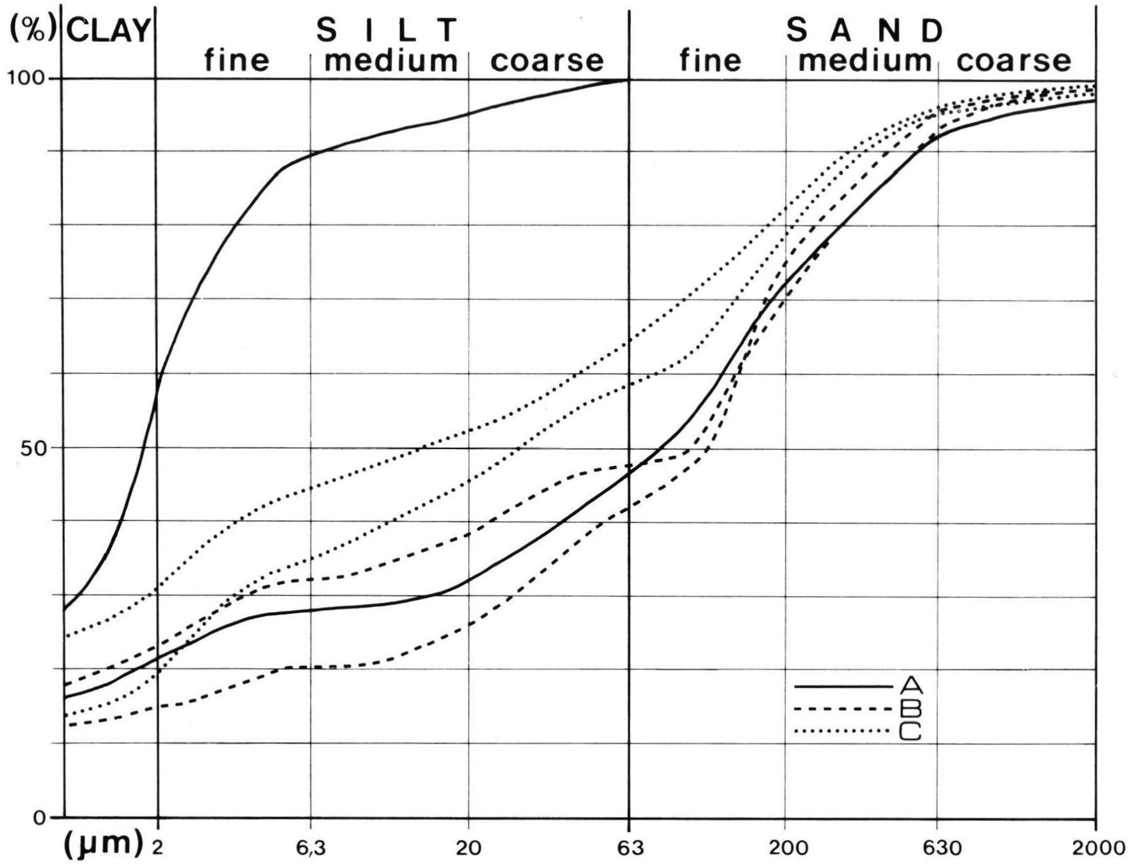

Fig. 7: Grain-size distribution of the tills A, B, C in the outcrop at Ujście.
Abb. 7: Korngrößenverteilung der Geschiebemergel A, B und C.

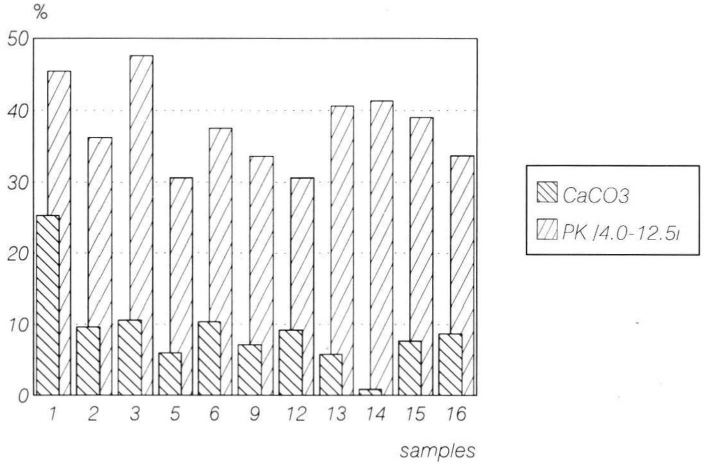

Fig. 8: Calcium carbonate content of the four tills in the outcrop.
Abb. 8: Kalziumkarbonatgehalt in den vier Geschiebemergeln.

consists almost entirely of grey components, whereas red ones are rare. Both samples contain dolomite and relatively few sandstones and very few flints (Table 1). The composition of the coarser 12.5 - 20 mm fraction is similar.

The boulders in the >20 mm fraction, used for indicator boulder countings, also contain more Palaeozoic limestone (43%) than crystalline (39%). This distribution in all investigated fractions already indicates a general ice advance from NE. Thirty-one boulders were identified as indicator boulders with a high percentage of Åland granites. The TGZ (Fig. 9a, 10) indicates an East Baltic influence which is supported by the high quantity of Palaeozoic limestone.

Table 1: Percentage of petrographic content of 4-12.5 mm gravel fraction.
Tab. 1: Die petrographische Zusammensetzung der Kiesfraktion 4 - 12,5 mm in Prozenten.

