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DEVELOPMENT OF A FORE-MOUNTAIN ALLUVIAL FAN OF THE OLZA RIVER (SOUTHERN POLAND) DURING THE PLEISTOCENE

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Abstract: A series of Pleistocene deposits with different lithology is present where the Olza River flows out from the Carpathian foothills to the Oświęcim Basin. The deposits are mostly composed of gravels forming several series of different ages, which are intercalated with much finer silts and sands as well as organic silts. A complex of glaciogenic deposits is also found as a thin layer of till, glaciolacustrine and glaciofluvial sediments. Loess-like deposits occur in the top part of the section under study.

Gravels were deposited in the zone of a fore-mountain fan. The co-occurrence of lithologically different deposits reflects a great variability of sedimentation conditions, which depended mostly on climate changes. However, the formation of fan was also controlled by other factors. Neotectonic movements probably played an important role in its evolution. In this paper, we describe the successive stages of fan development and the factors determining this process. The interpretation is based on the analysis of deposits exposed in the eastern part of the fan, at the Kończyce site.

The fan of the Olza River was built up with alluvia mostly during successive glaciations. It was dissected towards the end of each glaciation. During interglacials the fan was only slightly transformed. A special period of fan development occurred during glaciation when the ice sheet advanced on the fan surface. The aggradation of the fan was probably stopped due to uplift of the area. Then, aeolian loess-like deposits started to accumulate on a considerable part of the fan surface. Former opinions about the stratigraphy of the fan deposits are strongly diversified. Precise age of the successive series is still difficult to establish. In the light of contemporary studies, it can not be excluded that age of the Olza fan might be younger than previously suggested.

Key words: fore-mountain alluvial fan, sedimentology, Pleistocene, Kończyce section, southern Poland.

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INTRODUCTION

The development of alluvial fans depends on many factors, which are determined mainly by morphology and geology of the substratum, climate conditions, vegetation cover, hydrological regime, amount and type of weathered material delivered to the fan, etc. (*cf.* Beaty, 1963; Schumm, 1977; Boothroyd & Nummedal, 1978; Heward, 1978; Nilsen, 1985; Rachocki & Church, 1990; DeCelles *et al.*, 1991; Stanistreet & McCarthy, 1993; Blair & McPherson, 1994; Blair, 1999; Viseras *et al.*, 2003). Apart from high-mountain areas, the most favourable conditions for development of alluvial fans occur usually in morphologically diversified areas with sparse vegetation, both in warm and cold climatic zones. In Europe, the fans are found most frequently in the Mediterranean Sea region (*cf.* Nemec & Postma, 1993; Amorosi *et al.*, 1996; Guzzetti *et al.*, 1997; Sorriso-Valvo *et al.*, 1998; Harvey, 1996; Harvey *et al.*, 1999; Robustelli *et al.*, 2005). The fans are also common under cold climatic conditions in the northern part of Europe (*cf.* Lønne & Nemec, 2004). During the Pleistocene, alluvial fans were formed abundantly also in other parts of the continent, such as mountain forelands of Central Europe, *i.e.* in the Sudetes and Carpathian forelands (Książkiewicz, 1935; Stupnicka, 1963; Starkel, 1967; Gilot *et al.*, 1982; Niedziałkowska *et al.*, 1985; Niedziałkowska & Szczepanek, 1993, 1994; Krzyszkowski, 1993; Badura *et al.*, 2005). Their intensive development fell especially on the glaciation periods. In this paper, an attempt is made to reconstruct the Pleistocene evolution of a relatively small fan of the Olza River. This fan was formed in the zone, where the Olza River flows out from the Carpathians Foothills to the Oświęcim Basin (area of the Carpathian Foredeep). The reconstruction is based on detailed sedimentolo-

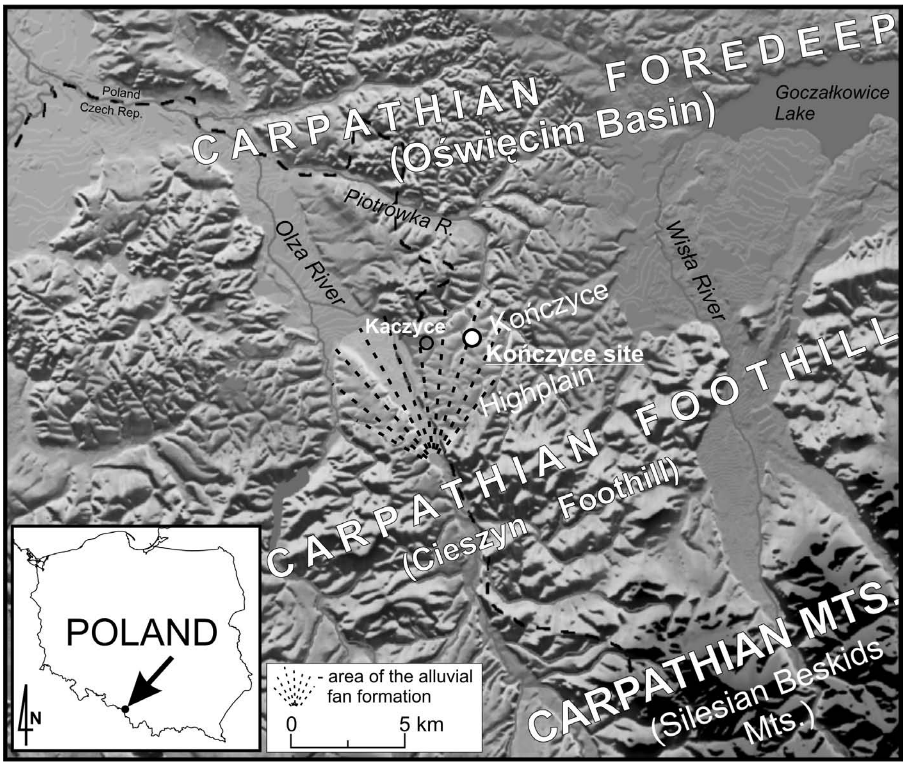


Fig. 1. Topography of the study area with location of the Kończyce site

gical analysis of sediments exposed at Kończyce. Sedimentary succession comprises several series of alluvial gravels and sands, locally intercalated with much finer silts and sands as well as organic silts. Alluvial deposits are capped with loess cover. A complex of glaciogenic deposits is found in the middle part of the studied section.

Although the Kończyce site has been known in geological literature for over 25 years and examined by many authors (Jersak, 1983; Budek *et al.*, 2004; Drewnik *et al.*, 2004; Wójcik *et al.*, 2004), stratigraphic position of the deposits is not agreed by all the researchers.

According to Jersak (1983), the series of gravels and sands occurring in the lower part of the succession was formed during the Middle Polish Glaciations (Saalian) – Odranian or Wartanian, whereas organic deposits and the overlying loess were accumulated during the Vistulian (Weichselian) Glaciation. Based on the results of palynological and palaeomagnetic analyses, Wójcik *et al.* (2004) assumed these deposits to be much older. They related the upper layer of organic deposits to the Cromerian II–III Interglacial, and loess-like deposits to several younger glaciations. They also found the lowermost layer of organic sediments and glacial deposits, and correlated it, respectively, to the Cromerian I Interglacial, and Narewian Glaciation (Menapian). Drewnik *et al.* (2004) and Budek *et al.* (2004) studied the loess deposits and suggested a different age and multi-stage development of this series.

