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GLACIOMARGINAL DEPOSITION IN THE OTMUCHÓW DEPRESSION, SW POLAND, AND ITS PALAEOGEOGRAPHICAL IMPLICATIONS

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Abstract: This paper focuses on the problem of depositional environments and the development of glaciomarginal zone in the Otmuchów Depression, SW Poland, during the Odranian (Drenthe) glaciation. The research was conducted at the Wójcice site, which is situated on the southern border of a hill train, the so-called Otmuchów-Nysa Hills, rising on the northern side of the Nysa Kłodzka River valley. The sediments under study were deposited in the distal zone of glaciomarginal fans prograding into a bay of a large lake formed in the dammed valley of the Nysa Kłodzka River. Sedimentation was characterised by frequent oscillations of water level in the lake, which caused fan dissection and lateral migration of depositional subenvironments. These phenomena are recorded by abundant erosion surfaces and vertical succession of alternating lithofacies associations of the deposits, which are typical of different parts of the distal fans. Sedimentological analysis has also enabled palaeogeographical reconstruction of the glaciomarginal zone. It is found that the ice-sheet lobe advanced into the Nysa Kłodzka River valley from the NE.

Key words: glaciomarginal zone, sedimentology, Pleistocene, Otmuchów Depression, SW Poland.

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INTRODUCTION

The development of a glaciomarginal zone in the foremountain reach of the Nysa Kłodzka River valley, i.e. in the Otmuchów Depression (Fig. 1), has been discussed for decades (Behr, 1930; Woldstedt, 1932; Anders, 1939; Schwarzbach, 1942; Rembocha, 1958, 1960, 1964; Walczak, 1954, 1966, 1968, 1970, 1972; Szponar, 1974; Wroński & Kościówko, 1982; Badura *et al*., 1996; Przybylski, 1998). However, a consistent concept concerning the maximum extent of the Odranian (Drenthe) ice-sheet in this area has not been established so far (Fig. 2). In all previous geomorphological, geological and palaeogeographical analyses the attention has been mainly put to the so-called Otmuchów-Nysa Hills, clearly visible in the morphology. These hills form a train stretching latitudinally along the northern side of the Nysa Kłodzka River valley between Kamieniec Ząbkowicki and Nysa (Figs. 1, 2). The hills rise up to 280 m a.s.l., i.e. about 80 m above the valley floor. In other parts of the Otmuchów Depression glacial forms and deposits are extremely rare. The central part of the depression is occupied by the Nysa Kłodzka River valley filled with alluvium, and its southern part is cut by many tributaries of the Nysa Kłodzka River.

In this paper, the results of research on the deposits occurring on the southern border of the Otmuchów-Nysa Hills are reported. The research was carried out at the Wójcice site, several kilometres to the west of Nysa. The aim of this study is to provide detailed sedimentological analysis and interpretation of sedimentary environments. The final result is a reconstruction of palaeogeographical development of the glaciomarginal zone in this specific part of the Sudetic Foreland.

RESULTS OF PREVIOUS STUDIES

Numerous concepts on the origin of the Otmuchów-Nysa Hills have been published so far. These distinct landforms, composed of sandy-gravelly and diamictic deposits,