Sample/till		K	S	TU	F	KK	PK	D	L	Q	WQ	SUM
1	A	36,9	9,9	-	0,5	0,2	45,4	0,6	-	6,5	-	100,0
2		37,5	17,6	-	1,0	1,4	36,2	2,0	0,4	2,7	1,2	100,0
3	B	37,8	10,6	0,2	0,3	0,8	47,6	0,3	-	2,4	-	100,0
4		42,2	14,1	0,8	2,0	0,2	29,5	0,2	-	11,0	-	100,0
5		53,3	10,5	0,6	0,6	0,2	30,6	-	-	4,2	-	100,0
6	C	40,0	13,9	-	0,8	1,6	37,5	3,7	-	2,5	-	100,0
7		35,9	19,3	-	1,7	-	33,4	2,1	-	7,6	-	100,0
8		47,3	11,8	0,7	1,4	-	33,3	1,4	0,3	3,8	-	100,0
9		43,1	17,1	0,7	-	-	33,6	1,4	-	3,4	0,7	100,0
10	D1	44,7	12,0	1,4	1,9	-	35,7	-	-	4,0	0,3	100,0
11		36,1	11,0	-	3,0	0,2	37,2	0,4	-	12,1	-	100,0
12		48,6	9,9	2,3	0,5	-	30,6	0,9	-	6,7	0,5	100,0
13		38,3	8,8	0,3	2,3	-	40,6	-	-	9,7	-	100,0
14		42,8	5,8	0,7	2,9	-	41,3	0,7	-	5,8	-	100,0
15	D2	45,4	8,5	-	0,7	-	39,0	-	-	6,4	-	100,0
16		43,8	12,7	0,9	2,4	-	33,7	-	-	6,5	-	100,0

Table 2: Coefficients of 4-12,5 mm gravel fraction.
Tab. 2: Koeffizienten der Kiesfraktion 4 - 12,5 mm.

Sample/Till		Q/K	F/K	S/K	(PK+D)/K	K/(PK+D)	(PK+D)/S	F/PK	K/D
1	A	0,176	0,013	0,268	1,247	0,802	4,656	0,010	59,75
2		0,108	0,027	0,468	1,018	0,982	2,173	0,028	18,50
3	B	0,062	0,009	0,280	1,268	0,788	4,521	0,007	83,75
4		0,260	0,047	0,335	0,702	1,424	2,097	0,067	215,0
5		0,078	0,011	0,196	0,575	1,739	2,927	0,019	-
6	C	0,061	0,020	0,346	1,030	0,970	2,970	0,022	10,88
7		0,211	0,048	0,537	0,994	1,007	1,848	0,051	16,33
8		0,080	0,029	0,250	0,735	1,360	2,941	0,041	34,00
9		0,095	-	0,397	0,810	1,235	2,040	-	31,50
10	D1	0,091	0,042	0,268	0,798	1,252	2,977	0,053	-
11		0,335	0,084	0,305	1,039	0,962	3,403	0,081	101,5
12		0,138	0,009	0,203	0,648	1,543	3,180	0,015	54,00
13		0,254	0,059	0,229	1,059	0,944	4,370	0,056	-
14		0,136	0,068	0,136	0,983	1,017	7,250	0,070	59,00
15	D2	0,140	0,015	0,187	0,860	1,164	4,580	0,018	-
16		0,149	0,050	0,290	0,770	1,298	2,650	0,070	-

4.2 Till B

Till B (Fig. 4) contains more sand (Fig. 7), and silt and sand show a bimodal distribution. The gravel content in the three samples taken for gravel analysis is also higher in comparison with till A. Most of the gravels are well rounded, indicating that probably a high percentage of fluvial material has been incorporated which would also explain the high sand content. The $CaCO_3$ content is <12% (Fig. 8).

Till fabric measurement for this till gave a general direction of ice flow from NNE (KASPRZAK & KOZARSKI 1985) (Fig. 4).

In samples 3 and 5 the proportion of crystalline to Palaeozoic limestone is higher than in till A (Table 1); two samples (3 and 4) contain a low quantity of dolomite, in one sample (5) dolomite is absent. Sample 4 is probably not representative for the whole till as it derives from a basal part and includes more quartz and flint (Q/K >2) (Table 1 and 2). As those "hard" components are normally enriched in fluvial material, it gives a further indication of the incorporation of fluvial and/or fluvioglacial material (BÖSE 1989).

With increasing particle size the proportion of crystalline increases; in the indicator boulder fraction (>20 mm) crystalline amounts to 50% whereas