A similar succession of sediments in the Czech part of the Olza River valley were described by Macoun *et al.* (1965), who correlated the series of gravels and sands to the Sanian (Elsterian) Glaciation, the organic deposits occurring over gravels to the “Great” (Holsteinian) Interglacial, and the overlaying loess to the Weichselian Glaciation.

In the former studies the gravels at the Kończyce site were related to alluvial deposition in an erosional trough oriented west-east, but they were not attributed to fan environment. The authors found many premises to support fan-origin of the sediments in question. Moreover, lithofacies variation of these sediments indicates that the fan developed in several stages. Each of them was controlled by different environmental factors.

MORPHOLOGICAL AND GEOLOGICAL SETTING

The valley of the Olza River, a right-bank tributary of the Odra River, dissects the western part of the Silesian Beskidy Mountains and the Cieszyn Foothills, occurring in their foreland (Fig. 1). The Carpathian part of the catchment rises over 1,000 m a.s.l., and relative heights in this area are about 400–500 m. The area is composed of flysch series belonging to the Magura, Fore-Magura, and Silesian units. The Cieszyn Foothills, built up mostly of Jurassic carbonate rocks and Cretaceous siliciclastic deposits, are characterized by hilly relief with relative heights reaching 70 m. Hill summits reach 350–400 m a.s.l. The mountain part of the Olza River catchment is about 380 km^2.

The examined deposits of the Olza River fan occur where the river leaves the Carpathian Foothills. This area, called the Kończyce Highplain, is a part of the Carpathian Foredeep (Fig. 1) filled with the Neogene molasse strata.

Table 1

Lithofacies code symbols used in text and figures

Textural symbols	
G	gravel
GS	gravelly sand
SG	sandy gravel
S	sand
SF	silty sand
FS	sandy silt
F	silt
D	diamicton
Structural symbols	
m	massive structure
h	horizontal lamination/stratification
p	tabular cross-stratification
t	trough cross-stratification
l	low-angle cross-stratification
r	ripple cross-lamination

The studied sediments directly overlie Miocene clays.

The described fan is not visible in the present relief because it is buried by loess-like deposits, a dozen or so metres thick. This area is an undulated highland (about 260–280 m a.s.l.) with relative heights up to 30 m. The fan prograded towards the north. It was a dozen kilometres long and up to 10 km wide. The elevations composed of Miocene strata and rising 270–280 m a.s.l. near Kaczyce caused the Olza River fan being a complex form, which was split into two parts in its distal zone.

METHODOLOGY

The study is based on lithofacies analysis. A three-fold division of depositional units is used, with a distinction of lithofacies, facies associations and series. Lithofacies associations distinguished in the series are denoted by code symbols of the most frequent beds. These symbols are explained in Table 1. The code is based on modified Miall's (1978) code.

LOCATION OF THE SITE

The study site is situated in a gravel-pit at Kończyce, at the right side of the small Piotrówka River valley. The latter is one of many erosional dissections cutting the highplain surface. The study site is located about 3 km to the east of the Olza River valley, and about 10 km to the north of the Carpathian Foothills (Fig 1).

LITHOFACIES AND THEIR INTERPRETATION

Seven sedimentary series of different lithology and origin have been distinguished in the Kończyce site (Fig. 2).

(1) Lower series of gravels

The lower series of gravels is about 12–15 m thick. Only its upper part, of the thickness of about 4–6 m, is visible in exposures (Fig. 3A). Lithofacies association Gm, (GSh, Sm, SGp) is distinguished in this part of the section (Fig. 2). It is dominated by lithofacies of matrix-supported gravels and sandy gravels with massive structure Gm (Fig. 3B). The gravel clasts reach 2–6 cm, and rarely exceed 10 cm in diameter. The thickness of lithofacies Gm is small or medium (5–30 cm), sporadically up to 50 cm. Subordinate lithofacies of sandy gravels with horizontal stratification GSh reach the thickness of a dozen or so centimetres. Gravel beds are sporadically intercalated with thin (3–10 cm), often discontinuous lithofacies of massive sands Sm. In other places medium-scale gravelly sands or sandy gravels with planar cross-stratification SGp or low-angle cross-stratification SGl are frequent lithofacies (Fig. 3C). Ice-wedges were observed in this series at several levels. They are few decimetres high, a dozen or so centimetres wide, and filled with gravelly-sandy sediments (Fig. 3D).

The described sediments represent the environment of a very shallow gravel-bed braided river (*cf.* Williams & Rust, 1969; Smith, 1970; Rust, 1972; Miall, 1977). The sediments were deposited as thin gravel sheets (the origin of thin lithofacies Gm and GSh) or low and flat longitudinal bars (the origin of thicker lithofacies Gm). The deposition occurred during flood peaks from supercritical and transitional flows. Poor sorting of matrix-supported gravels indicates that the deposition was sudden. Lithofacies Sm were also deposited as thin sheets. They were formed during waning flood stages when flow was reduced. Thin lithofacies SGp were probably associated with second-rank channels with flows of lower energy.

The series was deposited under very cold climatic conditions. It is evidenced by the presence of ice-wedges indicating occurrence of permafrost.

(2) Complex of glaciogenic deposits

In the NE part of the exposure the lower gravels are covered with the SFh, FSh, SFr association of sandy and sandy-silty sediments (Fig. 2). The association's thickness increases to the north from about 1.5 m to about 3.5 m over a distance of 100 m. The lower part of the association consists of fine-grained sands and silty sands with horizontal lamination (Sh, SFh), and ripple cross-lamination (SFr). They are overlain by lithofacies of silty sands and sandy silts with horizontal lamination (SFh, FSh). Lithofacies of massive diamicton Dm, up to 0.5 m thick, is found locally in the upper part of the association (Fig. 2). The upper erosional surface of the association is topped with a layer of gravel pavement containing Scandinavian material (Fig. 3E).

