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The Wartanian Siedlec Sandur (Zedlitzer Sander) southwards the Trzebnica Hills, Silesian Lowland, Southwestern Poland: re-examination after fifty years

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Push moraine, stratigraphic correlation, sandur deposit, sedimentological investigations, classical sections, Wartanian ice-sheet, Siedlec Sandur, Southwestern Poland

Abstract: The Siedlec Sandur (Zedlitzer Sander) in Silesia, Southwest Poland, was at first described by M. SCHWARZBACH in 1942. It was interpreted as the Wartanian proglacial outwash, formed at the southern margin of ice-pushed ridge (Trzebnica Hills, Trebnitzer Katzengebirge). Some recent investigations reject this interpretation and denay the occurrence of the Wartanian ice-sheet in Southwestern Poland. The paper presents new sedimentological investigations from deposits of the Siedlec Sandur. The main result of this study is detailed description of some classical, described by SCHWARZBACH, and some new sections. From them, it was concluded that the Siedlec Sandur represents the proglacial alluvial fan with sedimentary structures typical for fans deposited in semi-arid climates. In turn, the glaciofluvial material of the fan suggests that sedimentation took place in polar desert conditions. This conclusion confirms rather SCHWARZBACH's view, than views of his opponents, and confirms indirectly an occurrence of the Wartanian ice-sheet in Silesia. The paper discuss also a possible extent of this ice-sheet in Trzebnica Hills.

[Der warthezeitliche Zedlitzer Sander südlich des Trebnitzer Katzengebirges, Schlesisches Tiefland, südwestliches Polen: eine Neuüberprüfung nach fünfzig Jahren]

Kurzfassung: Der Zedlitzer Sander (Siedlec Sandur) in Schlesien, im südwestlichen Polen gelegen, wurde zuerst von M. SCHWARZBACH im Jahr 1942 beschrieben. Er wurde als ein warthezeitlicher Sander gedeutet, der am Südrand der Stauchmoräne (Trzebnica Hügel, Trzebnica Katzengebirge) entstanden war. Einige neuere Untersuchungen widersprechen dieser Interpretation und negieren das Auftreten warthezeitlichen Eises in Südwest-Polen. Der vorliegende Beitrag präsentiert neue sedimentologische Untersuchungen aus den Ablagerungen des Siedlec Sanders. Das wichtigste Ergebnis dieser Studien ist eine detaillierte Beschreibung einiger klassischer, schon von SCHWARZBACH beschriebener und einiger neuer Aufschlüsse. Aus diesen Aufschlüssen wurde geschlossen, daß der Siedlec Sander einen eiszeitlichen Schwemmfächer mit Sedimentstrukturen repräsentiere, wie sie auch in Schwemmfächern semiarider Klimate vorkommen. Das glaziofluviatile Material des Schwemmfächers legt nahe, daß seine Sedimentation in einer kalten Polarwüste erfolgte. Dieser Schluß spricht für SCHWARZBACHS Deutung und nicht für die seiner Opponenten, und er belegt indirekt das Auftreten warthezeitlichen Eises in Schlesien. Im vorliegenden Beitrag wird außerdem die mögliche Ausdehnung des Eises in das Trebnitzer Katzengebirge diskutiert.

1 Introduction

MARTIN SCHWARZBACH in his work "Das Diluvium Schlesiens" (1942) discussed broadly the problem of extent and sediment stratigraphy of the Wartanian (Warthe) stage in Middle Silesia. His major data came from the Trzebnica Hills (Trebnitzer Katzengebirge) and from its southern foreland. SCHWARZBACH (1942) definitevely established that the maximum extent of the Wartanian stage in Middle Silesia is on the top of the Trzebnica Rampart. The main arguments were the till of this age which was found in several sections near Trzebnica and because the Wartanian outwash plain was found (Zedlitzer Sander, Siedlec Sandur) in the southern foreland of the rampart. Now, after fifty years, the discussion on status of the Wartanian stage in Silesia is coming back. A series of papers has presented data which suggest that there ist no Wartanian deposits in Middle Silesia (WINNICKI 1990, 1991, WINNICKI & SKOMPSKI 1991). Fortunately, some of the "classical" sections, which were examinated by SCHWARZBACH (1942), have been lately again exposed. This make possible to re-examine SCHWARZBACH's interpretation and discuss more critically the "Wartanian problem" in southwestern Poland. The paper presents detailed data from Pierwoszow (Pürbischau) outcrop (SCHWARZBACH 1942, page 212-218, figures 6-10) and from two new outcrops which are located southwards the Trzebnica Hills, on the plain which has been supposed to represent the Wartanian proglacial sandur (Fig. 1).

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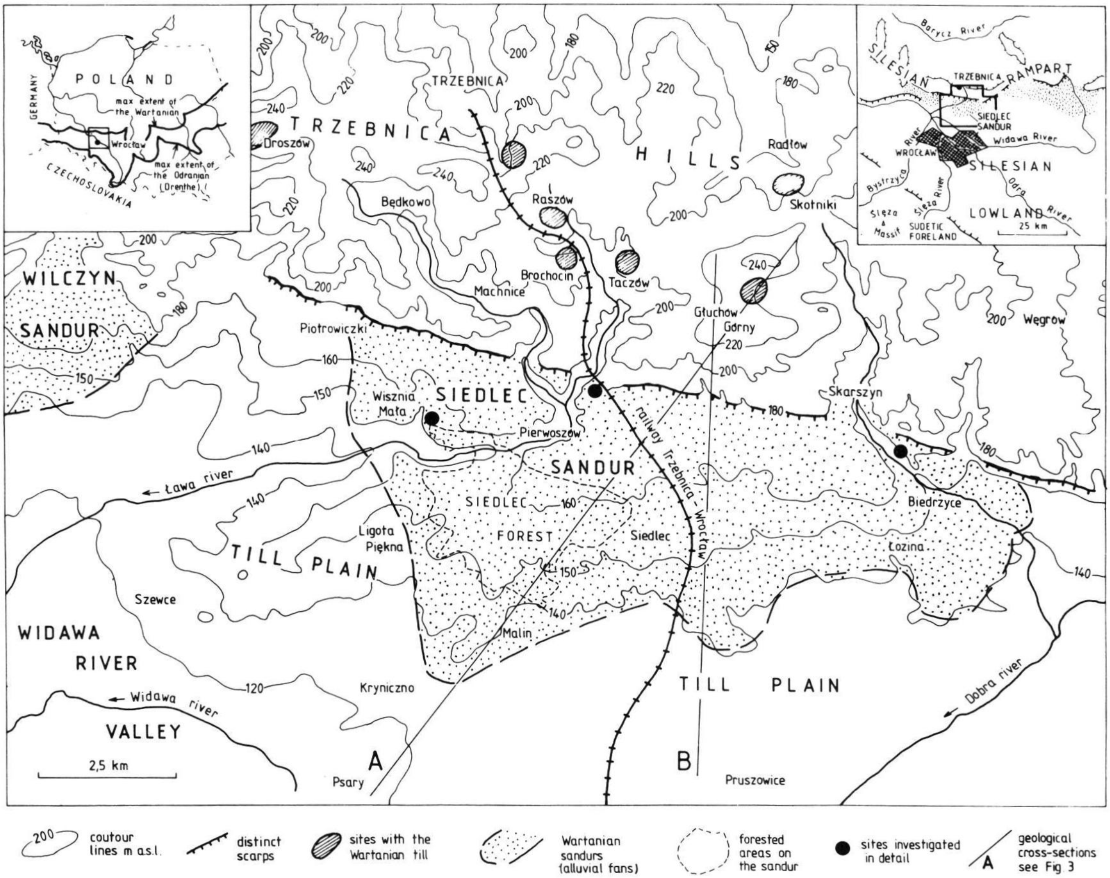

Fig. 1: Location of the Siedlec Sandur southwards the Trzebnica Hills.