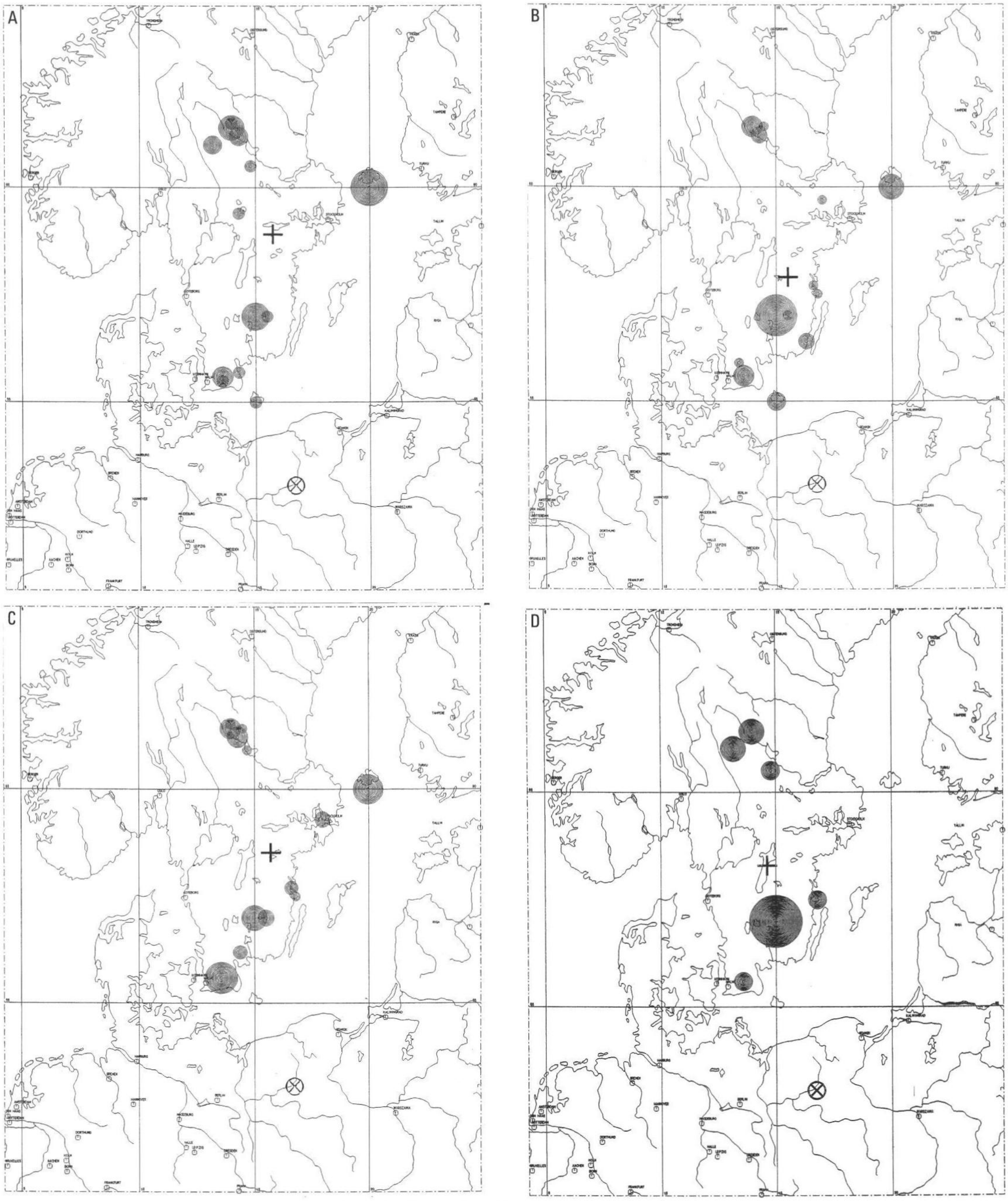

Fig. 9: Distribution of the source areas of the indicator boulders based on their percentage content; A = till A, B = till B, C = till C, D = till D.

Abb. 9: Die Herkunftsgebiete der Leitgeschiebe gemäß der prozentualen Verteilung; A = Geschiebemergel A, B = Geschiebemergel B, C = Geschiebemergel C, D = Geschiebemergel D.

limestone totals 26%. The flint content is also higher (6%) than in till A. This material is more influenced by material from the western Baltic basin and Swedish rocks mainly from the Växjö area and some from southern Sweden; the TGZ value is situated much farther south and more to the west than that of the till above (Fig. 9b, Fig. 10).

4.3 Till C

Till C has a different appearance: its colour is greyish and its friable structure evidences heavy stress and pressure. The granulometric analyses show a poorly sorted sandy silty matrix (Fig. 7). The two samples whose calcium carbonate content has been determined are very similar to those of the overlying till (Fig. 8).

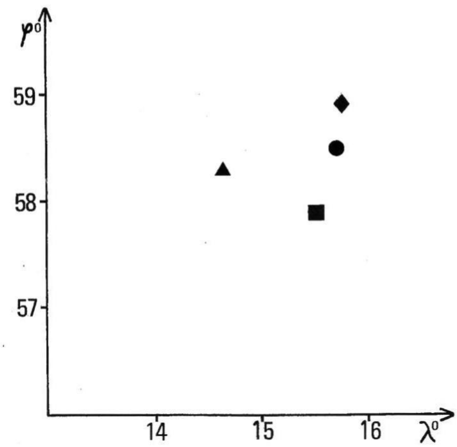

Fig. 10: TGZ values (det. MEYER, GÓRSKA):
Chodzież till A ◆ 15 45'E 58 55'N
Leszno-Poznań till B ■ 15 31'E 57 53'N
Saalian till C ● 15 42'E 57 31'N
Saalian or Elsterian till D▲ 14 36'E 58 17'N

Abb. 10: TGZ-Werte (det. MEYER, GÓRSKA)
Kolmarer Geschiebemergel A 15 45'E 58 55'N
Brandenburg-Frankfurter Geschiebemergel B 15 31'E 57 53'N
Saalezeitlicher Geschiebemergel C 15 42'E 57 31'N
Saale- oder elsterzeitlicher Geschiebemergel D 14 36'E 58 17'N

Till fabric measurements indicate the local ice flow direction which shifts from ENE in the lower part of the till layer towards NNE in the upper part (Fig. 4). The almost easterly direction in the basal part may be due to a very local flow direction as the till dips down from east to west in the outcrop into a very shallow palaeo-depression. Between the till and the underlying sands is a transitional zone. Hence these sands are of proglacial origin, from the same ice advance as till C.