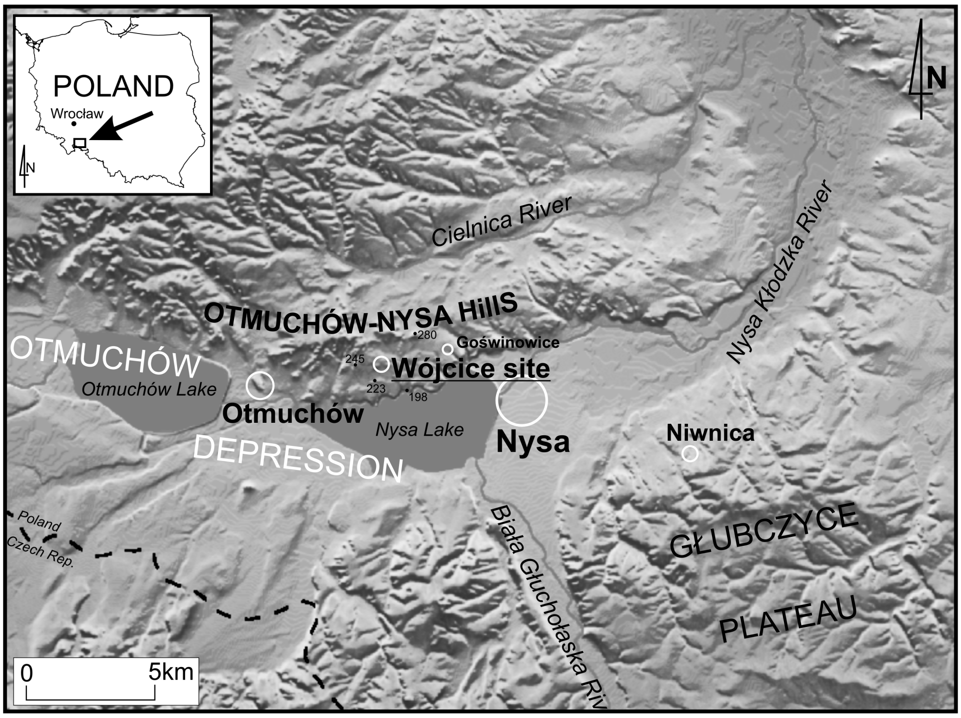

Fig. 1. Relief of the Otmuchów Depression and the location of study area

were most often interpreted as frontal moraines of the Odranian (Drenthe) ice sheet. Such a view was presented by German researchers: Behr (1930), Woldstedt (1932), Anders (1939), and Schwarzbach (1942), who related the hills to the maximum extent of the glaciation (Fig. 2). Rembocha (1958) described the hills as "erosional remnants of basal moraine" developed as diamictic-sandy cover overlying glaciofluvial sands, which are underlain by alluvial sands. On a detailed geological map of the Sudetes the same author presented the Otmuchów-Nysa Hills as composed mostly of "preglacial" sands. Glaciogenic deposits, distinguished as glaciofluvial sands and less often as lacustrine silts, form only small caps on the hill-tops (Rembocha, 1960, 1964). Walczak (1954, 1966, 1968, 1970, 1972) published different genetic and morphostratigraphic ideas concerning the Otmuchów-Nysa Hills. At first, he considered these hills as frontal stadial moraines from the period of ice-sheet recession (Walczak, 1954). Then he came to a conclusion that these were terminoglacial outwash fans deposited during a recession standstill (Walczak, 1966, 1968, 1970, 1972). Szponar (1974) studied the hills in the following years, and his opinion was similar to that published by Rembocha (*op. cit.*). He divided the deposits into two series of different origin. The lower, fine-grained sandy series was deposited by the Nysa Kłodzka River, and the upper, coarser one, built of sands and gravels, was deposited by meltwaters flowing from the front of the ice sheet, stagnating in a more northerly position in the Cielnica River valley. In his opinion, the present-day hills are erosional remnants. Another view on the origin of the Otmuchów-Nysa Hills was presented by Wroński and Kościówko (1982), who interpreted them as kames. Badura *et al*. (1996) rejected this view, and regarded the hills as fragments of a delta prograding into a terminoglacial lake. Similar interpretation is comprised in Przybylski's (1998) palaeohydrographical analysis of the Sudetic Foreland.

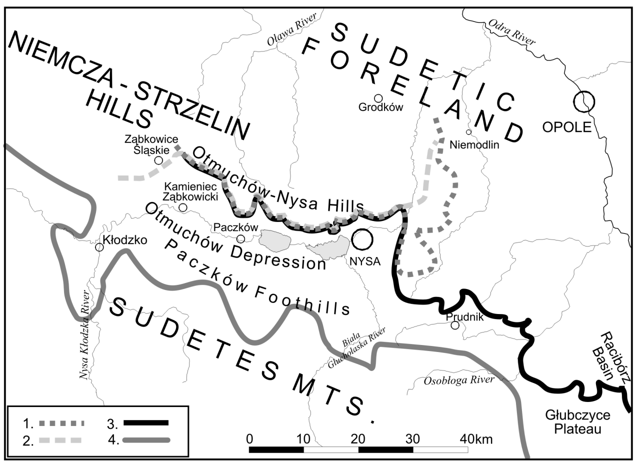

Fig. 2. Maximum extent of the Odranian Glaciation according to: *1* – Woldstedt (1932), *2* – Behr and Mühlen (1933), *3* – Anders (1939), *4* – Walczak (1970)

LOCATION OF THE SITE AND ITS MORPHOLOGICAL AND GEOLOGICAL SETTING

The Wójcice site is located approximately 1 km southwards from the axis of the hills, on the lower morphological level at 240–250 m a.s.l. (Fig. 1). The ground surface is slightly undulated. This zone is about 500-800 m wide. Towards the south, it passes into the next, lower morphological level (about 220–230 m a.s.l.), which is a high terrace of the Nysa Kłodzka River. The exposed sandy and sandy-gravelly deposits are up to 15 m thick. These are underlain by lacustrine silts (Rembocha, 1958; Badura *et al.*, 1996). Till occurs on the northern slopes of the Otmuchów-Nysa Hills. Neogene clays of the Poznań Formation underlie Quaternary sediments.

LITHOFACIES CHARACTERISTICS

Two sedimentary series are distinguished in the exposure.

Series 1 is mostly composed of fine-grained sands, less often medium-grained sands. Several lithofacies associations have been distinguished there (Fig. 3).

Lithofacies association Sh, (Sl) is the most frequent one. It is dominated by lithofacies of sand with horizontal stratification Sh. These are usually accompanied by lithofacies of sand with low-angle cross-stratification Sl, sporadically by sand of ripple cross-lamination Sr. Tabular beds are slightly inclined northwards (Fig. 4a). A similar association Sh, (Sl, Sp) is also found in the lower part of the exposure. This association is characterised by the occurrence of secondary sand lithofacies with planar cross-stratification Sp. The packages are divided by distinct, extensive erosional surfaces dipping at a 5–10^{o}. Each erosional surface is usually overlain by one or two sand lithofacies with large-scale planar cross-stratification Sp, in which the dip direction of laminae is the same as the inclination of the basal erosional surface.

Locally, the association Sh, (Sl, Sm) occurs, in which lithofacies Sh and Sl are accompanied by few lithofacies of massive sand Sm. Some of these lithofacies, especially Sh units, are characterised by a rather high content of coarse-grained sand, and sporadically even fine-grained gravel.

Association Sh, Src, composed of finer-grained deposits, occurs between the associations Sh, (Sl) in the lower part of the series 1 (Figs. 3, 4b). It is also dominated by lithofacies of fine-grained sand with horizontal stratification Sh. Sandy lithofacies with ripple cross-lamination Src coexists there, too. The mentioned lithofacies occur in cosets 1 to 3 m thick.

The finer-grained lithofacies associations Src, SFw, (Sr) occur between the associations Sh, (Sl) in higher position within series 1 (Fig. 3). They are dominated by fine sand ripple structures. These are mainly 5–50 cm thick lithofacies of climbing ripples Src. A ripple coset is usually topped by silty sand with wavy lamination SFw, 1 to 10 cm thick. Lithofacies Src and SFw form repeated, small-scale fining-upwards rhythms (Fig. 4c). Silty lithofacies with horizontal lamination occur sporadically, and very thin layers of sand with horizontal stratification are also rare. Both associations Src, SFw, (Sr) and Sh, (Sl) are typified by tabular form and large horizontal extent (Fig. 4d).

In the middle part of series 1, association Src, Sm occurs as well, being formed by 10–50 cm thick sandy cosets of climbing ripples Src, and thinner (10–25 cm) beds of massive sand Sm (Fig. 3). Medium- and small-scale sand beds with horizontal stratification Sh, and silty sand with wavy lamination SFw are secondary lithofacies. The presence of distinct erosional surfaces is a characteristic feature of this part of the succession (Fig. 4e). The depth of incision reaches 1.5 m.

Sediments of completely different structure and texture than those described above can also be found. The association SGm, Sm occurs in the middle part of the succession (Figs. 3, 4f), and is characterised by a limited horizontal extent. It starts from a large-scale erosional surface. Two-metre-deep troughs are filled up with massive gravelly sand. The uppermost part of this association contains weakly sorted sand, with single clasts of fine-grained gravels, usually with massive structure.

The upper **series 2** is 4 m thick, and contains considerably coarser sediments, which are poorly exposed. Medium- and coarse-grained sand or gravelly sand predominate in the lower part of the series. Sand beds with horizontal stratification Sh, trough cross-stratification St, and rarely sandy-gravelly units of the same structure SGt are found in some places. The overlying fine-grained gravel and sandy gravel form over 1 m thick, large-scale lithofacies with planar cross-stratification GSp (Fig. 5a), and 25–40 cm thick massive gravel Gm. Another characteristic element of series 2 is a silty-sandy diamicton forming a small lens, 30 cm thick and several metres long (Fig. 5b).