2 Geology of the Trzebnica Hills and its southern foreland

2.1 Historical background

The Trzebnica Hills were for many years the stratotype region for the Silesian Pleistocene stratigraphy. FRECH (1901, 1904) described two tills in superposition in Trzebnica outcrops: the Elsterian and the Saalian one; both were deformed together with Neogene clay in substratum. Later, TIETZE (1910, 1915) and FRECH (1913) found that two Pleistocene tills occur also southwards the Trzebnica Hills, near Wroclaw. DITTRICH (1914) and then MEISTER (1935) and SCHWARZBACH (1942) described the next till near Trzebnica, which overlay discordantly deformed, older tills and Neogene clay. This till, which was supposed to represent the Wartanian (SCHWARZBACH 1942), was found only in few sections: Gluchow Górny, Taczów Wielki, Radlow, Raszyn, Trzebnicki Las Bukowy and Droszów (DITTRICH 1914, MEISTER 1935, SCHWARZBACH 1942). In all cases, it was only 2-4 m thick, usually covered by loess and its lateral extent was unknown, presumably small.

At the same time, there was discussion on genesis of the Neogene/Quaternary sediment deformation found in Trzebnica Hills. Older authors prefered tectonic (endogenic) genesis (FRECH 1901, 1913, OLBRICHT 1924, CZAJKA 1931, MEISTER 1935). However, since the work of BERGER (1937), the glaciotectonic genesis (push moraine) have been usually prefered and the age of deformation was related to the Wartanian stage (SCHWARZBACH 1942, WOLDSTEDT 1954, 1955, KRYGOWSKI 1950, WALCZAK 1951, PACHUCKI 1952, RÓZYCKI 1957, 1968, ROTNICKI 1960, 1967), although GOLAB (1951) and LYCZEWSKI (1964) still advocated arguements on their tectonic genesis.

2.2 Results of recent geological investigations

Recent geological investigations indicate that the Silesian Lowland (Wroclaw region) can be subdivided into two regions: the Wroclaw Basin with 40 - 80 m thick Pleistocene sequence, which is surrounded by areas with thin (below 20 m) or no Pleistocene deposits and with Neogene clays at the ground surface (CZERWONKA & KRZYSZKOWSKI 1992). Three Pleistocene glacial units, including three tills have been found in the Wroclaw Basin (CZERWONKA & KRZYSZKOWSKI 1992). The lowermost till, the Pietrzykowice Till, is characterized by large predominance of Scandinavian, crystalline rocks; the middle till, the Wierzbno Till, is characterized by a predominance of Baltic limestones; and the uppermost, the Smolna Till, is again characterized by predominance of Scandinavian crystalline rocks. On the other hand, the locally-derived rocks show palaeotransport from NW to SE for both Pietrzykowice and Wierzbno Tills and from NE to SW for the Smolna Till. These tills were interpreted to represent two stadials of the Elsterian (Pietrzykowice and Wierzbno Tills) and the older Saalian (Drenthe, Odranian) stage (Smolna Till) (CZERWONKA & KRZYSZKOWSKI 1992). In the northern part of the Wroclaw Basin, at the southern margin of the Trzebnica Hills, this sequence is covered additionally by 10 - 30 m thick series of sands and gravels - the Siedlec Formation, and by 0,5 - 1,5 m thick loess (Figs 2 and 3).

The Pleistocene geology of the Trzebnica Hills is more complex. Most of outcrops have only one till, which most problably represent an equivalent of the Smolna Till (the Odranian-Drenthe stage) (WINNICKI & SKOMPSKI 1991). This till is usually deformed together with glaciofluvial and glaciolacustrine deposits and/or with Neogene clay forming fold or thrust zones. KRZYSZKOWSKI (1992) described in the northern part of Trzebnica Hills, from both outcrops and borings, a set of synclines and anticlines which comprise at least two tills. The lower till may correspond with the Wierzbno Till and the upper one with the Smolna till of the Wroclaw Basin. Other parts of Trzebnica Hills has even less valuable data. Most of borings have only simple lithological description of deposits with no petrological data. Hence, lithostratigraphic correlation of deposits is very difficult, although it seems that at least two tills occur here, similarly to the northern part of Trzebnica Hills (Fig. 2). Some of borings comprise several alternating sequences of tills, sands, glaciolacustrine silts and Neogene clays. Other borings, in turn, comprise only Neogene deposits with 5-10 m thick till or loess at the top. Such sequences can be easily interpreted as representing thrust structures (Fig. 3 a). The age of sediment deformation in Trzebnica Hills, as in whole Silesian Rampart, is recently related rather to the Odranian (Drenthe) stage than to the Wartanian (Warthe) (SZCZEPANKIEWICZ 1969, BRODZIKOWSKI 1982, 1987). The rampart is interpreted as push moraine overrided by an ice-sheet during a continuous advance. The margin of the Odranian ice-sheet is located about 70-80 km sosuthwards from the Trzebnica Hills.

The occurrence of the Wartanian till in Trzebnica Hills cannot be confirmed or rejected by recent investigation. The conclusion by WINNICKI (WINNICKI

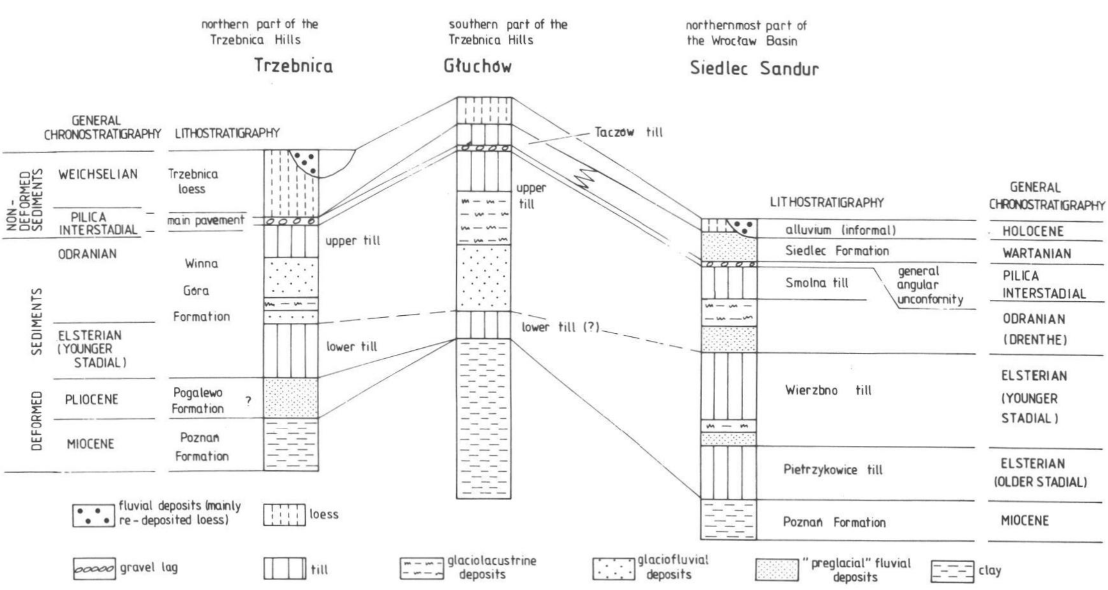

Fig. 2: Stratigraphy of Pleistocene deposits of the northern part of Silesian Lowland (Wroclaw Basin) and Trzebnica Hills.