The sediments are characterized by occurrence of different scale deformations. The small deformation structures are usually drag folds with vergence to the south. They are

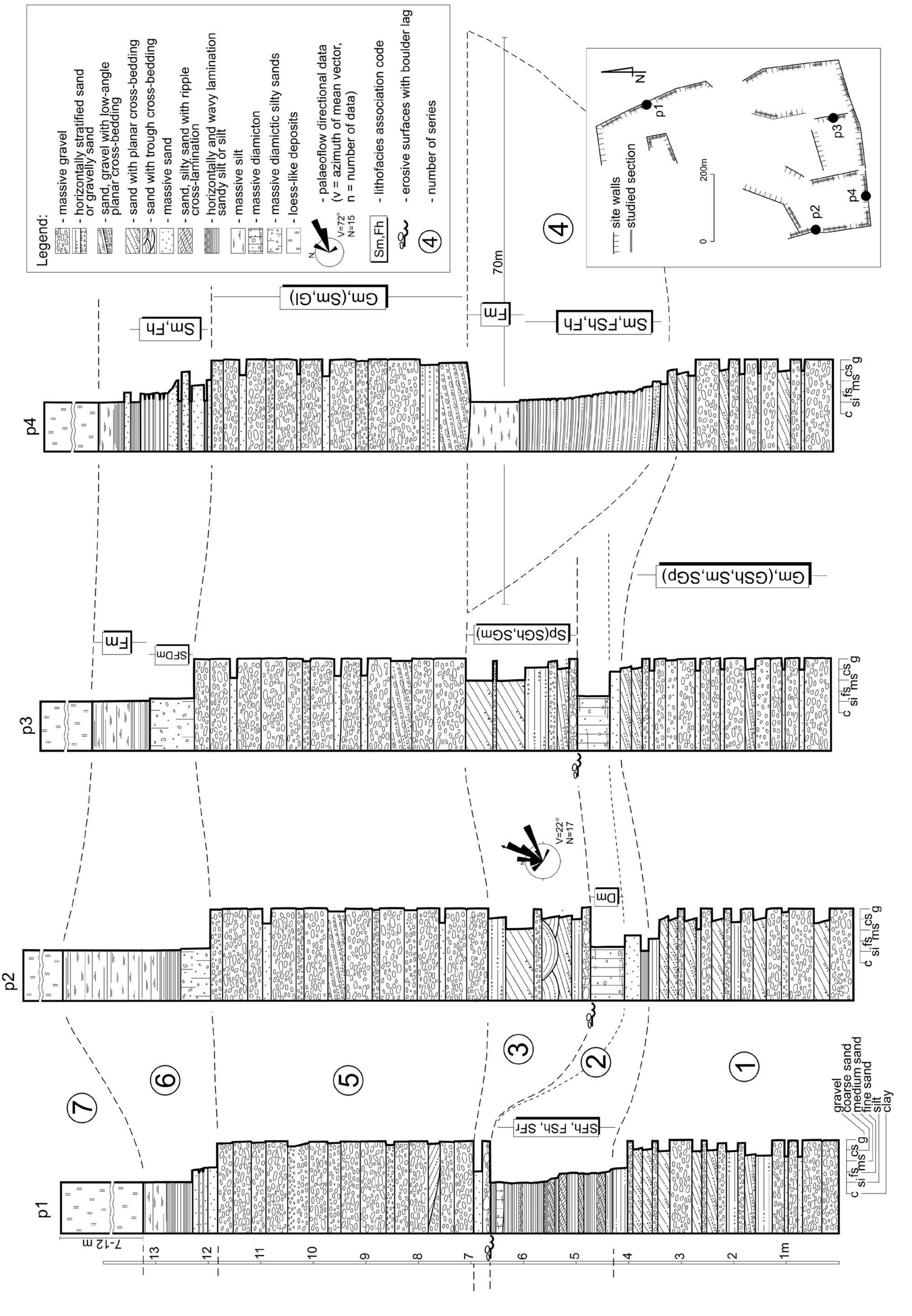


Fig. 2. Sedimentary logs from the Kończyce site

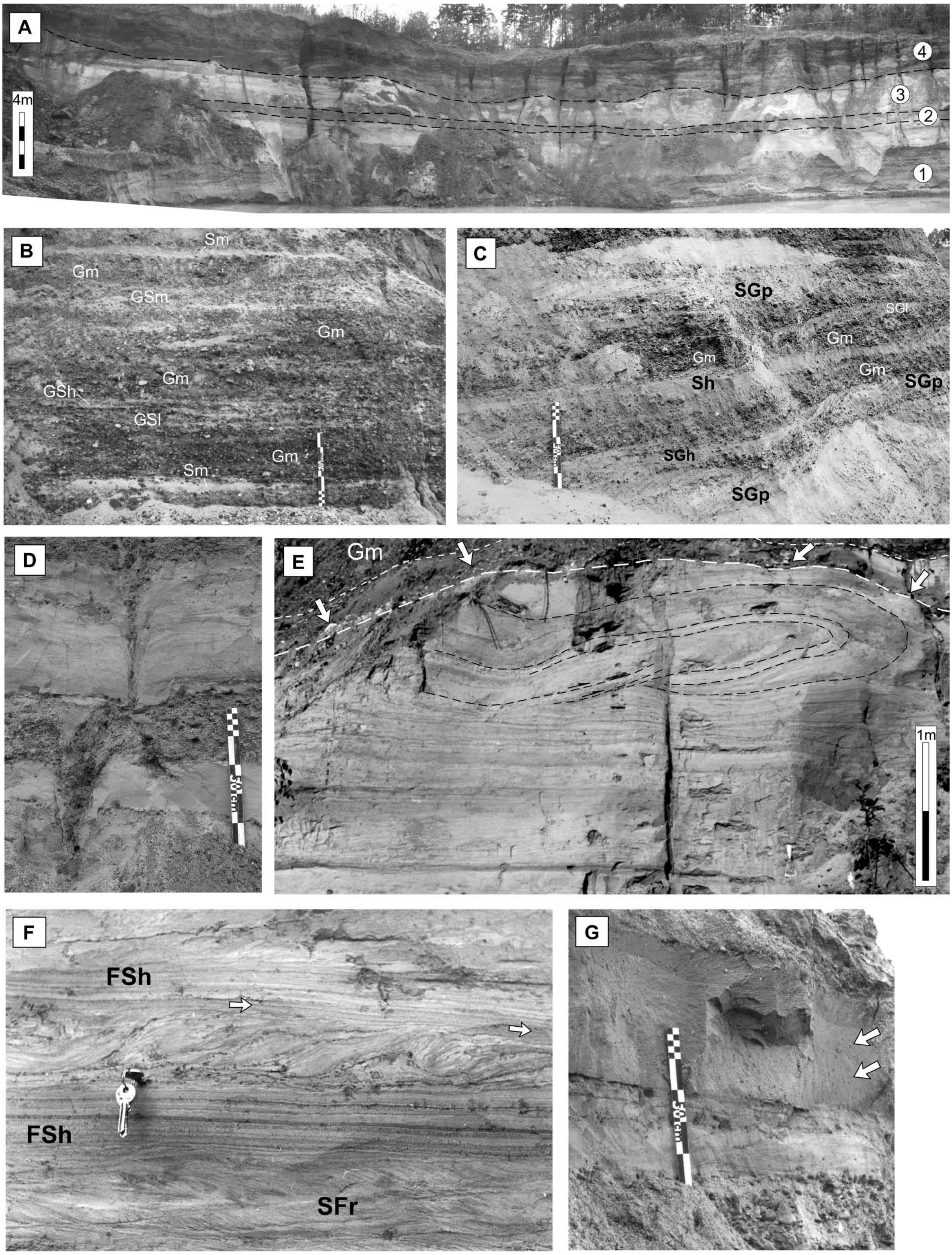
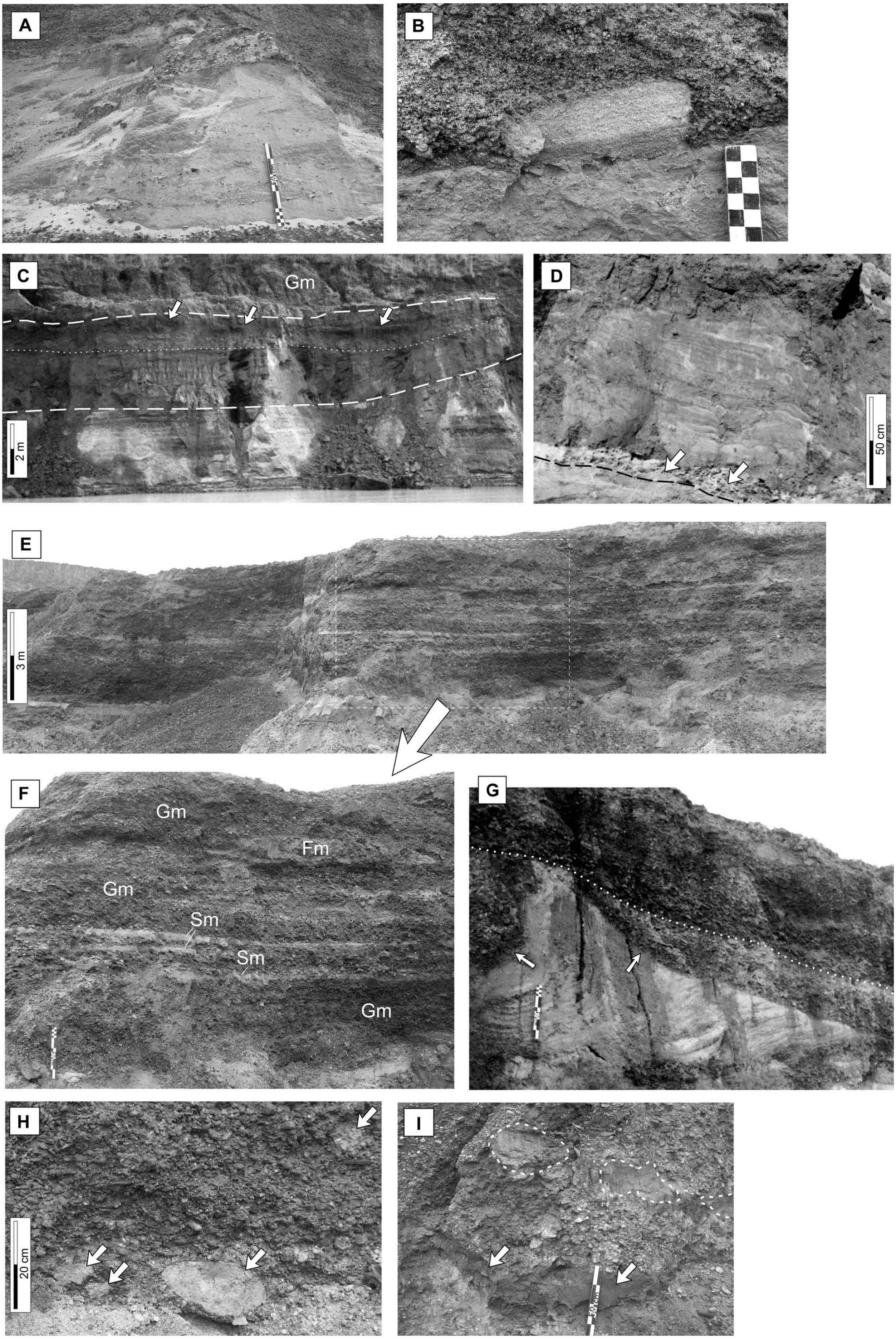