Directional data

In series 1, the dip directions of cross-stratification were measured within the lithofacies Sp, Sl, and Sr. The obtained results indicate palaeocurrents towards the NNW–NE sectors (Fig. 3). In series 2, the number of measurements of lithofacies Gp and GSp was smaller, however, they indicate a similar direction of palaeoflow.

Petrographic composition

Petrographic composition was analysed from gravels in the fraction 5–10 mm and over 10 mm, separated from the sediments of both series (samples 1 and 2, respectively) (Fig. 3, Table 1). The samples are characterised by similar composition, being dominated by quartz. A secondary group consists of Sudetic rocks, and the content of Scandinavian erratics is very low.

SEDIMENTARY ENVIRONMENT

In series 1, the most frequent association Sh, (Sl) is dominated by lithofacies Sh, which was deposited from very shallow supercritical or transitional flows in the upper-stage plane-bed conditions. Secondary lithofacies Sl, derived from washed-out, low-relief bed forms, was pro-

Table 1

Petrographic composition of gravels in the fraction 5–10 and >10 mm from both series (for sample location see Fig. 3)

Origin of rocks or minerals	Rocks/minerals	Sample 1 5–10 mm	Sample 1 > 10 mm	Sample 2 5–10 mm	Sample 2 > 10 mm
Scandinavian or Sudetic	quartz	55.5	43.3	61.3	50.6
	feldspar	0.2	0.3	0.4	0.0
	quartz & feldspar aggregates	1.7	0.7	1.2	3.4
	siliceous rocks	2.9	3.4	0.0	0.0
Scandinavian crystalline rocks	granitoids	4.8	2.1	0.0	0.0
	volcanic rocks	0.6	0.0	0.0	0.0
Sudetic crystalline rocks	granitoids	4.0	0.0	7.7	4.5
	gneisses	14.5	12.4	5.4	12.1
	melaphyres	0.0	0.3	0.0	0.0
	basaltoids	0.0	0.7	0.0	0.0
	metamorphic schists	1.5	4.8	1.0	3.1
Scandinavian or Sudetic crystalline rocks	granitoids	0.0	1.0	0.0	0.0
	gneisses	0.0	1.7	0.0	0.0
	amphibolites & gabbros	0.4	0.0	0.0	0.6
	volcanic rocks	0.0	0.0	1.0	0.0
Scandinavian sedimentary rocks	sandstones	0.0	0.0	0.0	0.0
	Dalarna quartzites	0.2	0.7	0.2	1.1
	limestones	0.0	0.0	0.0	0.0
	dolomites	0.0	0.0	0.0	0.0
Baltic and Polish Lowland	Mesozoic limestones	0.0	0.0	0.0	0.0
	flints	1.5	1.0	0.2	1.1
	lignites	0.0	0.0	0.0	0.0
Sudetic sedimentary rocks	Mesozoic sandstones	1.3	3.1	0.4	1.7
	Carboniferous sandstones	0.6	4.5	3.8	3.4
	Carboniferous mudstones	3.4	4.1	4.2	4.5
	ignimbrites	3.2	12.4	10.3	11.5
	lydite	1.3	1.4	1.6	1.1
	quartzites	0.6	0.7	0.6	0.8
concretions	clay	1.1	0.3	0.0	0.0
	ferrous	0.0	0.0	0.0	0.0
	manganese	0.8	1.0	0.8	0.6
	undetermined	0.0	0.0	0.0	0.0
TOTAL		100.0	100.0	100.0	100.0

duced during waning flood stages. Tabular form and large horizontal extent of the associations Sh, (Sl) indicate that they were deposited from non-channelised flows of sheetflow nature. The deposition of sand deposits from extensive sheetflows is commonly related to the subenvironment of distal fans (Amajor, 1986; Zieliński & Van Loon, 1999, 2000).

Lithofacies association Sh, (Sl, Sp) was formed in different conditions. Lithofacies Sp is usually related to transverse bars indicative of a channel subenvironment (McDonald & Benerjee, 1971; Smith, 1972; Cant, 1978; Cant & Walker, 1978; Miall, 1996). However, in the studied case these lithofacies are not the result of progradation of mid-channel bars. The situation and orientation of lithofacies Sp are especially noteworthy. The occurrence of Sp lithofacies directly above inclined erosional surfaces indicates that they were forms deposited in the marginal parts of channel incisions. The deposition was mainly controlled by flow velocity reduction in the zones of abrupt depth increase. The occurrence of lacustrine silts under sands indicates that the fan prograded into standing water. Dissections of channels (formation of extensive erosional surfaces) in the distal part of the fan could have resulted from falling of water level in the lake, i.e. the falling base level.