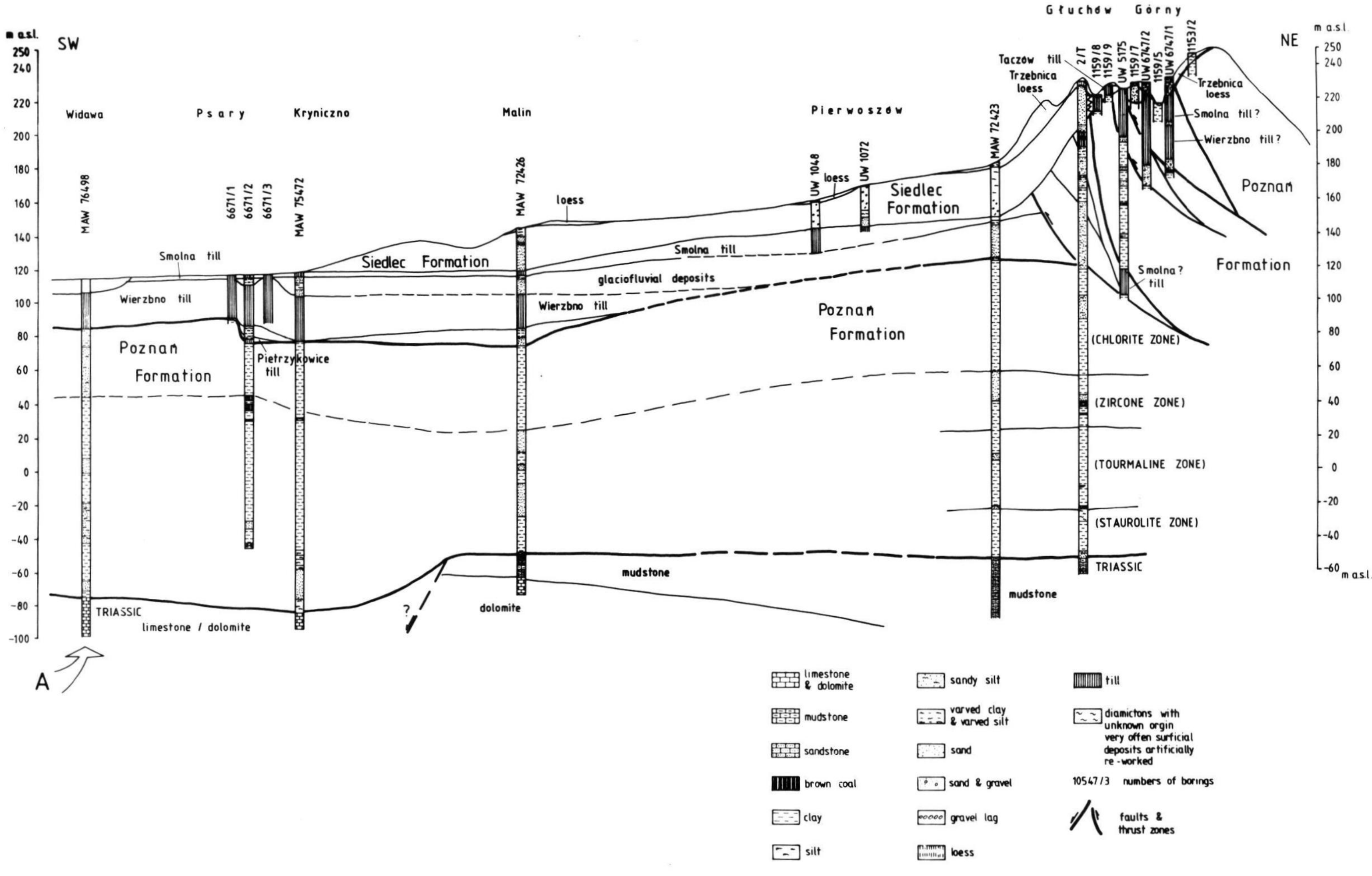

Fig. 3: Geological cross sections throughout the Siedlec Sandur and southernmost part of Trzebnica Hills. Location of sections is in Fig. 1.

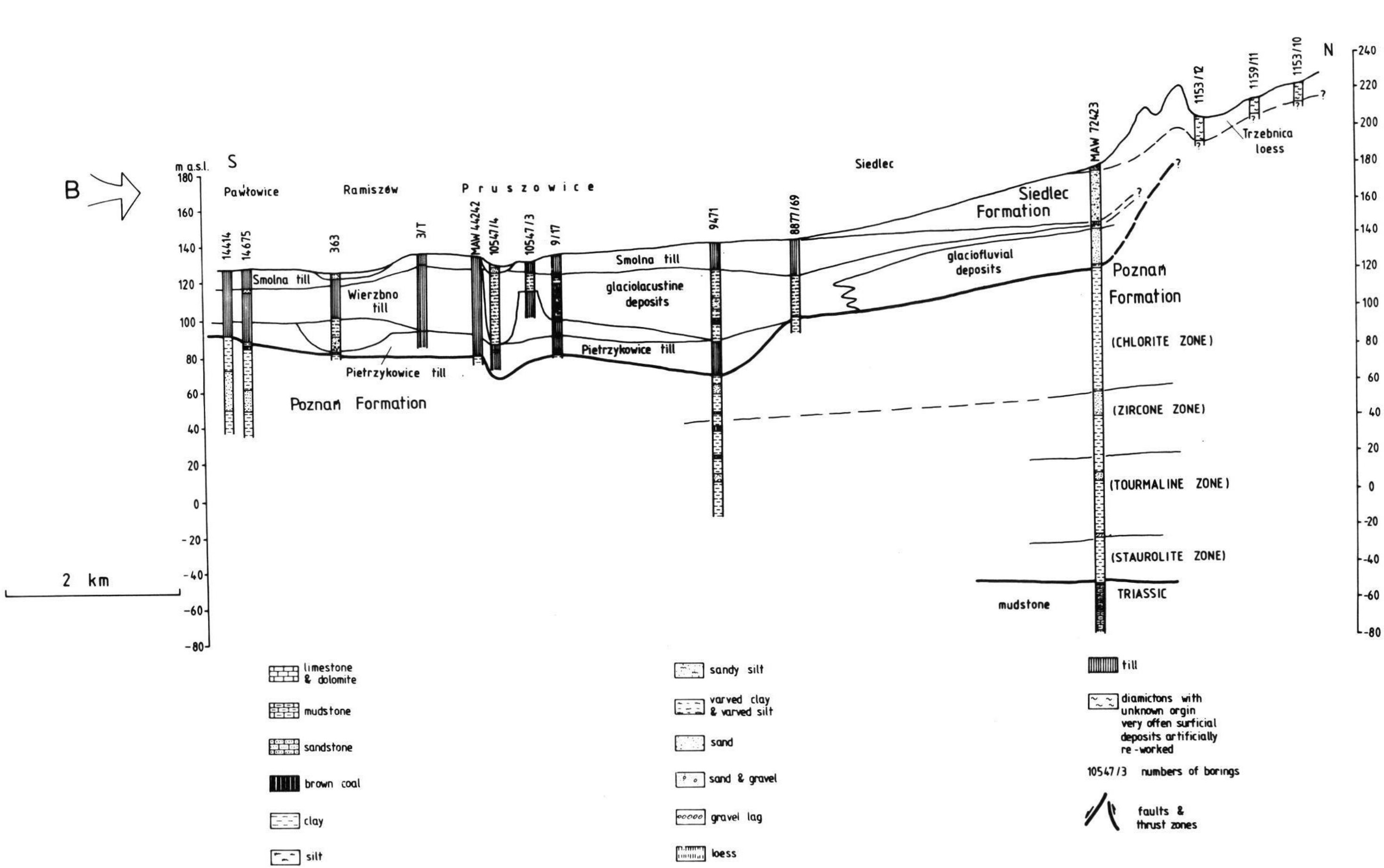

Fig. 3: Geological cross sections throughout the Siedlec Sandur and southernmost part of Trzebnica Hills. Location of sections is in Fig. 1.