The four samples (6, 7, 8 and 9) reveal a much more homogeneous petrographical composition than those of the tills described above. Till C contains on average more crystalline, and the sandstone content is more consistent. Sample 7, taken in the lowest part of the till layer, again shows an increasing amount of quartz (Q/K >2) and flint (Table 1 and 2).

In the indicator boulder fraction (>20 mm) numerous boulders show weathering features at their surfaces. The crystalline content increases with the size of the particles. Among the 50 indicator boulders Åland rocks are quite frequent, but Hardeberga sandstone from southern Sweden and boulders from Småland are also included (Fig. 9c). The east Baltic influence is represented by the Palaeozoic limestone as well as dolomite (4%). The TGZ-value is situated nevertheless somewhat farther to the south and west than that of the uppermost till A (Fig. 10).

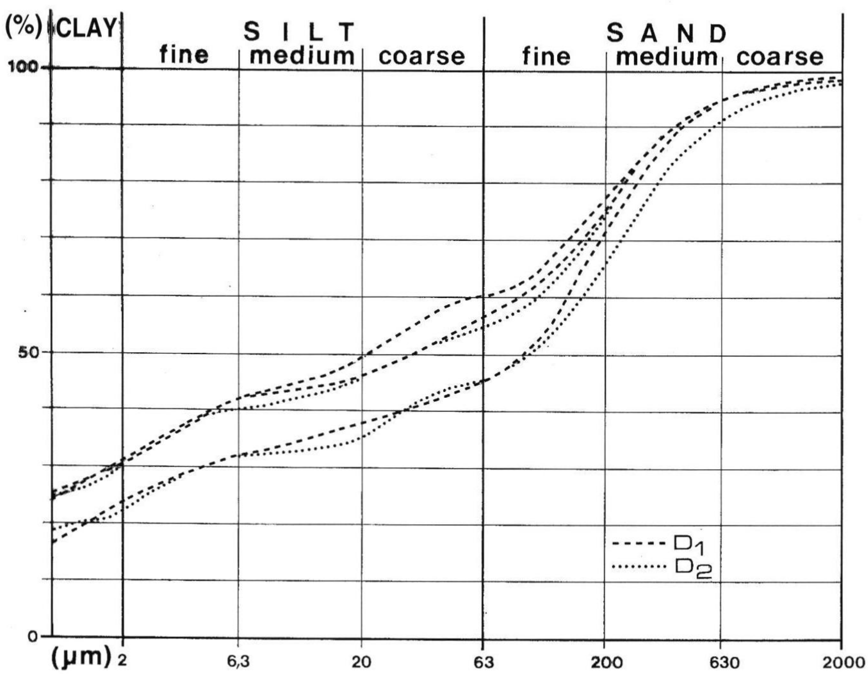

Fig. 11: Grain-size distribution of till D in the outcrop at Ujście.
Abb. 11: Korngrößenverteilung im Geschiebemergel D.

4.4 Till D

The lowest till layer (Fig. 4), unknown until now, is sandy-silty and poorly sorted, too. The bottom part is partly brownish and more sandy (Fig. 11). The five samples - three from the black and two from the brownish part - show a somewhat greater variety in their calcium carbonate content, especially sample 14 has an extremely low $CaCO_3$ content in the fine material (Fig. 8).

Till fabric measurements in the lower part indicate north to eastnortheasterly directions; in the upper part of the till layer the western part of the outcrop indicates an ice flow from the east, whereas about 150 m to 200 m to the east northerly directions are indicated (Fig. 4). This may also be due to a very local effect of ice flow into a shallow depression or directed by a slope in the eastern part of the outcrop, as has already been described for till C.

Seven samples for gravel analysis have been taken, two of them (15 and 16) from the brownish bottom part (Table 1). The crystalline content is always higher than the Palaeozoic limestone content. The flint occurs in varying amounts, but is generally higher than in the other three tills, whilst sandstone and crystalline are less frequent. Samples 11 and 13 have a higher quartz content, which is also clearly shown in the quartz/crystalline ratio (>2). Besides the Nordic components, some probably Tertiary lignite and pyrite as well as secondary iron concretions have been found.

The indicator boulders were from central and, more often, southern Sweden (Fig. 9d); consequently the TGZ value is clearly different (Fig. 10).

Between this till and the Tertiary surface is a sequence consisting of about 40 m of Quaternary sediments of unknown composition. The surface of the Tertiary sediments forms a northwest-southeasterly oriented trench where the pre-Quaternary surface is situated between -20 and -50 m below sea level. A small tributary branch in an eastnortheast-westnorthwest direction is located just below the outcrop at -10 m, filled with fine sand containing charcoal (cf. Mapa Geologiczna Polski 1:200 000, Piła, 1977).

5 Discussion

The interpretation of the sediments in this study is mainly related to stratigraphical questions.

Lithostratigraphical investigations of tills have been conducted by several Polish authors (cf. NUNBERG 1971; RZECHOWSKI 1980; CHOMA-MORYL et al. 1991; KRZYSZKOWSKI 1988, 1990, 1994). Problems arise in comparing the results of different studies as the methods differ to a certain extent.

NUNBERG (1971) bases her interpretation on two coefficients:

- *O/K* and
- *A/B*

O are sedimentary rocks: Palaeozoic limestone, dolomite, sandstone, quartzite, and brown coal, i. e. both Nordic material and more local, Tertiary material are included.

K are crystalline and quartz.