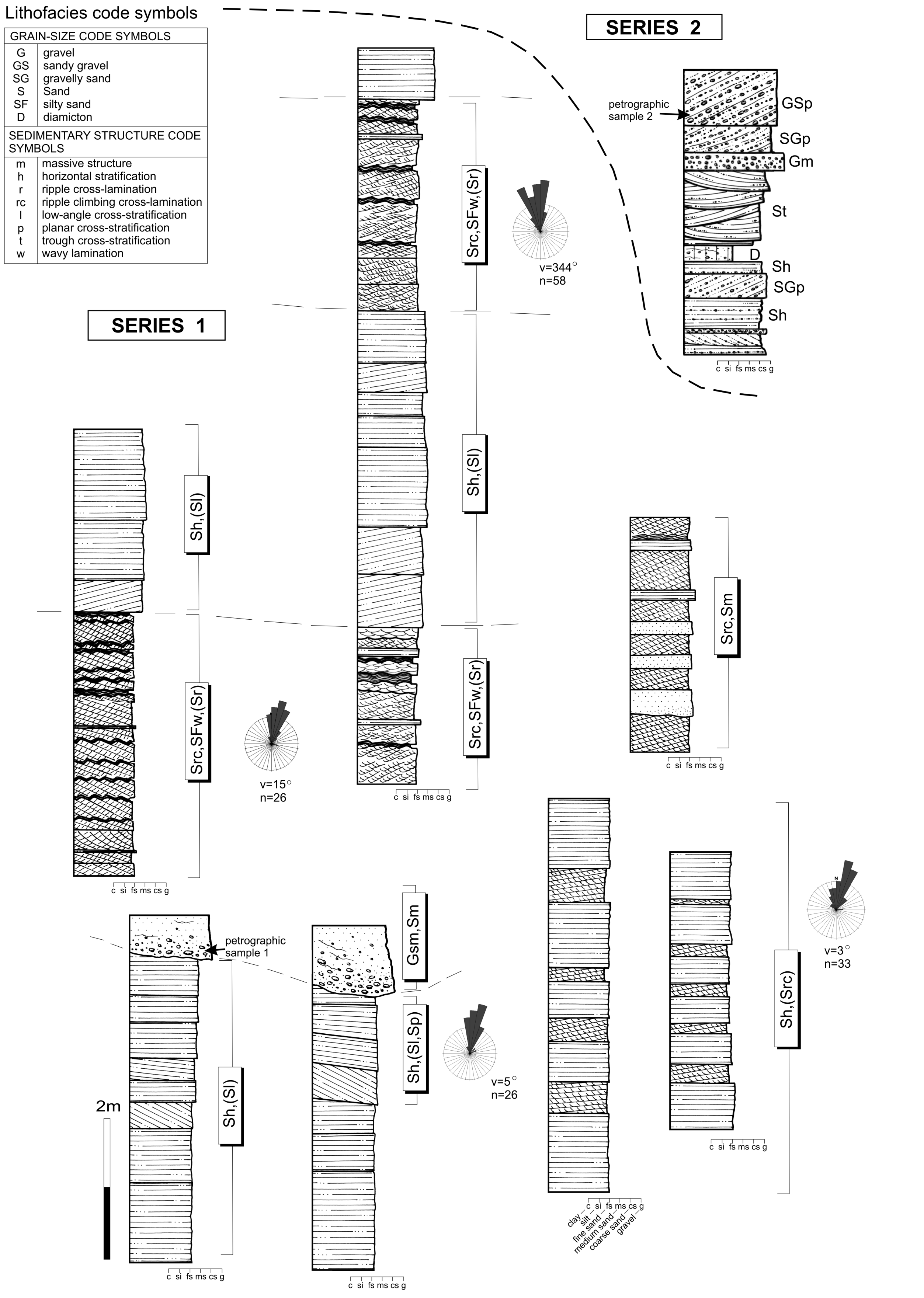

Fig. 3. Sedimentary logs from Wójcice site

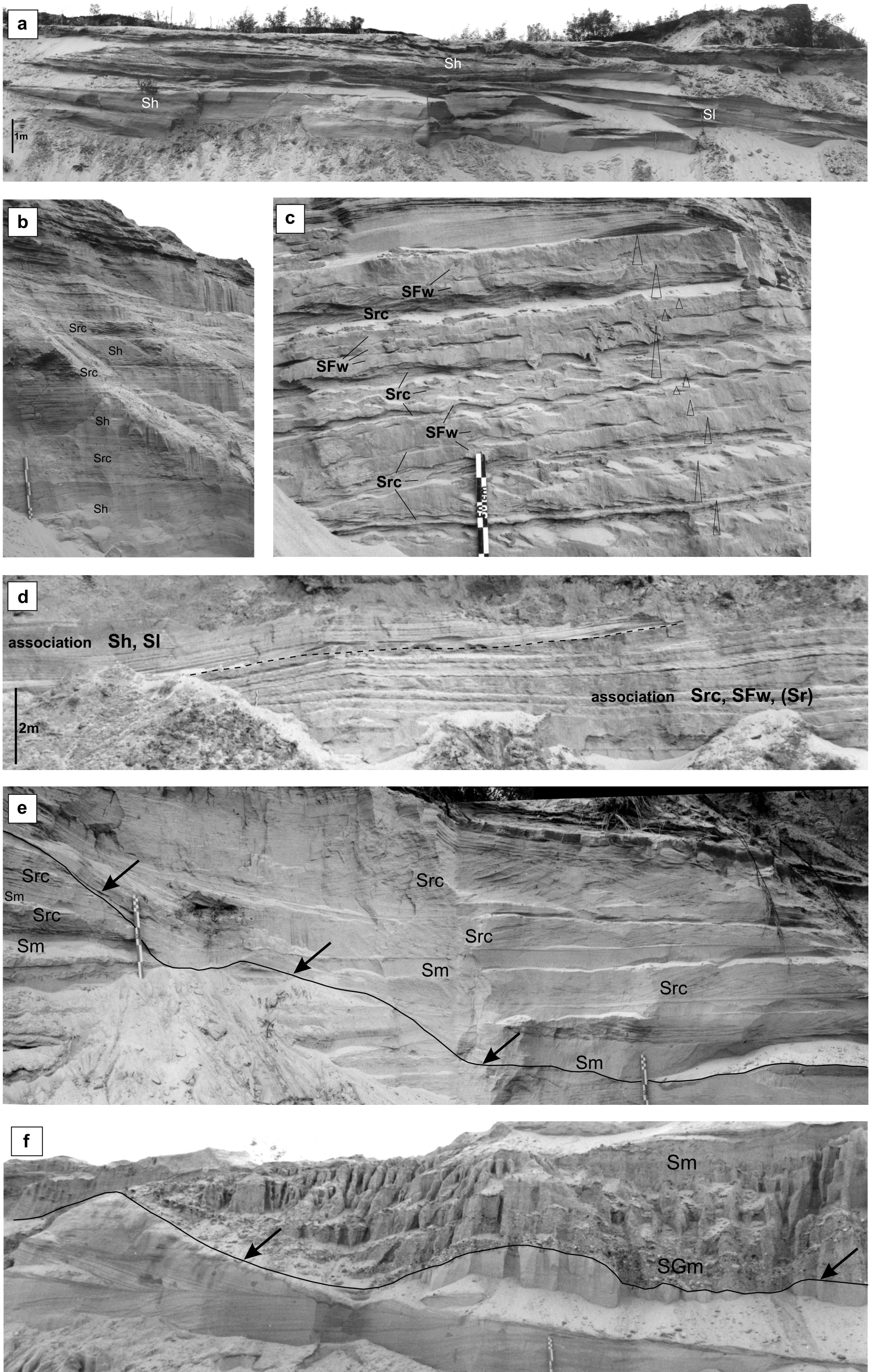

Fig. 4. Deposits of series 1: **a** – tabular beds of lithofacies association Sh, (Sl); **b** – lithofacies association Sh, Src. Scale is 50 cm; **c** – lithofacies association Src, Sfw, (Sr). Superimposed fining-upward cycles Src-SFw are marked. Scale is 50 cm; **d** – contact of two lithofacies associations (Src, SFw, (Sr) and Sh, (Sl)), dominated by fine-grained, sheet-like beds; **e** – lithofacies association Src, Sm. Two sandy packages are separated by large-scale erosional surface (marked by line and arrows). Scale is 50 cm; **f** – lithofacies association GSm, Sm. Erosively based fining-upward succession contains the lower member of massive sandy gravel SGm, which passes into massive sand Sm (scale 50 cm)