1990, 1991, WINNICKI & SKOMPSKI 1991), that he did not find the Wartanian till in Trzebnica Hills during his geological mapping is rather wrong. None of the outcrop described by MEISTER (1935) and SCHWARZBACH (1942) have been re-examined, simply because these outcrops are completely destroyed and vegetated. Hence, it seems that the older descriptions are still correct and can be adopted to recent stratigraphy. If so, the possible Wartanian till is a till lying discordantly on older glacial and Neogene deposits. I propose a lithostratigraphic name for this till - the Taczów Till, from Taczów outcrop, described in detail by MEISTER (1935, p. 8) (Fig 2). The similar sequence was then described in the next village - Brochocin (Brockotschine = Moltketal) by SCHWARZBACH (1942). All sites with the Taczow Till mentioned by MEISTER (1935) and SCHWARZBACH (1942) are shown approximately in Fig. 1 and they mark possible southernmost extent of the Wartanian ice-sheet in Trzebnica Hills.

3 The Siedlec Sandur

3.1 General morphology and geology

The Siedlec Sandur (Siedlec Formation) is a sandy-gravelly, cone-shaped deposit lying on the Smolna till in the southern foreland of the Trzebnica Hills (Fig. 3 a & b). The plan view of these deposits is fan-shaped and the contours bow downlope from two apexes, one near Pierwoszów and other near Skarszyn, which lie at the border of ice-pushed ridge (Fig. 1). The cross fan profile is convex and radial profiles are usually flat or concave in the uppermost part but they are convex in the lowermost part of the fan. The slope inclination varies from 0,50 % to 1,67 %. Generally, three segments of the fan can be recognized from its morphology: the upper part of the fan with slope inclination ranging from 1,0 % to 1,33 %, the middle part of the fan with slope inclination between 0,5 % to 0,67 % and the lower part of the fan, near its southernmost margin, with slope inclination up to 1,67 %. The thickness of deposits decreases systematically from apex zones (ca. 30 m) to its southern margin, where is only thin (below 10 m) sandy cover on the hill. The southern margin of the Siedlec Sandur is marked by scarp, which represent also a sharp lithological boundary, between a sand and a till (Fig. 1). The last one forms a widespread till plain around the Siedlec Sandur. The boundary between the sandur and till plain sometimes visible as boundary between a forest and fields (Fig. 1). There are no good traces of outflow from the sandur to the Odra river valley, being south, from the time of its formation. The Siedlec Sandur is probably dissected only by younger valleys, infilled with Weichselian and Holocene fluvial deposits (Fig. 1). In the northern part of the sandur, sandy-gravelly deposits are covered by 0,5 - 1,5 m thick loess cover, which continues northwards, into a thick loess cover in Trzebnica Hills (6 - 20 m) (Fig. 2).

3.2 The sandur deposits

The principal deposit of the Siedlec Sandur is a coarse sand with a varying amount of gravel, low-

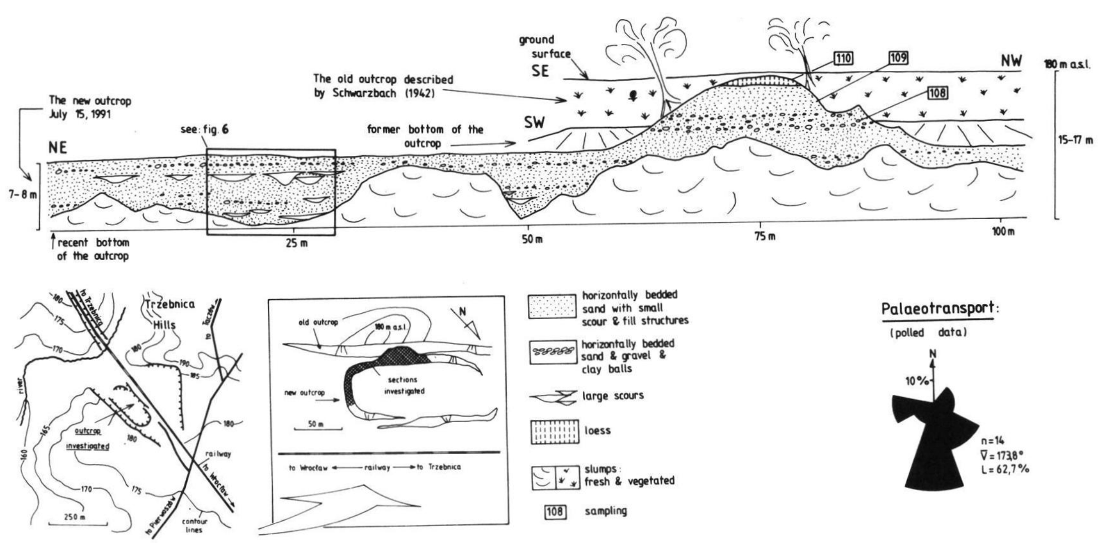

Fig. 4: General stratigraphy and sediment characteristic in Pierwoszów outcrop.

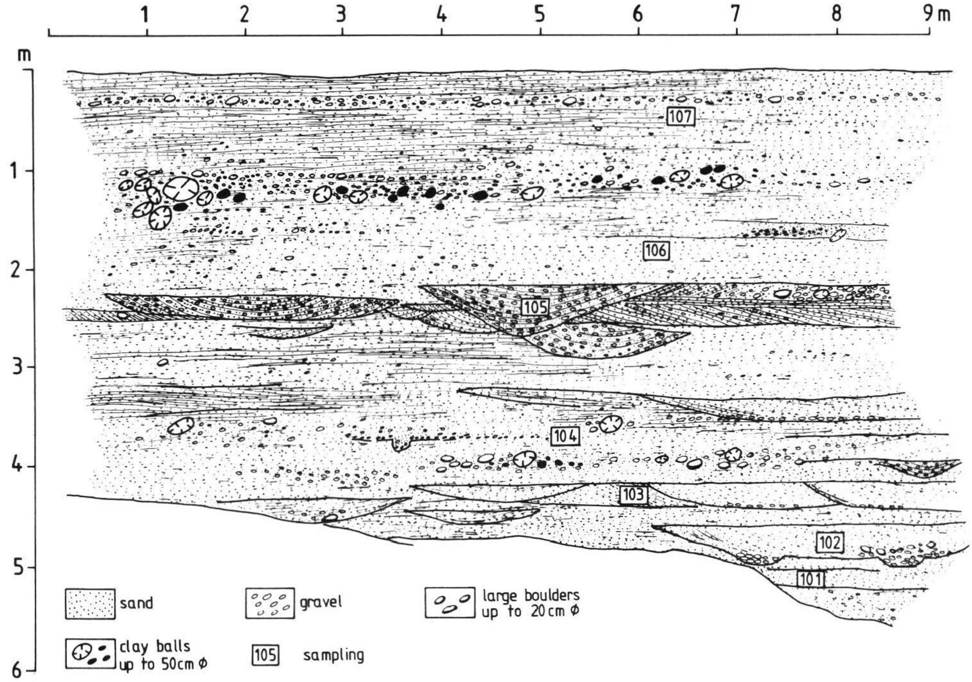

Fig. 5: Detailed section of the Pierwoszów outcrop (location is in Fig. 5) with levels of shallow troughs and gravels and clay balls, separated by horizontally bedded sands and pebble sands.