Fig. 3 The Kończyce site. **A** – sediments of the SE part of the site: 1 – lower series of gravel (series 1), 2 – till (series 2), 3 – series of fluvial sand (series 3), 4 – upper series of gravel (series 5); **B–D** – deposits of the lower series of gravel: **B** – lithofacies of massive gravel and sandy gravel dominated in the series (scale is 50 cm); **C** – medium-scale gravelly sand with locally high frequency, usually occur as single beds or rare in small cosets, alternately with thin beds of massive gravel (scale is 50 cm); **D** – ice-wedge structures developed in two horizons, filled with massive sand gravelly deposits; **E–G** – deposits of the glaciogenic complex: **E** – glaciolacustrine series built up of silts and sands. Medium-scale recumbent fold is visible in the upper part of the series. Fold is oriented to the south. Gravel pavement with Scandinavian material occurred above the erosive surfaces of the series (marked by arrows); **F** – close-up view of the glaciolacustrine deposits. Silty sands or sandy silts with horizontal lamination or ripple-cross lamination (in the lower part of the photo) are visible. Ripplemarks migrated to the south. Small-scale drag folds are also visible; these are oriented to the south as well; **G** – thin bed of basal till (arrowed)


A
B
C
Gm
2 m
D
50 cm
E
3 m
F
Gm
Fm
Gm
Sm
Sm
Gm
G
H
20 cm
I

found at several levels, and form distinct horizons with the thickness of 5–15 cm (Fig. 3F). Much greater ones occur in the upper part of the association. Most frequent are recumbent folds about 2–2.5 m high and with vergence also to the south (Fig. 3E).

In the southern part of the exposure, the lower gravel series is overlain by a thin (up to 1.5 m) cover of glaciofluvial sand and till (Figs 2, 3A). The till is silty-sandy diamicton, which forms a continuous, *ca.* 0.5–0.7 m thick layer (Fig. 3G). The diamicton has massive structure and many sandy interlayers and lenses. Fabric measurements indicate a strongly preferred orientation of gravel clasts. The diamicton is covered with erosional pavement, *i.e.* over ten centimetres thick layer of gravels and sands with a considerable content of Scandinavian material. The same pavement overlies the silty-sandy association in the NE part of the exposure (Fig. 2).

Sandy-silty association SFh, FSh, SFr was deposited in a small, shallow glaciomarginal lake. The lithofacies Sh, SFh, SFr, occurring in the lower part of the association, were derived from a shallow near-shore zone of the lake, in which the material delivered by rivers was spread over the lake bottom by weak currents. The lithofacies SFh, FSh, occurring in the upper part of the section, was formed in a somewhat deeper lake characterized by lower energy. In that lake, the sediments were deposited not only by periodic currents but also settled from suspension in almost stagnant water. The directions of palaeoflows indicate that the lake was fed from two directions, both from the north and south. An ice-sheet was the southern source of supply. It was also the main cause of the lake origin. The lake was formed because the channels of the northwardly flowing Olza River were dammed by ice masses.

Diamictic lithofacies, occurring within the glaciolacustrine deposits, are flow tills redeposited into the pond from the ice sheet surface. Deformation structures, especially the horizons of small folds, are associated with these tills. Larger structures of overturned folds were formed probably by the ice sheet advancing over glaciolacustrine deposits.

The continuous layer of diamicton in the SW part of the exposure is a basal till deposited by the advancing ice sheet. Its subglacial origin is evidenced by a flat basal surface, and especially by strongly preferred orientation of gravel clasts. The pavement overlying till and glaciolacustrine deposits, which primarily also had to be covered by till, indicates that glacial deposits are strongly reduced by erosion.