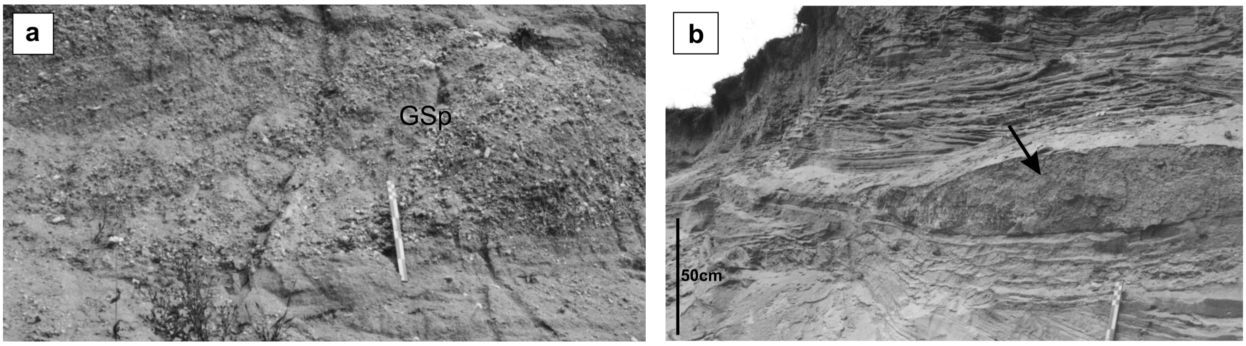

Fig. 5. Deposits of series 2: **a** – sandy gravel with planar-cross stratification GSp (scale bar is 50 cm long), **b** – glaciofluvial sandy gravel deposits with a lens of flow till (marked ba rrow)

Other lithofacies associations of series 1 represent mostly low-energy depositional environment. In the case of the association Sh, Src, this is evidenced by finer grain size of deposits, and high frequency of the lithofacies Sr and Src, which were deposited in the lower part of the lower flow regime.

The lithofacies association Src, Sm represents a similar environment of low-energy flows. The lithofacies of massive sand Sm, connected with these flows, is considered by some authors to be indicative of sheetflows (cf. Heward, 1978; Todd, 1989). Erosion on flat fan surfaces (Fig. 4e) had to be connected with a sudden change of environmental conditions. It did not result from the increase of flow energy, because the dissection is filled with the low-energy rhythms Sm-Src. Most probably, erosion started like in the former case, i.e. as a result of the lake level fall.

The lithofacies associations Src, SFw, (Sr), alternating with those of Sh, (Sl) in the upper part of the complex, were deposited from very low-energy, periodically decaying flows. The periods of weak currents were followed by episodes of lacustrine deposition. At that time, the lithofacies of silty sand SFw were settled from suspension. Similar sandy-silty associations, related to distal sheetflows, were noticed, *i.a*. by Amajor (1986), Zieliński (1992), Wu *et al.* (1992), Dreyer (1993), and Hartley (1993).

All mentioned lithofacies associations were deposited from shallow flows of sheetflow nature. Generally, they represent subenvironments of the distal fan. Some deposits, for example the association Sh, SFw, (Sr), can be correlated with the subenvironment of shallow subaqueous part of the fan. Additionally, the occurrence of numerous erosional dissections supports the hypothesis that the distal alluvial fan was bordered by a lake characterised by frequent fluctuations of water level. On the other hand, alternating occurrence of Sh, (Sl), and Src, SFw, (Sr, Sh) association sequences indicates highly variable conditions of deposition, controlled by rising and falling lake level.

The association SGm, Sm, found in the middle part of the succession, represents completely different conditions of deposition. Distinct erosion surface with troughs, considerably coarser grain size of deposits, and massive structure indicate an episode of deposition from much more intensive and higher flows. Channel bed was eroded in the initial phase of this episode, and followed by abrupt deposition of sandy-gravelly sediment. The described association is the record of a sudden outburst of ablation water on the ice-sheet foreland. As a result of this flood, the facies typical of more proximal zones was shifted to the distal part of the fan.

The deposits of series 2 represent a higher-energy depositional environment. The deposits coarsen upwards within the studied succession indicating an increasing energy of flows. Gravelly lithofacies Gp, occurring in the upper part of series 2, can be regarded as typical of proximal glacimarginal environment. The proximity of the ice-sheet margin is indicated by the occurrence of a diamicton lens, which was probably a package of flow till redeposited from the ice-sheet surface.

PALAEOGEOGRAPHICAL INTERPRETATION

Both series, together with the underlying silts, form a sequence connected with the ice-sheet advance. However, the directions of palaeoflows recorded in the sedimentary succession are not typical for such an interpretation. All measurements indicate that ablation waters flowed towards the N-NNE. Szponar (1974) obtained similar directional data. Therefore, he considered the deposits, probably corresponding to series 1, as alluvia of the Nysa Kłodzka River. In the case of the overlying sandy-gravelly deposits, he related the same dip directions of cross-stratifications to antidunes, assuming *a priori* that the series had to be deposited from the N-NE direction. However, the style of sedimentation of fine-grained deposits of series 1 does not correspond with the alluvia of the Nysa Kłodzka River environment. Northward directions of palaeoflow suggest that glacial ice occurred rather to the south of the study area. Therefore, these indicate that the ice sheet entered the latitudinal valley of the Nysa Kłodzka River from the NE, *i.e.* from the Odra River valley. The ice sheet had to advance into the Otmuchów Depression as a small lobe. The described glaciomarginal fans were formed at its northern margin, and deposited towards the simultaneously formed Otmuchów-