A are "non-resistant rocks" such as Palaeozoic limestone, dolomite, and brown coal;

B are "resistant rocks" such as crystalline, quartzite, quartz and flint.

Cretaceous limestone (KK) as well as Palaeozoic shale and siltstone (TU) have not been distinguished.

RZECHOWSKI (1971; 1980) uses three coefficients, two of which are similar to those of NUNBERG. His sedimentary rock components (*O*) are Palaeozoic sandstone, quartzite and Palaeozoic limestone; as in NUNBERG (1971), *K* represents crystalline and quartz.

His "non-resistant" components consist of Palaeozoic limestone, Palaeozoic shale and siltstone, and dolomite, so brown coal is absent but Palaeozoic shale and siltstone is included; his "resistant" rocks are crystalline, sandstone, quartzite and quartz. Flint is not taken into consideration in the coefficient.

K/W is his third coefficient consisting of crystalline to calcareous material. The tills are related to Saalian deposits, but his study area is situated in Middle Poland, and therefore too far away for comparison with the results from Ujście.

CHOMA-MORYL et al. (1991) give much more general indications about the types of rock material of their coefficients. *O/K* represents sedimentary rock to crystalline, *K/W* crystalline to calcareous material in general. The components of the "non-resistant to resistant" coefficent *A/B* are not specified, so it is difficult to compare any other results with them.

KRZYSZKOWSKI (1988, 1990, 1994) also uses these three coefficients. For the sedimentary rocks he distinguishes Palaeozoic limestone, dolomite, sandstone, quartzite, Palaeozoic shale and siltstone; for *K*, he distinguishes crystalline and blue quartz in his paper of 1990, but only crystalline in his other paper published in 1994. As this paper mentions only milk quartz and not the other, more frequent quartzes (blue and shiny) they are presumably considered to be part of the crystalline.

KRZYSZKOWSKI'S *A/B* coefficient consists of the "non-resistant" rocks Palaeozoic limestone, dolomite, Palaeozoic shale and siltstone. The "resistant" ones are crystalline, sandstone and quartzite.

The coefficient *K/W* corresponds to K/PK+D in Table 2. Cretaceous limestone (KK) is not taken into consideration.

Since various authors use the same coefficient names to denote different compositions, even diagrams which look very similar at first glance are not wholly compatible (CHOMA-MORYL et al. 1991; KRZYSZKOWSKI 1994).

Nevertheless, in order to compare a general trend in the diagrams the values of the coefficients *O/K*, *K/W*, and the *A/B* have been defined for this study as follows:

O = S (sandstone and quartzite) + TU + F + KK + PK + D

K = K

W = PK + D

A = S (sandstone and quartzite) + TU + KK + PK + D

B = K + F + L + Q + WQ

Unlike KRZYSZKOWSKI and RZECHOWSKI, we have not included quartz in *K*, because the amount of quartz in a sample is not only related to the crystalline content (cf. changing Q/K-coefficient in Table 2) but depends also on the amount of locally reworked fluvial or glaciofluvial material as described in the samples 4, 11 and 13 (Table 1), and can therefore easily be enriched.

Hence only a limited comparison is possible between the diagrams (Fig. 12 a-d) and the results of CHOMA-MORYL et al. (1991) who have been working in the Szamotuly area.

KRZYSZKOWSKI (1990) presents a north-south profile from the Baltic Sea coast to the Leszno terminal moraines in western Poland. He indicates three tills which however do not correspond to the views of other authors. His lower Weichselian till reaches from the Baltic coast down to an area still north of the Pomeranian ice margin and is probably related to a first Middle-Weichselian ice advance. His "Middle Weichselian till" extends only as far as the area of the Chodzież subphase and is restricted to a west-east stretch (cf. KRZYSZKOWSKI 1990: Fig. 1). It is considered to be rich in limestone (>50%). The "Upper Weichselian till" of KRZYSZKOWSKI corresponds to the Leszno-Poznań phase; for the Pomeranian phase, no separate till is indicated, a view which is supported by the studies of KARCZEWSKI (1994) but cannot be correlated with the results from the northeastern part of Germany where the Pomeranian phase is a definite readvance with its own till (MALMBERG-PERSSON & LAGERLUND 1994; CEPEK 1972). According to KRZYSZKOWSKI (1994) all morphologically relevant end-moraines are due to smaller readvances so that the ice marginal positions almost always contain more than one till layer.

6 Interpretation

The uppermost till A has been interpreted by KOZARSKI & NOWACZYK 1985, KASPRZAK & KOZARSKI 1985 and KOZARSKI 1991 as belonging to the Chodzież subphase, a distinct readvance of unknown distance between the Poznań and the Pomeranian ice marginal positions. The lithostratigraphical composition of the till indicates a strong east Baltic influence which is even supported by the indicator boulder counting showing the most northeastern position on the TGZ of all the samples investigated in Ujście. According to EHLERS (1983) the dynamics and direction of ice flow change during each glaciation: first, the main ice stream comes largely from the Scandinavian mountains which implies a more north-south directed ice advance; during glaciation the ice dome and therefore the ice divide shift more to the east so that younger tills of the same glaciation are subjected to a more easterly influence.

The diagram (Fig. 12a) shows a dominance of Palaeozoic limestone in relation to crystalline (cf. Table 2). A Weichselian till similar to the uppermost Ujście till has not been found by CHOMA-MORYL et al. (1991).