(3) Series of sands

The erosional pavement topping the glaciogenic complex is covered with a discontinuous complex of sandy and sandy-gravel deposits (Figs 2, 3A). Its thickness varies from 0.5 to 3 m. The series is mostly composed of sands (more rarely gravelly sands and gravels) with large-scale planar cross-stratification Sp, (SGp) (Fig. 4A). They are usually accompanied by medium- or small-scale lithofacies of sandy gravels or gravelly sands with horizontal stratification SGh or massive structure SGm. In the lower part of this series, silty clasts were observed (Fig. 4B). The azimuths of cross-stratification dip indicate that palaeocurrents flowed towards the N/NE (Fig. 2).

The sediments were deposited in the environment of a sand-bed braided river, what is evidenced by high frequency of Sp and SGp lithofacies. These lithofacies represent mid-channel transverse bars accreting downstream (McDonald & Banerjee, 1971; Smith, 1972; Cant, 1978; Cant & Walker, 1978). The lithofacies SGh and SGm were deposited from supercritical flows as the sheets in the shallow zones of channels. In comparison with series (*1*), this series was associated with a river system of considerably lower competence. However, it was also deposited under cold climate conditions. It is confirmed by numerous soft-sediment clasts, especially sandy ones, which were transported as frozen elements (Fig. 4B).

(4) Lower series of silts

The series of much finer-grained sediments is found in the southern part of the exposure, close to the axis of the Piotrówka River valley. The sediments fill a shallow (up to 5 m) and wide (at least 70 m) trough (Figs 2, 4C). These are sands, silty sands, sandy silts, and silts characterized by alternate occurrence of laminae of different thicknesses and grain sizes (Fig. 4D). In other places their structure is massive. The top of these sediments is erosional. The upper part of the succession consists of organic clayey silts reaching the thickness of 1–1.3 m in the axis of the trough and thinning out towards its margins (Fig. 4C). These silts contain numerous plant macroremnants and pollens. Palaeobotanical analysis presented by Wójcik *et al.* (2004) shows domination of deciduous forests at that time.

The deposition of the series was preceded by erosion, which caused the formation of a wide trough. Fine-grained character of the infilling sediments indicates that they were associated with very low-energy flows and periods of water

Fig. 4. The Kończyce site. **A, B** – series of fluvial sands: **A** – sands with planar-cross stratification (scale is 50 cm); **B** – sandy clast in the bed of fine-grained gravel transported as frozen element (scale is 10 cm); **C, D** – series of lower silts: **C** – overall view on the fragment of the series. Bottom erosive surfaces are visible. Lower part of succession is built up of alternately laminated poorly sorted sands, sandy silts and silts. Upper part of succession is built up of silts; in their upper part organic silts occur (arrowed); **D** – close-up view of the marginal part of lower series of silts. Bottom erosive surfaces are emphasised by gravel pavement (arrowed); above laminated sandy and silty sediments are visible; **E–I** – upper series of gravel: **E, F** – overall and close-up view of the series in the southern part of site; **G** – distinct erosive surfaces separated two gravel units. The lower unit is strongly deformed with the sands of the underlying series and cut by the upper one; **H** – well rounded silty clasts in the bottom part of the gravel series; **I** – strongly scored lens of silts (marked by arrows). Above, irregular silty clasts (marked by dotted lines) are also visible

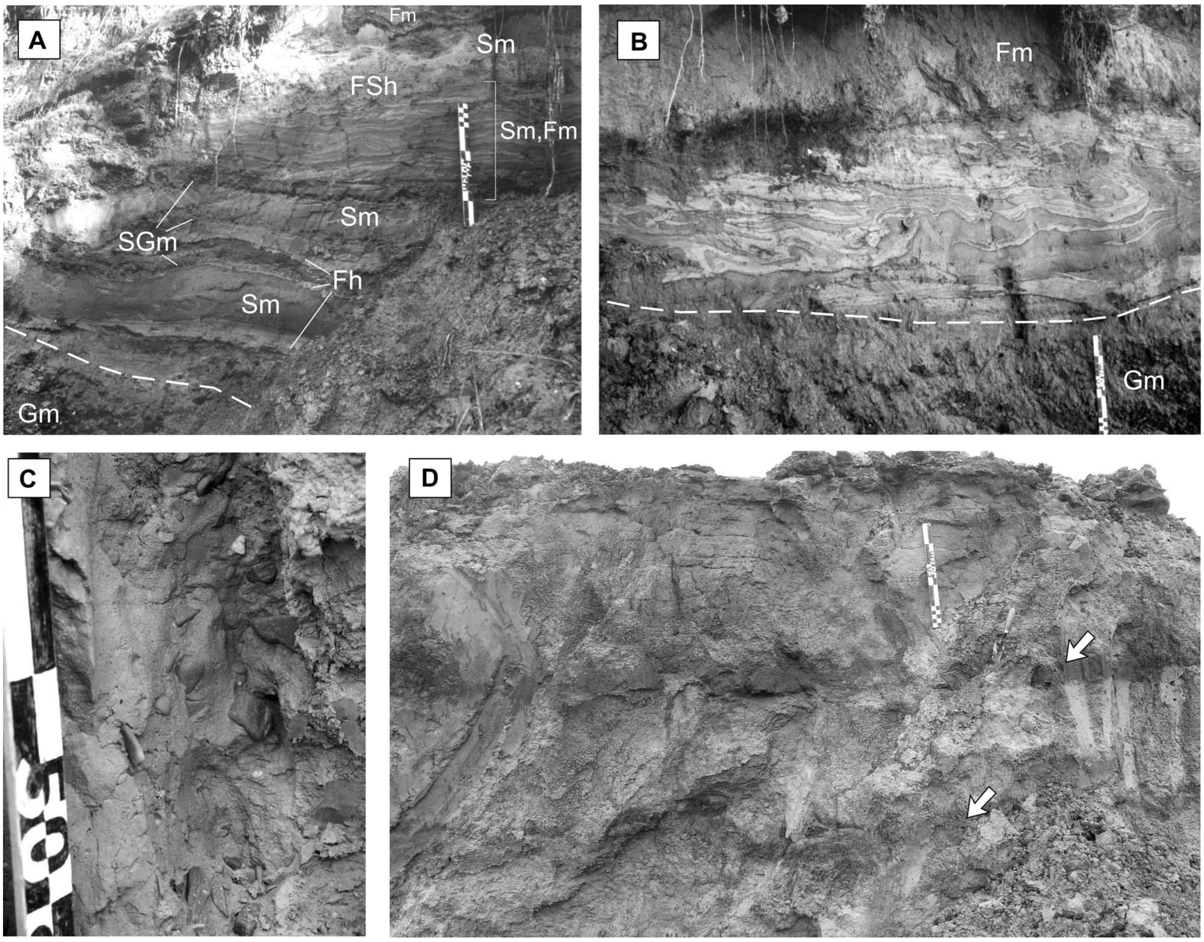


Fig. 5. Upper series of silts. **A** – poorly sorted massive sands, alternately with thin laminae of silts, occur locally in the lower part of the series (scale is 50 cm); **B** – slightly deformed sandy and silty lithofacies with distinct vergence of deformation structures to the north; **C** – massive sandy silts with dispersed gravel clasts; **D** – silts of the upper part of the series. Organic horizons are arrowed

stagnation. The alternate occurrence of sediments of different grain sizes and their poor sorting, especially in the trough marginal parts, indicate the high content of slope deposits washed into the erosional dissection. Organic silts were accumulated when flow completely ceased. Lithological character of sediments and high content of organic material suggest that the series was deposited under warm climate conditions. Wójcik *et al.* (2004) interpreted the pollen succession as an interglacial one (Cromerian I).