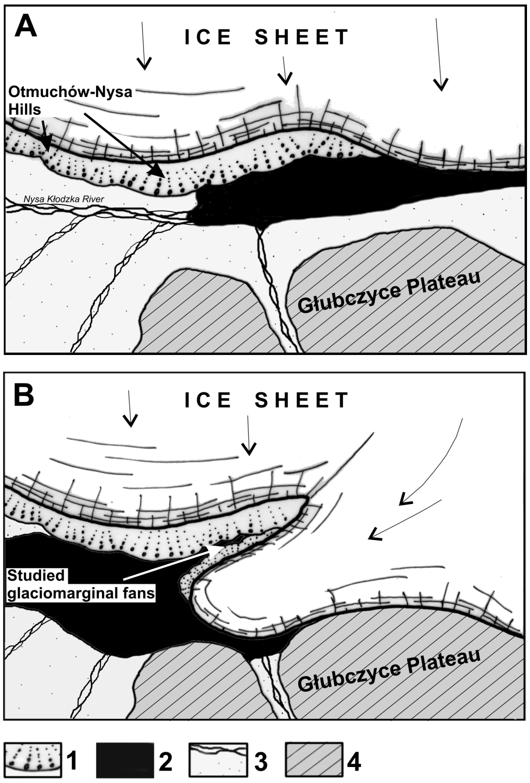

Fig. 6. Model of evolution of the glaciomarginal zone in the Otmuchów Depression. *1* – glaciomarginal fans, *2* – glaciomarginal lake, *3* – outwash plain, *4* – upland. Detailed explanation in the text

Nysa Hills. However, these forms did not have any direct genetic link. Walczak (1968) documented the deposits of the Otmuchów-Nysa Hills. They were outcropping in several pits which do not exist nowadays. Sedimentary successions contained thick sand packages with horizontal, wavy or cross-stratification, with interbeds of coarse erratic gravels, and subordinate sandy till, especially at the tops of hills and their northern slopes. In the light of sedimentological analysis it seems likely that the depositional environment of these sediments was not an outwash plain, as Walczak suggested, but most probably the end-moraine fans, as it was assumed earlier by German researchers (Woldsted, 1932; Behr & Mühlen, 1933; Anders, 1939). Till and silty sand, occurring as interbeds within sandy deposits, and also in thicker packages on hilltops, are probably mass-flow deposits, which were gravitationally transported from the surface of the ice sheet to its foreland. Lithofacies of such type are indicator units of the environment of end-moraine fans, especially of their proximal parts (Ruszczyńska-Szenajch 1982; Kasprzak & Kozarski, 1984; Kozarski 1990; Zieliński 1992; Zieliński & Van Loon, 1996, 1999).

A surprisingly low content of Scandinavian material in the examined deposits appears to confirm our hypothesis about the ice-sheet advance from the NE direction. The lobe advanced into the area of the Otmuchów Depression from the Odra River valley, and along the Nysa Kłodzka River valley, which were the source of abundant local material. Glacial deposits in the Eastern Sudetes foreland often contain only several per cent of Scandinavian rocks. Therefore, their low content should not be surprising in the conditions of ice-sheet advance along the river valley covered with alluvia. The advance of the ice sheet along the Nysa Kłodzka River valley is also indicated by the orientation of glaciotectonic structures arranged along the valley, for example at the Niwnica site in the SW part of the Głubczyce Plateau (Salamon, 2005), and in the easternmost part of the Otmuchów-Nysa Hills (Badura & Przybylski, 1993, 1997). At Niwnica, the direction of the ice-sheet advance from NE/ENE is also evidenced by the orientation of clasts within till (Salamon, 2005).

Basing on the above discussion, several stages of glaciomarginal zone development in the Otmuchów Depression can be presented. During the first stage, the ice sheet reached the line of the Otmuchów-Nysa Hills. The end-moraine fans started to form at the ice margin, and during long standstill they grew into a large row of hills (Fig. 6A). The ice front was slightly active, as is evidenced by only small deformations of glaciotectonic nature (Walczak, 1968). When the ice-sheet front was stagnating at the line of the Otmuchów-Nysa Hills, a small lobe advanced from the NE along the latitudinal reach of the Nysa Kłodzka River valley (Fig. 6B), into the area to the south of the hills. Glaciomarginal fans developed on its margin and prograded to the north, in contrast to the Otmuchów-Nysa moraines.

Glaciomarginal forms, which were deposited from different directions, prograded into standing water. In the case of the examined deposits, it was most probably a bay of a terminoglacial lake formed in the ice-dammed valley of the Nysa Kłodzka River, though frequent and considerable fluctuations of water level suggest that it could have been also a small-size, isolated lake. Therefore, it is possible that intensive glaciomarginal deposition resulted in, at least temporary, cut-off of the bay from the main terminoglacial lake. The accumulation of deposits in the lakeshore zone was confirmed by Przybylski (1998), who investigated the Goświnowice site situated about 4 km away (Fig. 1). He interpreted the large-scale lithofacies of sands with inclined stratification as delta slope facies, and the underlying silty-sandy deposits as lacustrine ones.

The small lobe formed in the Nysa Kłodzka River valley was a secondary sub-lobe of the considerably larger lobe unit, *i.e.* the Upper Odra lobe, which advanced along the depression of the Silesian Lowland towards the Racibórz Basin.

CONCLUSIONS

The marginal zone of the ice sheet in the Otmuchów Depression was formed in a different way than it has been accepted so far. In its northern part, in the area of the Otmuchów-Nysa Hills, the ice sheet was stationary, but another lobe entered the valley of the Nysa Kłodzka River from the NE-E direction, from the Odra River valley.

A small lobe bordered the eastern part of the Otmuchów-Nysa Hills from the south.

A terminoglacial lake was formed at the ice-sheet front in the dammed valley. At the northern margin of the lobe, sediments were deposited as glaciomarginal fans prograding into a narrow bay of the lake.

Two sedimentary series have been distinguished in the studied succession. The deposits of the lower series represent the distal zone of terminoglacial fans, predominated by the low-energy sheetflows. Sedimentation was characterised by frequent oscillations of water level in the lake, which caused fan trenching and lateral migration of depositional zones. These phenomena are recorded by the existence of evident erosional surfaces, which are not typical of the fans dominated by sheetflows, especially in their distal parts, and by the vertical succession of alternating lithofacies associations Sh, (Sl), and Src, SFw, (Sr, Sh), typical of different parts of the fan distal zones.

The upper series represents flows of considerably higher energy. These deposits were formed in a more proximal position to the ice-sheet margin. Together with the occurrence of the lowermost silt series, the studied sedimentary section can be regarded as a typical progradational succession of a glaciomarginal zone.