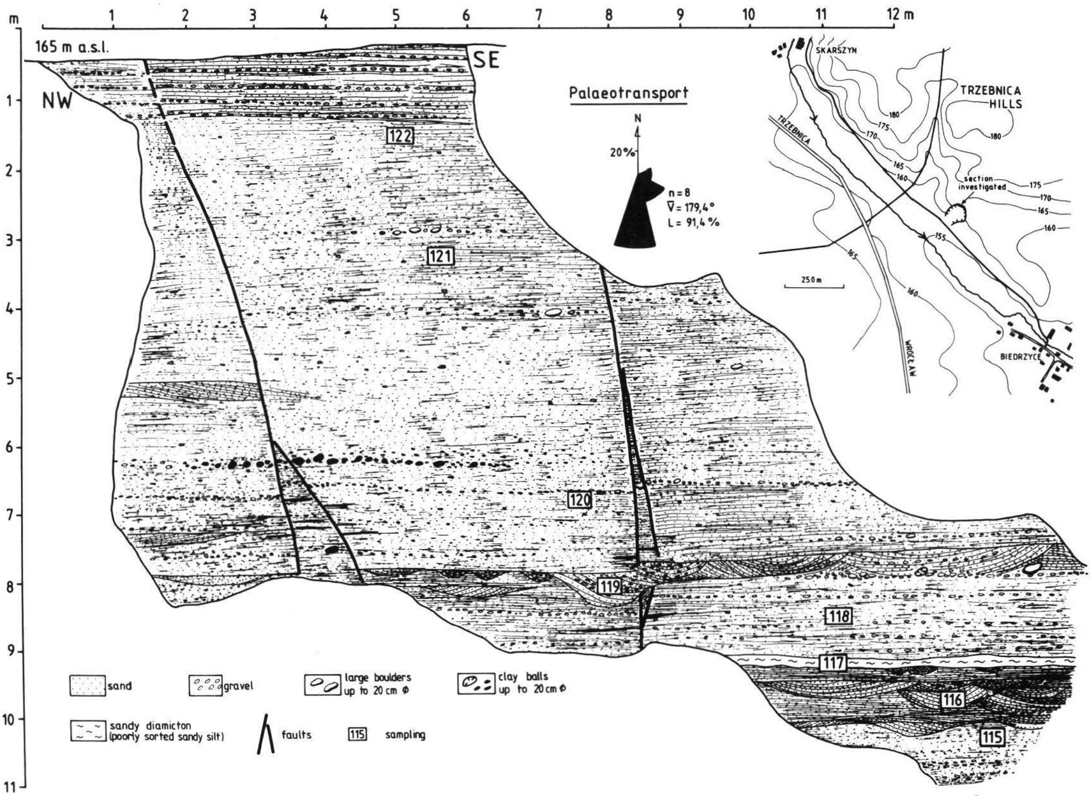

Fig. 6: The stratigraphy and sedimentary structures of deposits in Biedrzyce outcrop. Two levels of shallow troughs and one level of clay balls are visible in lower part of the section.

angle or horizontally bedded. The latter sediment (Sh facies) dominate in the general picture of sandur sequence (Tabula 1, A). Gravels and/or clay balls may be concentrated in levels or be present in an isolated position. The lateral extension of horizontal strata is general in the order of some tens of metres. The thickness of these strata varies from several decimetres to several metres. The low-angle units have average lenght from some decimetres to some metres and smaller thickness, reaching up to 0,5 m. These sediments are thought to represent sheet-flood deposit (Bull 1972), deposited over large area by a shallow, supercritical flow during short periods with considerable discharge (McKee, Crosby & Berryhill 1967, Williams 1971, Miall 1977, Frostick & Reid 1977, Tunbridge 1981). The erosional surfaces between deposits from different sheet-floods are often marked by small scour-and-fill structures (Sc facies) (Tabula 1 D). They are usually 2 - 6 centimetres deep and 10 - 20 centimetres long, infilled by coarser material than in horizontal laminae. Small scours were formed locally during the sheet-floods.

In the sandur deposits described, the channel deposits are less frequent and represent two types of channel-fills: shallow, single depressions (troughs) and trough cross-bedded sets with thickness up to 2 m (st facies). The shallow troughs are up to 0,5 m deep and about 1 - 2 m wide and they usually have "festoon" lamination, parallel to the lower profile of trough (Tabula 1 B, C). The shallow troughs are often concentrated in levels, occurring in horizontally bedded deposits (Fig. 4, 5 & 6). The shallow troughs formed most probably during the vanning stages of floods, when low discharge occurred. Channel-fills formed during the next sheet-flood. The levels of shallow channels are believed to represent a former fan surface. In turn, the thick trough cross-bedded sets, which are usually interbedded with thin beds with horizontal bedding and some planar cross bedding (Sp facies) Fig. 7), represent most probably large channel fills (Bull 1972, Church & Gilbert 1975, Boothroyd & Ashley 1975, Miall 1977, 1978, 1985, Allen 1983).

Very rare deposit, found in two sections, is a massive, fine sand to sandy silt. It is usually poorly sorted deposit (diamicton, Dm facies). This facies forms 10 - 15 cm thick, laterally extensive layers. Most probably, this facies represent an overbank deposit, formed after main floods.

Additional feature of the sandur deposits are normal faults (Tabula 1 E and Fig. 6). They were found in one outcrop (Biedrzyce), which is located on the valley bank. The faults cross all deposits, from the top to the bottom of outcrop. It seems, that they represent completely post-depositional feature, formed during the sediment gravity relacation on the slope.

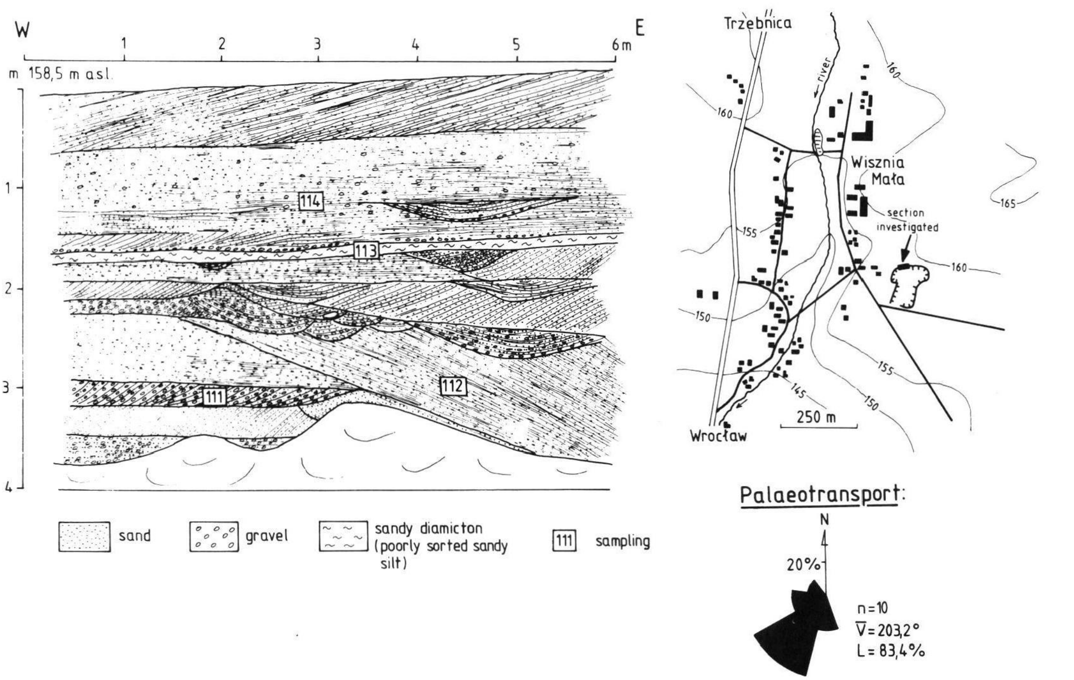

Fig. 7: The stratigraphy and sedimentary structures of deposits in Wisznia Mala outcrop.