(5) Upper series of gravels

The series of gravels reaches the thickness of 5–6 m. It is composed of lithofacies association Gm (Sm, Gl). The series covers an erosional surface, locally in the form of shallow troughs (Fig. 3A). The association consists mostly of gravel lithofacies of massive structure Gm, usually of medium or large scale. The lithofacies thickness is from a dozen or so to over 50 centimetres (Fig. 4E, F). These are mostly matrix-supported gravels. The mean gravel size is 2–6 cm. Locally, in the lower part of the series, large-scale gravel or sandy gravel with planar, usually low-angle cross-stratification Gl are observed. The gravels usually built infillings of trough structures. In the basal part of series, the gravels contain abundant silty clasts. Their size is from 1 to more than 20 cm, their shape is irregular and rounded (Fig. 4H). Concentration of the clasts is the largest in the 1-m-thick band extending over erosive surfaces of the series. However, irregular silty fragments were also observed in other parts of the series (Fig. 4I). Sandy lithofacies were also noted in the series, but their frequency is much lower than the gravel ones. These are thin, elongated lenses of massive sands Sm (Fig. 4E, F). Rare elements of the series are lenticular beds of planar cross-stratified sand Sp with very low lateral extent (1–2 m) and massive silts Fm (Fig. 4F, I). Erosional surfaces have been locally noted within gravel packages (Fig. 4G). In places the gravels are deformed with the sands of underlying series (Fig. 4G).

The beds of series (*5*) are inclined to the north at a slightly greater angle than the units of underlying series. In the NE part of the exposure the gravels occur directly over the pavement topping glaciogenic sediments. The series of fluvial sands is almost completely reduced in these places.

The dominance of lithofacies Gm indicates a connection of the sediments with the environment of gravel-bed braided river (Williams & Rust, 1969; Smith, 1970; Rust, 1972; Miall, 1977). They were mostly deposited as longitudinal bars and gravel sheets under conditions of upper flow regime. The thickest lithofacies Gm are identified with the longitudinal bars. Lack of lithofacies which could be related to lower flow regime suggests that all channels of the fluvial system were shallow. Poor sorting and massive structure of gravels indicate rapid depositional processes. Sudden reduction of flow competence in the final phase of flood enabled deposition of sands. They usually formed thin sheets in the secondary channels.

Cross-stratified gravels infilling scours in the lower part of the series were derived from deeper channel zones, which functioned during river surges onto the previously inactive plain. The channel flows were characterized by high erosive potential. Intensive erosion during that initial period of series development can be inferred also from a large number of sediment clasts in the bottom part of the series.

The presence of channel-like erosional surfaces and abundant frequency of massive silts within the channels infills suggest frequent episodes of avulsion in the fluvial system. These types of sediments were accumulated probably quite commonly in the system, but usually were eroded during later flood flow events. It is confirmed by the presence of numerous clasts and irregular fragments of silts in the gravel lithofacies in different part of the series. Avulsion caused that some channels underwent sudden abandonment and other ones were trenched in the same time.

(6) Upper series of silts

Gravel series (*5*) is overlain by fine-grained deposits, 1.2 to 3.5 m thick (Fig. 2). The lower part of the series is characterised by a high lateral variability. Diamictic massive sandy silts with scattered gravel clasts dominate locally (Fig. 5C). In other places small- or medium-scale beds of poorly sorted massive sands have been noted. The sands contain rare granules and the silt laminae of various thicknesses (Fig. 5A). The frequency of silt intercalations increases towards the top of the series. Sandy-silty sediments are often deformed (Fig. 5B). The series represents a fining-upward succession. The upper part of the series is predominated by massive silt. Few thin horizons of brown organic silts occur there (Fig. 5D). Rich assemblages of floristic remnants and pollen of thermophilous plants have been found in this part of sedimentary section (Wójcik *et al.*, 2004).

The basal part of the series is composed of fluvial sediments deposited most probably in an overbank zone. Sand beds derived from short-lived flows and all fine-grained lithofacies were mostly settled from suspension. Frequency and intensity of currents decreased progressively during sedimentation of this series. The upper part of the series was formed in stagnant waters. Results of pollen analysis reveal the high variability of flora. The pollen spectra point to two warm periods, which made Wójcik *et al.* (2004) to believe that the studied series might correspond even with two interglacial stages (Cromerian II–III). According to Jersak (1983), organic deposits were formed in tundra condition during the Vistulian.

(7) Series of loess-like deposits

The silt series is covered with loess deposits. Their thickness reaches a dozen or so metres. The loess is usually laminated in the lower part and massive in the upper one. Load cast structures occur at the contact of loess with the underlying deposits.

In Jersak's (1983), opinion the mentioned sediments together with underlying silts of series (*6*) represent one stratigraphic horizon of the last glaciation. Wójcik *et al.* (2004) and Drewnik *et al.* (2004) discern fragmentarily preserved initial palaeosols in the loess series, which point, in their opinion, to different ages of sediments.

DEVELOPMENT OF THE OLZA RIVER FAN

Sedimentological model

The predominance of flysch material indicates that the examined gravels (*series 1, 5*) were transported from the Carpathian Mts. by the Olza River. The occurrence of gravels at a distance of several kilometres from the present valley of the Olza River shows that the river freely migrated, where it left the Carpathian Foothills. The wide lateral spread of gravels appears to indicate that they were deposited as a fan (Fig. 6A). This sedimentary environment is also inferred from relatively small thicknesses of successive series. For example, the upper series of gravel, correlated with one glacial period, is only 5–6 m thick. In comparison, the thickness of alluvia building the terraces in the mountain and foothill valleys reaches often more than a dozen or so metres (Starkel, 1977). Small thickness of the studied series can be explained by intensive lateral migration of the river channels on a broad fan surface. Frequent avulsion is interpreted from numerous marks of fragmentarily preserved sediments deposited in abandoned channels. It is also confirmed by ice-wedge structures developed at different levels. These indicate periods of various fluvial activity in individual parts of fan surfaces, what is typical for alluvial fans.

Lithofacies character of the series indicates that the fan was mostly aggraded in cold periods when the river system acted as a braided pattern. Great supply of deposits to river channels in the mountain section of the valley, associated with disappearance of a forest cover, resulted in river overloading and intensive deposition.