Till B is related to the Leszno-Poznań phase (KOZARSKI & NOWACZYK 1985, KASPRZAK & KOZARSKI 1985): the composition of two samples (Fig. 12b) resembles Weichselian samples studied by CHOMA-MORYL et al. But one sample (5) is more like the upper till than the samples of the same layer. Sample 3 fits in with the description by KRZYSZKOWSKI (1994) of the Bytyń till as the uppermost Weichselian till layer south of the study area but in the hinterland of the Poznań end moraine. Taken in the upper part of the till, it already indicates the more easterly influence, although the dolomite content is slightly lower than in the overlying till and some Paleozoic shale and siltstones are still present (Table 1); similar characteristics have already been described from an area more than 200 km to the west (BÖSE 1989; 1990). No till has been identified corresponding to the Maliniec till, the uppermost Weichselian till in the Konin area, where crystalline and Palaeozoic limestone are represented in almost equal proportions. Indicator boulder counting shows the dominant influence from the Swedish area which is surely typical of the main part of the till layer.

In till C the indicator boulders show weathering signs giving a first hint of a time hiatus with warmer climatic conditions. The Palaeozoic limestone content is lower than the crystalline content, but nevertheless the quantity of dolomites is higher than in the uppermost till (Table 1). Dolomite-rich tills are typical for the Warthanian glaciation (KRZYSZKOWSKI 1990; 1994). Compared with the results of CHOMA-MORYL et al. (1991) of Warthanian till, the values *O/K* are similar, *K/W* show the same tendency but are somewhat higher in Ujście, and *A/B* are different because the values in Ujście are clearly higher (Table 2, Fig. 12c).

This is probably due to the fact that the proportion of carbonatic rocks in the Ujście till has been reduced by weathering processes, clearly showing the east Baltic influence by the relation PK and D, although they have both been reduced. Dolomite is also represented in a considerable quantity among the indicator boulders and the TGZ is situated farther northeast. The results allow us to interpret this till

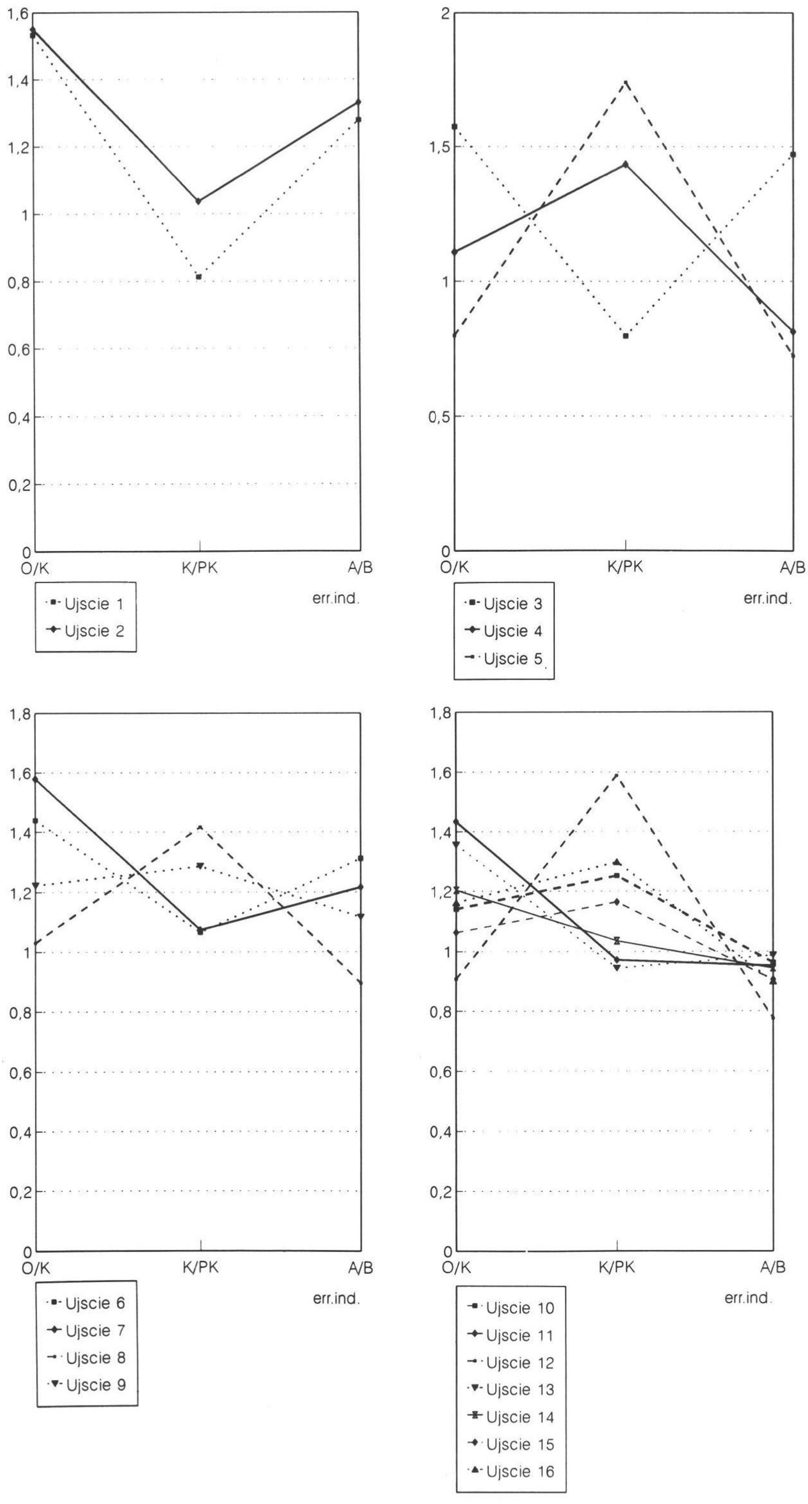

Fig. 12: Gravel coefficients of four tills in Ujście (explanation cf. chap. 5).
Abb. 12: Koeffizienten der Kiesfraktion aus den vier Geschiebemergeln (Erklärung vgl. Kap. 5).