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REFERENCES

Amajor, L.C., 1986. Alluvial fan facies in the Miocene–Pliocene coastal plain sands, Niger delta, Nigeria. *Sedimentary Geology*, 49: 1–20.

Anders, G., 1939. Zur Morphologie der Ostsudeten. *Veröffentlichungen d. schlesische Gesellschaft für Erdkunde*, 31: 1–124, Breslau.

Badura, J., Bobiński, W. & Przybylski, B., 1996. *Objaśnienia do Mapy Geologicznej Polski w skali 1: 200 000, arkusz Nysa*. (In Polish). Państwowy Instytut Geologiczny, Warszawa: 1–57.

Badura, J. & Przybylski, B., 1993. *Szczegółowa mapa geologiczna Polski w skali 1: 50 000, arkusz Skoroszyce*. (In Polish). Państwowy Instytut Geologiczny, Warszawa.

Badura, J. & Przybylski, B., 1997. *Szczegółowa mapa geologiczna Polski w skali 1: 50 000, arkusz Nysa*. (In Polish). Państwowy Instytut Geologiczny, Warszawa.

Behr, J., 1930. Das Staubecken von Ottmachau. O.-S. *Sitzungsberichte der Preuss. Geol. L.*, 5, Berlin.

Behr, J. & Mühlen, L., von zur, 1933. Zur Gliederung und Altersstellung des oberschlesischen Randdiluviums. *Jahrbuch der Preussische Geologische Landesanstalt*, 53: 188–207.

Cant, D. J., 1978. Development of a facies model for sandy braided river sedimentation: comparison of the South Saskatchewan River and the Battery Point Formation. In: *Fluvial Sedimentology*. Canadian Soc. Petrol. Geol. Mem., 5: 627–639.

Cant, D. J. & Walker, R.G., 1978. Fluvial processes and facies sequences in the sandy braided South Saskatchewen River, Canada. *Sedimentology*, 25: 625–639.

Dreyer, T., 1993. Quantified fluvial architecture in ephemeral stream deposits of the Esplugafreda Fm. (Palaeocene), Tremp-Graus Basin, N Spain. *International Association of Sedimentologists Special Publication*, 17: 337–362.

Hartley, A. J., 1993. Sedimentological response of an alluvial system to source area tectonism: the Seilao Member of the Late Cretaceous to Eocene Purilactis Fm. of N Chile. *International Association of Sedimentologists Special Publication*, 17: 489–500.

Heward, A. P., 1978. Alluvial fan and lacustrine sediments from the Stephanian A and B (La Magdalena, Cinera-Matallana and Sabero coalfields), N. Spain. *Sedimentology*, 25: 451–488.

Kasprzak, L. & Kozarski, S., 1984. Analiza litofacjalna osadów strefy marginalnej fazy poznańskiej ostatniego zlodowacenia w środkowej Wielkopolsce. (In Polish, English summary). *Geografia UAM*, 29: 1–54.

Kozarski, S., 1990. Osady ablacyjne ostatniego zlodowacenia w Polsce środkowozachodniej: identyfikacja i paleogeograficzne implikacje. (In Polish, English summary). *Acta Universitatis Wratislaviensis*, 1056, *Prace Instytutu Geograficznego*, A, 4: 41–60.

McDonald, B.C. & Banerjee, I., 1971. Sediments and bed forms on a braided outwash plains. *Canadian Journal of Earth Science*, 8: 1282–1301.

Miall, A.D. 1996. *The Geology of Fluvial Deposits*. *Sedimentary Facies, Basin Analysis, and Petroleum Geology*. Springer, Berlin, 582 pp.

Przybylski, B., 1998. Glacial and neotectonic constrains on the Quaternary evolution of the Fore-Sudetic reach of the Nysa Kłodzka River. *Geological Quarterly*, 42: 221–238.

Rembocha, L., 1958. Czwartorzęd przedpola sudeckiego w okolicy Paczkowa. (In Polish). *Przegląd Geologiczny*, 6: 364–366.

Rembocha, L., 1960. *Szczegółowa mapa geologiczna Sudetów w skali 1: 25 000, arkusz Paczków*. (In Polish). Instytut Geologiczny, Warszawa.

Rembocha, L., 1964. *Szczegółowa mapa geologiczna Sudetów w skali 1: 25 000, arkusz Otmuchów*. (In Polish). Instytut Geologiczny, Warszawa.

Ruszczyńska-Szenajch, H., 1982. Depositional processes of Pleistocene lowland end moraines, and their possible relation to climatic conditions. *Boreas*, 11: 249–260.

Salamon, T., 2005. *Glacimarginalne środowiska depozycyjne obszaru przedgórskiego i dynamika lobu górnej Odry*. (In Polish). Unpublished Ph.D. Thesis, Uniwersytet Śląski, Katowice, 195 ms. pp.

Schwarzbach, M., 1942. Das Diluvium Schlesiens. *Neues Jahrbuch für Mineralogie*, Bd. B., 86: 189–246, Berlin.

Smith, N. D., 1972. Some sedimentological aspects of planar cross-stratification in a sandy braided river. *Journal of Sedimentary Petrology*, 42: 624–634.

Szponar, A., 1974. Etapy deglacjacji w strefie przedgórskiej na przykładzie przedpola Sudetów Środkowych. (In Polish, English summary). *Acta Universitatis Wratislaviensis* 220, *Studia Geograficzne*, 21: 1–89.

Todd, S. P., 1989. Stream-driven, high-density gravely traction carpets: possible deposits in the Trabeg Conglomerate Formation, SW Ireland and some theoretical considerations of their origin. *Sedimentology*, 36: 513–530.

Walczak, W., 1954. Pradolina Nysy i plejstoceńskie zmiany hydrograficzne na przedpolu Sudetów Wschodnich. (In Polish, English summary). *Prace Geograficzne IG PAN*, 2: 6–51.

Walczak, W., 1966. Problem zasięgu starszych zlodowaceń w Sudetach. (In Polish). *Czasopismo Geograficzne*, 37: 249–268.

Walczak, W., 1968. O genezie tzw. "moren otmuchowsko-nyskich" na przedpolu Sudetów Wschodnich. (In Polish). *Przegląd Geograficzny*, 40: 315–323.

Walczak, W., 1970. *Obszar przedsudecki*. (In Polish). Państwowe Wydawnictwo Naukowe, Warszawa: 1–415.