The formation of fans by rivers leaving mountain areas was very common phenomenon in cold periods (Książkiewicz, 1935; Stupnicka, 1963; Starkel, 1967; Gilot *et al.*, 1982; Niedziałkowska *et al.*, 1985; Krzyszkowski, 1993; Mastalerz & Wojewoda, 1993; Badura *et al.*, 2005). Narrow mountain valleys were predisposed to fast aggradation of alluvia. This resulted in a considerable increase in inclination of deposition surface at the valley outlet to the foreland, which is typical for fan environment. Location of the site indicates that the studied sediments were deposited in the middle or even more distal part of the fan.

Fluvial activity of the fan ceased when river started to cut into its surface. In opinion of many researchers (Rose, 1995; Kasse *et al.*, 1995; Mol, 1997; Huisink, 1997, 2000; Mol *et al.*, 2000; Vandenberghe, 2002; Kasse *et al.*, 2003), this process occurred in European river systems in the final stages of glaciations and resulted in decrease of deposit supply to river channels, and led to erosion. The disappearance

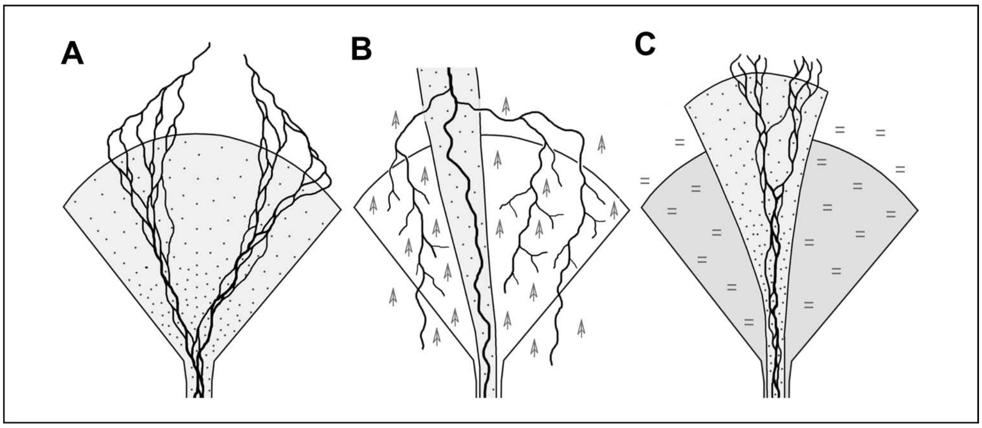


Fig. 6. Model of the Olza River fan's development. **A** – fan development under cold climate condition during glacial stages. The entire fan surface was aggraded by gravels and sands in a braided river system; **B** – fan development in final phases of glaciations and during interglacials under warm climate conditions. Main river activity was restricted to a narrow valley, which deeply dissected the fan surface. Outside part of the fan, slightly dissected by secondary valleys, was colonised by forest. These valleys were filled with fine-grained sediments; **C** – fan development under cold climate condition after tectonic uplift and/or during lower intensity of deposition. Fluvial processes restricted to smaller fan inserted in the older, dissected form. Intensive aeolian loess deposition on higher surfaces of the inactive part of the fan

of permafrost played also a considerable role (*cf.* Huisink, 2000; Mol *et al.*, 2000; Vandenberghe, 2001, 2002). At that time, the Olza River probably changed its pattern into one-channel system. Such process was recorded in many valleys during the end of the last glaciation (Starkel, 1977; Szumański, 1986; Kozarski, 1983; Kasse *et al.*, 1995; Mol *et al.*, 2000). In this way the river reduced its activity to a narrow dissection of the fan. This zone evolved with time into a flat-bottom river valley, like the present Olza River valley.

From the time when the river system had changed and the Olza River started downcutting, the fan was not aggraded with alluvia but fluvial processes on its surface were not completely stopped. Those parts of the fan, which were outside the Olza River tract, became the places of activity of secondary streams – the tributaries of the Olza River (Fig. 6B). These small streams also cut the fan surface. However, that process occurred much slower and on a smaller scale, because the energy of small streams was low. Their activity resulted in formation of the system of narrow and shallow, small valleys, which dissected the fan surface. One of such erosional dissections is recorded in the studied site as a channel structure filled with fine-grained sands and silts (*series 4*).

The valley system, described above, was being established during the interglacial stages. The fan surface was colonized by plant communities. Low activity of fluvial processes, limited to narrow, secondary valleys is reflected in the succession of series (*4*). Fine-grained nature of the deposits indicates their connection with low-energy flows, and periodically even with the deposition in completely stagnant water. It was probably associated with the occurrence of local waterlogged areas with stagnant water in a small valley. The deposition took place under warm climate conditions as evidenced by the occurrence of organic silts with pollen and remnants of thermophilous plants, especially deciduous trees (Wójcik *et al.*, 2004).

Environmental conditions of the fan probably changed in consecutive cold periods. The Olza River system took the form of a braided pattern again. Gradual disappearance of forests preceded the aggradation of the fan surface with the successive series of gravel alluvia. Gravels were deposited on the fan surface after filling the Olza River incision. In this way, the avulsion of channels and their unconfined migration on the fan surface were possible.

There were probably several such accumulational-erosional cycles during the development of the Olza River fan. However, precise determination of their number is impossible. Especially, the lower series of gravels is poorly examined because of their fragmentary exposition. This thick series can be multipartite. Wójcik *et al.* (2004) assumed that it can represent even tripartite division.

Presumably, the fan evolution was much more complicated than the presented model. It is very probable, for example, that the apex of the fan was shifted to the north during the successive cold periods, due to different levels of aggradation of the Olza River valley. This phenomenon occurred when aggradation of alluvia in the valley reached a lower level than in the former periods (*cf.* White *et al.*, 1996). Unfortunately, no geomorphic tool can be used in this study, because the fan is covered by thick loess-like deposits, and the primary fluvial relief is buried.

A quite different fan development occurred during the glacial period, when the ice sheet advanced on the examined region. The ice sheet covered the whole area of the Cieszyn Foothills, and reached its maximum extent a dozen or so kilometres to the south of the Kończyce site (Książkiewicz, 1935; Klimaszewski, 1952). The fan surface was built up by till and glaciofluvial deposits. Locally, small, dammed lakes existed in the fan zone in the front of advancing ice-sheet. Sandy and sand-silty deposits accumulated in these shallow ponds.

The series (*3*) occurring directly over the glaciogenic deposits differs from the other ones. It is composed not of gravels but mostly of sands. The NE direction of palaeoflows indicates connection of the series with the Olza River, the same as the gravel units. Presumably, the source material of these sands were mainly glacial deposits redeposited from the foothills section of the Olza River valley. Because of individual character of the series compared to gravel alluvial units, determination of the moment of its deposition is very difficult. It is possible that this series was associated with some cold period of lower rank, which occurred after the main phase of glaciation, or even with the phase of ice-sheet retreat.

The uppermost series of gravels was associated with the successive stage of fan building up during the next glaciation. Sands and silts occurring in its top part represent the last episode of fluvial deposition on the fan, mostly from suspension. They were probably deposited in secondary channels of streams flowing on the fan surface during greater floods, when the Olza River started to dissect its own alluvia. Flow routes started to concentrate in the main valley, which deepened at that time. However, erosion was so slow that, for some time, the river could have overflowed the surface of the dissected fan during floods. Fine grain size of deposits indicates that energy of flow was rather low, and transport occurred mostly in suspension. The temporary overbank flows, probably associated with great floods, rapidly turned into the phases of stagnant water. In later periods, these periodically active parts of the fan became the places where silts and organic deposits accumulated. They are very well preserved, mostly owing to the fact that during the successive cold stage the fan's building up with alluvia, usually preceded by erosion, did not occur.