C as belonging to the Wartha phase of the Saalian Glaciation.

The lowermost till of the outcrop, till D, is characterised by more flint in most of the samples (Table 1), so five of seven samples show an *F/K* coefficient of >0.04 (Table 2, Fig. 12d).

CHOMA-MORYL et al. (1991) have described a fourth till not far from the study area which they classify as belonging to the Elster Glaciation. This till contains few or no dolomites, and few Palaeozoic limestones (<26%), whereas the Ujście till has >30%->40% (Table 1). As a further indicator CHOMA-MORYL et al. (1991) give high *K/W* values due to a high crystalline content. This has not been found in the till D in Ujście as the K/PK+D coefficient is almost similar to those of the other tills. The $CaCO_3$ content of the till of CHOMA-MORYL et al. (1991) is much lower than in the other tills owing to weathering which is not the case in the till in Ujście (Fig. 8), where only sample 14 is significantly reduced in calcium carbonate but not in PK. The lowermost till is the only one in which the content of calcium carbonate does not parallel that of the Palaeozoic limestone.

CHOMA-MORYL et al. (1991) describe their values as typical in western Poland, but a similar till has not been found at Ujście. Consequently the composition of till D is not typical for the Elsterian till of the area.

The petrological composition of the Drenthe(-Odranian) till has not been studied in detail in western Poland, so no comparison is possible.

Like the gravel analyses, the indicator boulders sampled in the outcrop show that the ice stream flowed almost N-S (cf. BÖSE 1990: Fig. 5). This result supports the interpretation that this till is related to an early phase of a glaciation in the sequence of a glaciation cycle. It may be interpreted as an Odra till which has not undergone excessive weathering. But the possibility that it is an Elsterian till which has not been strongly weathered cannot be excluded.

Drillings in the Quaternary sediments below the outcrop could give more information, especially if further till layers were found and investigated.

Acknowledgments: The research was financially supported by the Deutsche Forschungsgemeinschaft (project Bo 659/5) and the National Committee for Scientific Research (Poland), research project no. 6 0318 91 01. We thank Prof. S. Kozarski, Poznań, for introducing us to the study area and giving help with our research. Prof. K.-D. Meyer taught Maria Górska the indicator boulder method and helped us to complete the countings. We thank Anne Beck for revising the English manuscript and students from Poznań and Berlin for helping with fieldwork.

7 References

AUSTIN, T. J. F. (1988): The palaeomagnetism of Quaternary sediments at Ujście, Poland. - Quaestiones Geographicae **10**: 19-27; Poznań.

BÖSE, M. (1989): Methodisch-stratigraphische Studien und paläomorphologische Untersuchungen zum Pleistozän südlich der Ostsee. - Berliner Geogr. Abh. 51; Berlin.

– (1990): Reconstruction of ice flow directions south of the Baltic Sea during the Saalian and the Weichselian glaciation. - Boreas, **19:** 217-226; Oslo.

CEPEK, A. G. (1972): Zum Stand der Stratigraphie der Weichsel-Kaltzeit in der DDR. - Wiss. Z. Ernst-Moritz-Arndt-Univ. Greifswald, XXI, math.-nat. R. **1:** 11-21; Greifswald.

CHOMA-MORYL, K., CZERWONKA, J. & MORYL, J. (1991): Petrograficzno-mineralogiczna charakterystyka glin zwałowych okolic Szamotul. - In: Kostrzewski, A. (Hrsg.): Geneza, litologia i stratygrafia utworów czwartorzędowych, Geografia **50:** 227-236; Poznań.

EHLERS, J. (1983): Different till types in North Germany and their origin. - In: Evenson, E. B., Ch. Schlüchter & J. Rabassa (eds.): Tills and related deposits: 61-80; Rotterdam.

KARCZEWSKI, A. (1994): Morpho- and lithogenetic diversification of the Pomeranian Phase in western and central Pomerania. - Zeitschrift für Geomorphologie, Suppl.-Bd. **95:** 35-48; Berlin/Stuttgart.

KASPRZAK, L. & KOZARSKI, S. (1985): Litostratygraficzne podstawy subfazy chodzieskiej ostatniego zlodowacenia w północej Wielkopolsce. - Sprawozd. Poznańskiego Towarzystwa Przyjaciół Nauk 101 (1983): 51-57; Poznań.

– (1992): Glacidynamometamorfoza osadów nieskonsolidowanych w makro- i mezoglacitektonitach Niziny Wielkopolskiej. Przegląd Geograficzny **64** (1-2): 95-119.

KEILHACK, K. (1897): Glaziale Hydrographie. - In: Berendt, Keilhack, Schröder & Wahnschaffe (Hrsg.): Neuere Forschungen auf dem Gebiet der Glacialgeologie Norddeutschlands, erläutert an einigen Beispielen. - Jahrbuch der Königl. Preuß. Geol. Landesanst. **18:** 88-103; Berlin.