3.3 The Pierwoszów outcrop

This outcrop is located in the main apex zone of the Siedlec Sandur, near village Pierwoszów (Fig. 1). It was described at first by SCHWARZBACH (1942). Recent outcrop is 7 - 8 m deeper than the SCHWARZBACH's outcrop, with a section up to 17 m high (Tabula 1).

The section comprises almost only horizontally bedded pebble sand and shallow channels, and a thin loess cover at the top (Fig. 4). The shallow channels are concentrated in two levels, one near bottom of the outcrop and other one about 5 - 6 m from its bottom. The uppermost part of the section (the old outcrop) has no shallow channels, containing only 8 - 10 m thick, horizontally bedded strata (Fig. 4). Moreover, there are observed several, up to 0,5 m thick, horizontally bedded levels with gravels and clay balls (Fig. 4). In place, large clay balls are very concentrated, forming the "clay ball lags" (Fig. 5). The clay balls are formed of Tertiary green clay and they have varying size, from a few millimetres up to 0,3 m, occasionally single clay balls may reach up to 0,5 m. The size of gravels is less changeable, from 1 to 10 centimetres.

The lower level of shallow channels have, in fact, at least three sub-levels of channels, which are separated by horizontally bedded sands (Fig. 5). Nevertheless, all these channels occur within the bed with thickness of 1 m. The channels are formed practically of coarse sand, except two small troughs with gravels. In turn, the upper level of shallow channels is more concentrated, contains larger troughs and it is formed in majority of gravels, although no clay balls have been observed (Fig. 5). Palaeocurrent measurements from troughs show that there is no difference between two levels mentioned, and that the transport of material was from north (Fig. 4).

3.4 The Biedrzyce outcrop

This outcrop is located in the apex zone of the small fan, tributary to the main alluvial fan, which is located between villages Skarszyn and Biedrzyce (Figs. 1 and 6). Recent outcrop is 11 - 12 metres high.

The Biedrzyce section, like in Pierwoszów, comprises almost only horizontally bedded pebble sands and shallow channels and additionally a 10 - 15 cm thick layer of massive, sandy diamicton. The shallow channels form two levels. The lower one is about 1 m thick and contains three sub-levels of troughs, separated by horizontally bedded sands. The channels are formed both of coarse sands and pebble sands, although the latter are less common (Fig. 6). The lower level of shallow channels is followed by thin layer of massive, fine sand to sandy silt (sandy diamicton) (Fig. 6). This bed is laterally continuous, at least 4-5 metres. The upper level of shallow channels lies about 1,5 m above the lower one and it is formed of only one, 0,2-0,5 m thick bed with troughs. Some troughs of this level are, however, much larger than troughs of the lower level (Fig. 6). Moreover, these troughs contains usually pebble sands and gravels (with diameter up to 20 cm).

Within the horizontally bedded sand, only one level with clay balls and several levels of gravels can be observed (Fig. 6). Single clay balls are also observed in other horizontal beds and troughs. Palaeocurrent measurements from troughs indicate transport directly from north (Fig. 6).

3.5 The wisznia Mala outcrop

This outcrop is located near the western margin of the Siedlec Sandur, near village Wisznia Mala (Figs. 1 and 7). The section investigated is only 4 m high.

The Wisznia Mala section is threefold. The lower part of the section comprises an alternating cross bedded and horizontally beddes sands or pebble sands. The cross bedded sets are represented by large troughs, small troughs and planar sets. These deposits are followed by thin, but laterally continuous, massive, sandy silt with single, floating gravels (sandy diamicton). The middle part of the section, about 1 m thick, is represented by horizontally bedded sand with one shallow channel (Fig. 7). This sediment, although thin, is very similar to sediments from Pierwoszow and Biedrzyce outcrops. The upper part of the section is occupied by planar cross bedded sand, representing, most probably, a part of similar sequence as in its lower part. The important fact is that no clay balls have been found in Wisznia Mala outcrop. The palaeocurrent measurements from trough and planar corss-bedding indicate transport from north-east (Fig. 7).

3.6 Grain size distribution

Most of sandur deposits are medium sands to pebble sands. Mean size varies from 1.84 Ø to -1.22 Ø sorting varies from 0,57 Ø to 2.25 Ø. Sporadically occur fine sands (M_Z 2.91 Ø, o 0.68 Ø) or sandsy diamictons (M_Z 1.87-2.17 Ø, o 0.90-1.73 Ø) (Fig. 8).

Very interesting is the vertical succession of sediments (Fig. 8). In Pierwoszów outcrop, there are three distinct layers which differ in grain size. The lower and upper one are represented mostly by medium to coarse sands with only rare gravel beds, whereas the middle one is represented by pebble sands with common gravel beds. The coarser layer