Walczak, W., 1972. Sudety i Przedgórze Sudeckie. (In Polish).In: Klimaszewski, M. (*Ed*.), *Geomorfologia Polski*, t.1. Państwowe Wydawnictwo Naukowe, Warszawa: 167–232.

Woldstedt, P., 1932. Über Endmoränen und Oser der Saale (Riss)-Vereisung in Schlesien. *Zeitschrift der D. Geol. Ges*., 84: 78–84, Berlin.

Wroński, J. & Kościówko, H., 1982. *Mapa geologiczna Polski w skali 1: 200 000, arkusz Nysa. A – mapa utworów powierzchniowych*. (In Polish). Państwowy Instytut Geologiczny, Warszawa.

Wu, C., Li, S. & Cheng, S., 1992. Humid-type alluvial-fan deposits and associated coal seams in the L. Cretaceous Haizhou Fm., Fuxin Basin of NE China. In: *Controls on the Distribution and Quality of Cretaceous Coals*. Geological Society of America Special Paper, 267: 269–286.

Zieliński, T., 1992. *Moreny czołowe Polski północno-wschodniej – osady i warunki sedymentacji*. (In Polish, English summary). Uniwersytet Śląski, Katowice: 1–95.

Zieliński, T., & Van Loon, A. J., 1996. Characteristics and genesis of moraine-derived flowtill varieties. *Sedimentary Geology*, 101: 119–143.

Zieliński, T. & Van Loon, A. J., 1999. Subaerial terminoglacial fans II: a semi-quantitative sedimentological analysis of the middle and distal environments. *Geologie en Mijnbouw*, 78: 73–85.

Zieliński, T. & Van Loon, A. J., 2000. Subaerial terminoglacial fans III: overview of sedimentary characteristics and depositional model. *Geologie en Mijnbouw*, 79: 93–107.

Streszczenie

SEDYMENTACJA GLACIMARGINALNA NA OBSZARZE OBNIŻENIA OTMUCHOWSKIEGO (SW POLSKA) I WYNIKAJĄCE Z NIEJ IMPLIKACJE PALEOGEOGRAFICZNE

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Rozwój strefy glacimarginalnej na obszarze przedgórskiego odcinka doliny Nysy Kłodzkiej, zajmującego Obniżenie Otmuchowskie (Fig. 1), od dziesięcioleci stanowi przedmiot dyskusji. We wszystkich dotychczasowych rozważaniach geomorfologiczno-geologicznych i paleogeograficznych najwięcej uwagi poświęcano wyraźnie zaznaczonym w rzeźbie Wzgórzom Otmuchowsko-Nyskim (Figs. 1, 2). W pracy analizie poddano osady deponowane na południowym obrzeżeniu wzgórz. Badania prowadzono w stanowisku Wójcice, kilka kilometrów na zachód od Nysy. Szczegółowa analiza sedymentologiczna osadów umożliwiła rekonstrukcję środowisk sedymentacji w rejonie SE obrzeżenia Wzgórz Otmuchowsko-Nyskich oraz wnioskowanie na temat paleogeografii strefy glacimarginalnej na obszarze Obniżenia Otmuchowskiego.

W odsłonięciu Wójcice wyróżniono dwa kompleksy osadów. Kompleks 1, o miąższości ok. 10–12 m, zbudowany jest głównie z piasków drobnoziarnistych. W jego obrębie wyróżniono kilka tabularnych zespołów litofacji o nieznacznie odmiennym wykształceniu: Sh, (Sl); Sh (Sl, Sp); Sh, (Sl, Sm); Sh, Src; Src, SFw, (Sr) (Figs. 3, 4). W środkowej części kompleksu obserwowano również bardziej gruboziarnisty zespół SGm, Sm (Fig. 3). Cechą charakterystyczną kompleksu 1 jest obecność powierzchni erozyjnych oraz naprzemianległe występowanie zespołów litofacji o nieznacznie różnym poziomie energetycznym. Kompleks 2 obejmuje osady o miąższości ok. 4 m i charakteryzuje się grubszym uziarnieniem (Figs. 3, 5). W dolnej części przeważają średnio i gruboziarniste piaski lub piaski żwirowe (litofacje Sh, St, SGt). Wyżej obserwowano drobnoziarniste żwiry i żwiry piaszczyste (GSp, Gm) (Fig. 5a). W kompleksie 2 obserwowano ponadto niewielkie soczewy diamiktonu z materiałem skandynawskim (Fig. 5b). Pomiary azymutów upadu warstwowań przekątnych w obu kompleksach wykazały paleoprzepływy w kierunku NNW–NNE (Fig. 3). Analiza składu petrograficznego żwirów wykazała duży udział kwarcu, a także skał sudeckich oraz bardzo małą zawartość materiału północnego (Tab. 1).

Osady kompleksu dolnego deponowane były w dystalnej strefie stożka progradującego do zbiornika wodnego. Depozycja odbywała się głównie z niskoenergetycznych zalewów warstwowych. Specyficzną cechą sedymentacji były częste wahania poziomu wody w zbiorniku powodujące rozcinanie stożków i oboczne przemieszczanie się stref depozycyjnych. Zapisem tego są nietypowe dla stożków zdominowanych zalewami warstwowymi powierzchnie erozyjne oraz powtarzające się w sukcesji pionowej zespoły litofacji osadów właściwych dla różnych części dystalnych stref stożków.

Górny kompleks osadów związany był ze znacznie wyżej-energetycznymi przepływami. Osady te były deponowane bliżej czoła lądolodu, co wraz z mułkami podścielającymi całą serię osadów piaszczystych wskazuje na transgresywny charakter całej sukcesji.

Strefa marginalna lądolodu na obszarze Obniżenia Otmuchowskiego kształtowała się w inny sposób niż przyjmowano do tej pory (Fig. 6). W północnej jej części lądolód stacjonował w rejonie Wzgórz Otmuchowsko-Nyskich, natomiast w dolinę Nysy Kłodzkiej wsunął się z kierunku NE od strony doliny Odry w postaci niewielkiego lobu okalającego wschodnią część Wzgórz Otmuchowsko-Nyskich od południa.

U czoła lądolodu w podpartej dolinie powstało rozległe zastoisko. U północnej krawędzi lobu osady były deponowane w postaci glacimarginalnych stożków progradujących do wąskiej zatoki zastoiska, która przypuszczalnie przez pewien okres była odizolowana od głównego zbiornika.