– (1898): Die Stillstandslagen des letzten Inlandeises und die hydrographische Entwicklung des pommerschen Küstengebietes. - Jahrbuch der Königl. Preuß. Geol. Landesanst. **19:** 90-152; Berlin.

KORN, J. (Bearb.) 1907): Geologische Karte von Preussen und benachbarten Bundesstaaten, Blatt Scharnikau, 1:25 000, Lieferung 159, Herausgegeben 1911; Berlin.

– (1917): Untersuchungen in der Glaziallandschaft östlich vom Odergletscher. - Jahrbuch der Königl. Preuß. Geolog. Landesanst., B. XXXVI 2 (1915): 396-420; Berlin.

KOZARSKI, S. (1962): Recesja ostatniego lądolodu północnej części Wysoczyzny Gnieźnienskiej a kształtowanie się Pradoliny Noteci-Warty. - Poznańskie Towarzystwo Przyjaciół Nauk, Prace Kom. Geogr. - Geolog. 2, H. 3; Poznań.

– (1986): Skale czasu a rytm zdarzeń geomorfologicznych vistulianu na Niżu Polskim. Czasopismo Geograficzne 57 (2): 247-270.

– (1991): Litostratygrafia górnego plenivistulianu Niziny Wielkopolskiej w granicach ostatniego zlodowacenia: nowe dane i interpretacje. - In: Kostrzewski, A. (Hrsg.): Geneza, litologia i stratygrafia utworów czwartorzędowych, Geografia 50: 471-496; Poznań.

– & KASPRZAK, L. (1987): Facies analysis and depositional models of vistulian ice-marginal features in north-western Poland. - In: Gardiner, V. (Hrsg.): International Geomorphology Part II: 693-710; Chichester etc.

– & NOWACZYK, B. (1985): Stratygrafia osadów plejstoceńskich w profilu Ujście nad Notecią. - Sprawozd. Poznańskiego Towarzystwa Przyjaciół Nauk 101 (1983): 49-51; Poznań.

KRYGOWSKI, B. (1961): Geografia fizyczna Niziny Wielkopolskiej. - Poznańskie Towarzystwo Przyjaciól Nauk, cz. 1 Geomorfologia; Poznań.

KRZYSZKOWSKI, D. (1988): The Rogowiec Formation in a Kleszczów Graben, a new view from the Warthanian (Warte) glaciation in Central Poland. - Biul. of the Pol. Acad. of Sci., Earth Sci. 36, 3-4: 287-298; Warszawa.

– (1990): Position and petrographical features of Weichselian tills in western Poland. - In: Lundqvist, J. & M. Saarnisto (Hrsg.): Termination of the Pleistocene, Field Conference, Norway - Sweden - Finland, May 9-16, 1990: 111-113; Espoo.

– (1994): A new approach to Late Weichselian ice sheet dynamics in western Poland. - Zeitschrift für Geomorphologie, Suppl.-Gd. **95:** 59-67; Berlin/Stuttgart.

LITYŃSKI, T. (1972): Analiza rolniczo-chemiczna, gleby i nawozy. Przewodnik metodyczny do ćwiczeń chemiczno-rolniczych. - Polskie Wydawnictwo Naukowe; Kraków.

LÜTTIG, G. (1958): Methodische Fragen der Geschiebeforschung. - Geol. Jb. **75:** 361-418; Hannover.

MAAS, G. (1904): Zur Entwicklungsgeschichte des sogenannten Thorn-Eberswalder Haupttales. - Zeitschrift der Deutschen geologischen Gesellschaft, B. **56:** 40-49; Berlin.

MALMBERG-PERSSON, K. & LAGERLUND, E. (1994): Lithostratigraphy and sedimentology of a coastal cliff, NW Poland. - Zeitschrift für Geomorphologie, Suppl.-Bd. **95:** 69-76; Berlin/Stuttgart.

MAPA GEOLOGICZNA POLSKI 1:200 000, Piła, 1977.

MEYER, K.-D. (1991): Zur Entstehung der westlichen Ostsee. - Geologisches Jahrbuch, **A127:** 429-446; Hannover.

NIEWIAROWSKI, W. & WYSOTA, W. (1994): Geomorphological, sedimentological and structural records of ice front dynamics during the Upper Plenivistulian: an example from the southeastern part of the Chełmno-Dobrzyń Lakeland. - Zeitschrift für Geomorphologie, Suppl.-Bd. **95:** 95-104; Berlin/Stuttgart.

NUNBERG, J. (1971): Próba zastosowania metod statystycznych do badań zespołu głazów fennoskandyjskich występujących w utworach glacjalnych północnowschodniej Polski. - Studia Geologica Połonica 37; Warszawa.

RZECHOWSKI, J. (1971): Granulometryczno-petrograficzne własności glin zwałowych. - Biul. Państw. Inst. Geolog. 254, Z badań nad czwartorzpedem w Polsce 13; Warszawa.

– (1980): An attempt of lithostratigraphical subdivisions of the Vistulian glaciation tills in Poland. - Quatern. Studies in Poland **2:** 107-120; Poznań.

SMED, P. (1989): Sten i det danske landskab. - Geografforlaget, 2 utgave; Brenderup.

Topographische Karte 1:25 000, Blatt 1499 (2966) Usch von 1876, Nachträge von 1919.

WOLDSTEDT, P. (1932): Über Randlagen der letzten Vereisung in Ostdeutschland und Polen und über die Herausbildung des Netze-Warthe Urstromtales. - Jahrb. Preuß. Geol. Landesanst, **52** (1931): 59-67; Berlin.

Manuscript accepted 26.09.1994