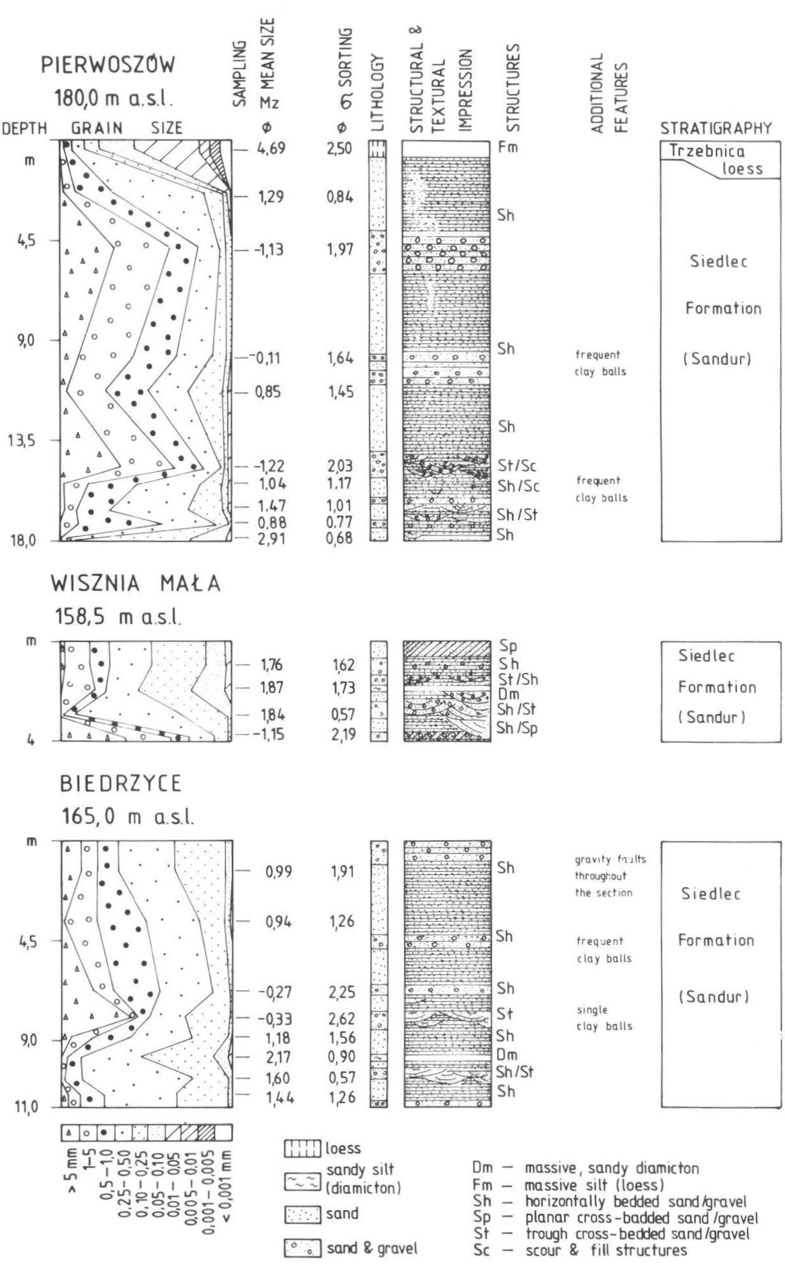

Fig. 8: The grain size distribution and vertical succession of features of deposits of the Siedlec Sandur.

comprises deposits from a bottom of upper level of shallow channels up to the uppermost gravel level, 3 - 4 m below the loess (Figs. 4 & 8). The Biedrzyce section have almost the same stratigraphy: the lower layer with medium to coarse sands and coarser layer lying above. The latter starts from the bottom of upper level of shallow channels and continues up to the top of the section (Figs. 6 & 8). The thickness of sediments in the Wisznia Mala outcrop is small, probably not enough for interpretation of vertical succession of grain size. Nevertheless, coarser deposits are more common in lower part of the outcrop, and probably they represent an equivalent of coarse, middle layer in Pierwoszów.

3.7 Gravel petrography

The gravel petrography have been examined in two outcrops: Pierwoszow and Biedrzyce. In the first one, samples have been taken from lower and upper part of the sequence. The size of examined gravels was 1 - 10 cm; the number of gravels in single sample varied from 128 (Pierwoszów) to 192 (Biedrzyce). The results are presented in Table 1. Generally, gravel petrography shows for glacial origin of deposits, most probably derived from a till. The time of deposition is rather young, because of large content of Baltic limestones, comparable with the limestone content in tills. Lacking of large number of flint suggests, in turn, that the source material (till) was also not rich in flint. The Smolna Till (Odranian, Drenthe), lying on the top of Trzebnica Hills is a flint-poor till (KRZYSZKOWSKI 1992), and it is one possible source of gravels. On the other hand, it seems that the source glacial deposits may be also the Taczow Till (Wartanian, Warthe) or directly glacial material (moraine) derived from the Wartanian ice sheet and transported by subglacial and proglacial streams.

The occurrence of non-resistant Mesozoic limestones and Tertiary mudstones as well as large number of clay balls in deposits of uppermost part of the san-

Tab. 1: Gravel petrography of deposits of the Siedlec Sandur near Trzebnica (%)

	Scandinavian crystalline rocks	Baltic limestones	Scandinavian quartzites & sandstones	flint	quartz	Mesozoic limestones	Tertiary mudstones	syderite concretions	other rocks
Pierwoszow sample no 108	32	40	6	—	11	6	2	2	1
Pierwoszow sample no 105	39	34	7	1	7	12	—	—	—
Biedrzyce sample no 119	44	25	7	1	11	11	1	—	—

dur suggest that transport of material was not long. The distance from outcrops investigated to the first outcrops of the Taczów or Smolna Tills and Tertiary clays beeing northwards is about 2 km (MEISTER 1932, WINNICKI 1988).

3.8 Palaeoenvironmental interpretation

The Siedlec Sandur is a typical alluvial fan. This is considered from its fan-shaped geometry, texture of deposits and sedimentary structures (BULL 1972, HEWARD 1978). The specific feature is that the sandur plan is formed of two fans with apexes about 6 km each from the other. The apexes occur at the mouths of deep valleys cutting the margin of the ice-pushed ridge (Fig. 9). The sandur was formed by proglacial meltwater flowing from north, from the stagnating ice-sheet. The proglacial streams eroded both older glacial deposits and Tertiary clays at the basement, forming 2 km long, narrow and deep valleys before they have reached the margin of the ridge. The predomination of horizontal or low angle bedding in the sandur deposits with only minor channel sedimentation suggest sedimentary conditions typical for alluvial fans in arid climates (BULL 1972). Glacial origin of the fan material suggest, in turn, the cold (periglacial) conditions, most probably a polar desert.

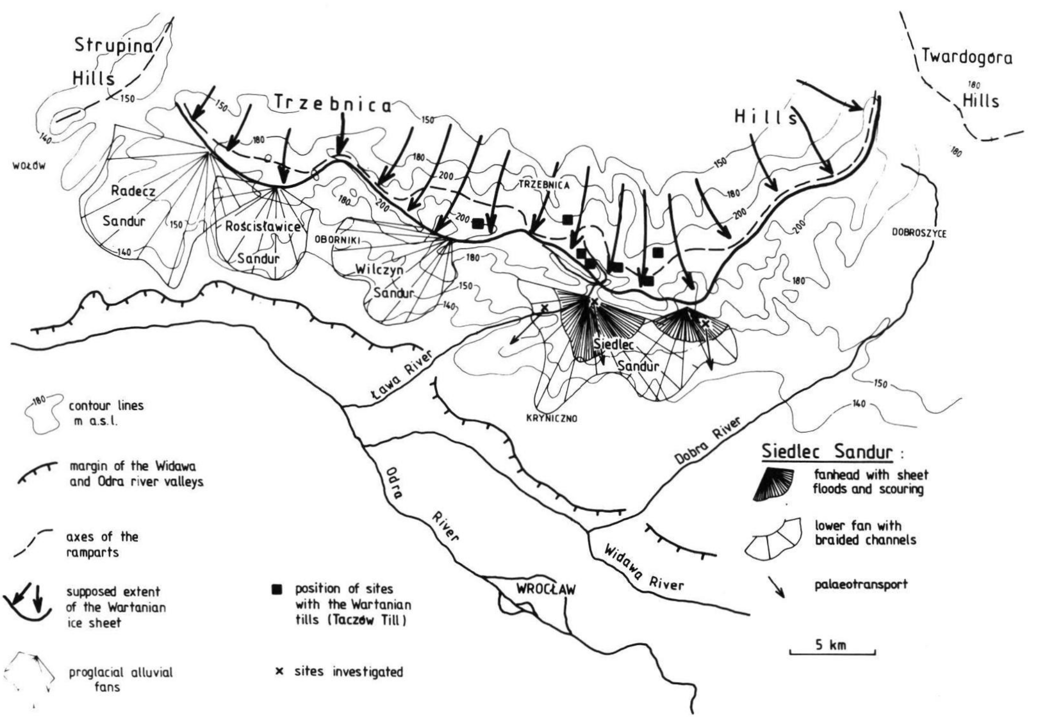

Fig. 9: General palaeogeographic interpretation of the Siedlec Sandur in relation to position of the Wartanian ice-sheet at the Trzebnica Hills.