Loess-like sediments were deposited by wind under the periglacial climate conditions. During their accumulation the fan was not covered with successive series of gravels. Most probably, fluvial activity on the fan had to be confined to a narrow zone (Fig. 6C). Aggradation in the Olza River valley was too small for river overflowing the fan surface. This can suggest the lower intensity of deposition. On the other hand, the same effect could have been brought by the uplift of substratum causing rise of the fan surface and the change of its hydrological condition. Neotectonic activity of the area during the fan formation is suggested by the discordant occurrence of successive series. The series of upper gravels is inclined to the north at a slightly greater angle than the older ones. Vertical movements could have been associated with isostatic relaxation of the substratum due to the retreat of the Scandinavian ice sheet. Such phenomena are commonly documented from the Sudetes foreland (Dyjor, 1983; Krzyszkowski & Stachura, 1998) and from the South-Polish Uplands (Liszkowski, 1993). The arrangement of layers indicates that the amplitude of uplift increased to the north. After deposition of the upper gravel series the area was again slightly uplifted. This is proved by the geology of the present valley bottoms of the Olza River and its tributaries. These rivers are incised several metres deep into the Miocene clays (Wójcik *et al.*, 2004).

Stratigraphic constraints

A fundamental question in the Olza River fan's development is stratigraphic correlation of successive units. The consequences of their interpretation have widespread influence on the palaeogeography of the region. Palynologically analysed organic silts and the complex of glaciogenic deposits are stratigraphic key layers in the deposits under study. According to Jersak (1983), the organic deposits overlying the upper gravels are of Vistulian age, pointing to a long period of fan activity and indicating that the Odranian (Saalian-1) Glaciation might have been the last stage of alluvial fan building up. This hypothesis is well explained by the fact that the end of fan's fluvial activity followed the accumulation of upper gravel (*series 5*). In this way, the cessation of fluvial aggradation can be interpreted as: reaction to isostatic movements that occurred after the Odranian Glaciation, when the ice sheet advanced as far as the northern boundary of the Moravian Gate (Lewandowski, 1988), and/or lower intensity of deposition in the Olza River valley during successive glaciations (Wartanian, Vistulian). However, the results of other studies (Wójcik *et al.*, 2004) suggest that the activity of fluvial processes finished much earlier, *i.e.* before the Sanian Glaciation (Elsterian-2). This assumption seems to be surprising in the context of subsequent glaciations (Sanian and Odranian), during which the ice sheet advanced far to the south (Lewandowski, 1988; Macoun & Králik, 1995; Marks, 2005; Mojski, 2005). The question has to be asked: why the Olza fan did not undergo alluvial aggradation in conditions of periglacial climate and proximity of ice sheet favouring intensive accumulation during the mentioned glaciations, especially that the valleys of Carpathian rivers aggraded then very intensively (Klimaszewski, 1948; Starkel, 1972). Wójcik *et al.*'s (2004) stratigraphic interpretation raises also another question: why two series of interglacial age (*series 6*) are not separated by a horizon of periglacial structures or any evident erosional surfaces, in a such dynamic zone like the fore-mountain area?

All these questions and doubts order to keep great caution for stratigraphic interpretation of the fan deposits. If we assume the universally accepted opinion about glaciation of the Carpathian foreland during the Sanian (Elsterian-2) Glaciation (Klimaszewski, 1952; Lindner, 1992; Mojski, 1993, 2005; Macoun & Králik, 1995; Marks, 2005), it can be concluded from the succession of the series, that the upper series of gravels should have been deposited during the Odranian (Saalian-1) Glaciation. The underlying and overlying series in this concept would be, respectively, older and younger. This supposition is still in contradiction to the results of palynological and palaeomagnetic analyses (Wójcik *et al.*, 2004), which are difficult to challenge. Finally, it can be concluded that in such morphologically diversified region any analyses can not be uncritically used for stratigraphic interpretation without considering all potential data. In the light of contemporary studies the age of the Olza fan is still far from unambiguous inference and can be younger than Wójcik *et al.* (2004) have suggested.

FINAL REMARKS

Sediments in the Kończyce site were deposited mainly by the Olza River in the zone of a fore-mountain fan, at the valley outlet from the Carpathian foothills. The fan was formed in many stages. Lithological differentiation of the

Table 2

Comparison of consecutive phases of fan development

Series of deposits	Climate conditions	Environment of sedimentation	Phase of fan development
(7) Series of loess	Cold climate conditions (glaciation)	Aeolian deposition of fine-grained deposits	Aggradation of loess on the higher part of fan surfaces
(6) Upper series of silts	Transition from cold to warm, finally warm climate conditions	The lower part of series connected with overbank deposition of fluvial system. Silts of the upper part of succession deposited in stagnant water condition	Low-energy deposition in the abandon channel system on the fan surface
(5) Upper series of gravels	Cold climate conditions (glaciation)	Shallow gravel-bed braided river	Fluvial aggradation of alluvia on the fan surface
(4) Lower series of silts	In the first phase transition from cold to warm, later warm climate conditions	Low-energy small fluvial system (tributary of the main river), occasionally deposition in stagnant water condition	Dissection of the fan surface and low-energy deposition in the secondary palaeovalleys
(3) Series of fluvial sands	Cold climate conditions (glacial stadial?)	Sand-bed braided river	Fluvial aggradation of alluvia on the fan surface
(2) Complex of glaciogenic sediments	Cold climate conditions (glaciation)	Glaciomarginal and subglacial deposition	Glaciogenic aggradation on the fan surface
(1) Lower series of gravels		Shallow gravel-bed braided river	Fluvial aggradation of alluvia on the fan surface

studied sediments reflects great variability of depositional conditions (Table 2). The fan evolution was mainly controlled by Pleistocene climatic changes.

Under cold climate conditions during glaciations, the fan surface was built up mainly of the series of gravels deposited by a shallow braided river. Gravels were deposited mostly as longitudinal bars and sheets. The channels were characterized by frequent avulsion. In the final phases of cold periods the fan was dissected, and the activity of the Olza River became restricted to a narrow valley. Besides the main river the fan was dissected also by secondary streams, the tributaries of the Olza River. During interglacials the fan was only slightly transformed. Geodynamic processes acted only in the axial narrow, small valleys. The fan surface was colonized by forests.

A special period of the fan development occurred during the glaciation when the ice sheet advanced on the Carpathian foreland. The fan became then a place of glaciogenic deposition. Neotectonic movements were probably an important factor in fan's development. These small-amplitude movements could have presumably been associated with isostatic relaxation of the substratum after the retreat of the Scandinavian ice sheet. Aggradation of the fan was terminated most probably due to uplift of the area. A considerable part of the fan became the place of aeolian accumulation of loess at that time.

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