Generally, the sandur has two sedimentary zones: the fanheads with practically only sheet flood deposition interrupted locally by minor scouring and further towards the bordering ice pushed ridge a lower fan with braided channels and limited number of sheet floods (Fig. 9). Both fans, forming the sandur plain, have similar stratigraphic and sedimentary sequences suggesting that they were formed simultaneously and due to the same processes, in spite of different source area. This well correspond with proglacial origin of the fan. The episodic floods occurred only during the melting of an ice-sheet, which is controlled regionally by changing year seasons. At first, the fanheads were characterized by frequent sheet floods interrupted by dry fan conditions with formation of only small channels. In turn, the next phase of fan development was characterized by rapid but more episodic floods. The accumulated material was usually coarser and no minor channels were formed, suggesting larger water discharge at this time. Probably, this change of sedimentary environment is a result of increasing aridity. The flood water was channelized into braided channels at the lower fan during both phases described. These channels were, most probably, also ephemeral. Lacking of outflow from the fan suggests that water might have evaporated or infiltrated almost at the fan. This probably agrees with the fan morphology. The middle segment of the fan is very flat, suggesting high aggradadion rates. The same processes might also have created the steep slope of the lowermost segment of the fan.

4 Conclusions

From description and interpretation above it is clear that the Siedlec Sandur may be considered as proglacial alluvial fan deposited in periglacial, arid climate and formed at the margin of the ice-pushed ridge. The proglacial sandurs are rather common southwards the Trzebnica Hills (Fig. 9) and they probably have the same features as sandur described. The similar sand bodies, with the same sedimentary structures, fan morphology and similar geographic position at the margins of Saalian ice-pushed ridges have been also described as alluvial fans (sandurs) in the Netherlands (AUGUSTINUS & RIEZEBOS 1971, RUEGG 1977, 1981).

The age of Siedlec Formation (sandur) can be considered from its relation to Smolna Till - the till deposited by the Odranian (Drenthe) ice-sheet. the sandur is undoubtedly younger, lying on the Smolna till (Fig. 2 & 3). Hence, it seems that it is a proglacial equivalent of the Taczow Till, deposited by the Wartanian ice-sheet stagnating on the top of Trzebnica Hills. This interpretation agrees with the former view by SCHWARZBACH (1942) but contradicts the view of WINNICKI (1990, 1991). The last author is interpreting the sand body of the Siedlec Formation as kame plateau deposited during the decay of the Odranian (Drenthe) ice-sheet.

Although the alluvial fan genesis for the Siedlec Formation deposits seems to be unquestionable, there are some problems which are still unclear. First of all, there is small evidence for braided channel sedimentation at the lower fan (one outcrop with section only 4 m high). Also, there is no outcrops at the steep slope of the lowermost segment of the sandur-hence, the genesis of this slope is not solved satisfactorily, yet. Periglacial conditions (polar desert) should be confirmed by an occurrence of frost fissures or ice wedge casts or other permafrost indicators, but deposits investigated have no such periglacial structures. This is unexpected characteristic of the Siedlec Sandur, because for example the Weichselian proglacial sandurs in Poland have large number of permafrost indicators (KOZARSKI 1974, 1992). Further sedimentological investigations of other Wartanian proglacial sandurs lying southwards the Trzebnica Hills (Fig. 10) should examine whether the sheet flood deposition is only local feature of the Siedlec Sandur or is climatically controlled occurring in whole region. These investigations should solve definitevely the problem of outflow from sandurs to the river Odra valley and solve the stratigraphic relation between the sandurs and so known "upper" terrace of the river Odra valley, supposed to represent the Wartanian (SZCZEPANKIEWICZ 1959, ROZYCKI 1969). Both problems have not been solved satisfactorily for the Siedlec Sandur.

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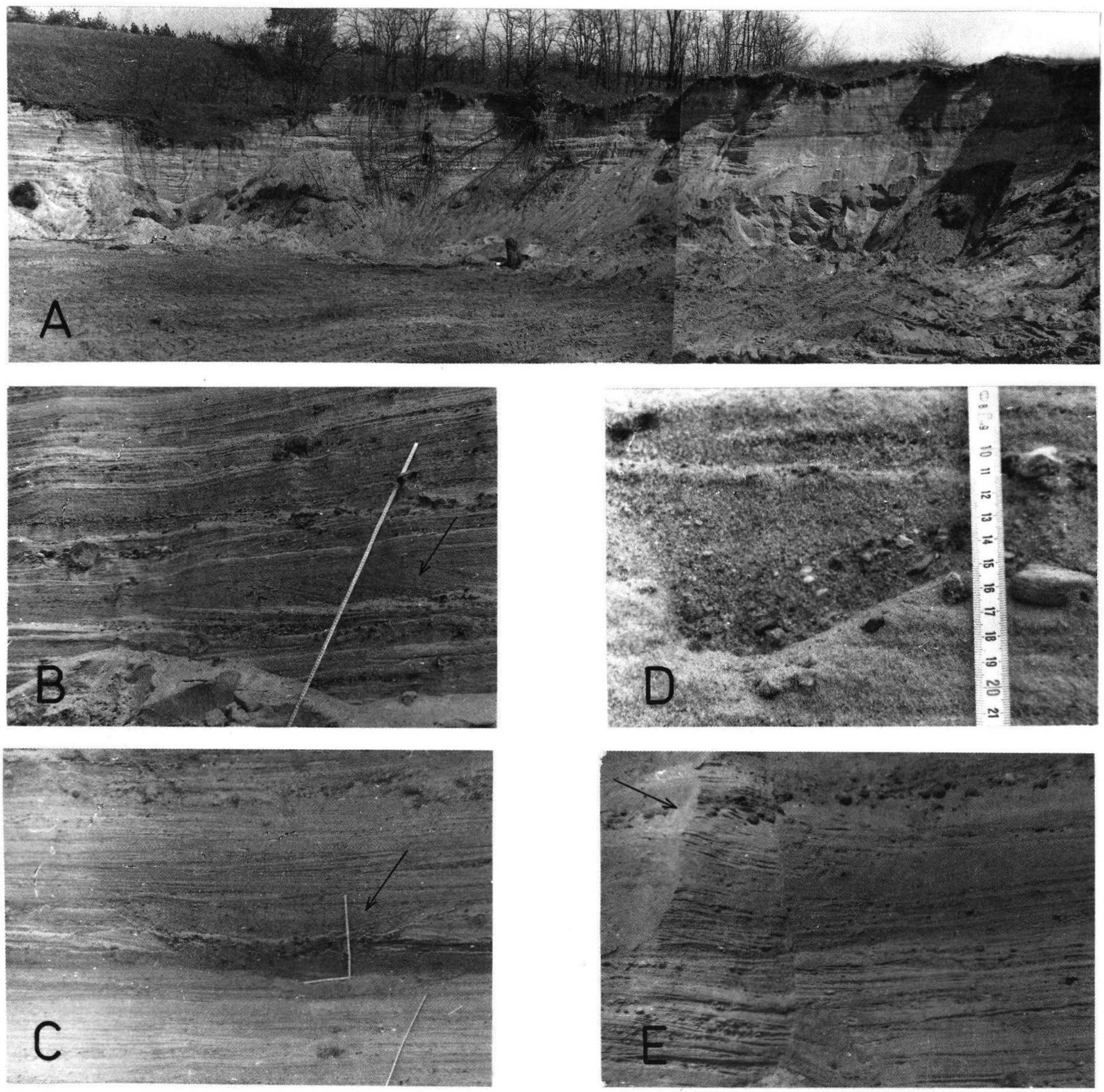

Plate 1. The deposits of Siedlec Sandur: A - the 7-8 m thick, monotonous sequence of horizontally bedded sands. B & C - examples of shallow depressions (trougs marked by arrows) lying within the horizontally bedded sands, D - small scour-and-fill structure, E - horizontally bedded sands with a level of large clay balls (arrows), the normal fault is visble on the left side of picture.