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The distinctive shapes of some kame ridges in the Łódź region of Central Poland

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Abstract: In the central part of the Rawka lobe of the Warta stage ice sheet of the Middle Polish glaciation (Saalian), areal deglaciation took place in the vicinity of Łódź. This is indicated by the numerous kames here, among which ridge forms are conspicuous. Some of the ridges which are situated on the slopes of river valleys and on the slopes of terrain depression possess unusual shapes which resemble „tongues" and „paws". These forms merge gently with the adjacent elevated upland, whereas their distal parts are sharply defined and may lie as much as several decametres above their bases.

„Kame tongues" and „kame paws" are built from paraglaciolacustrine and glaciofluvial deposits which accumulated in water bodies between dead ice blocks during the final phases of the ice sheet downwasting. The distinctive shapes of the landforms result from the varying thickness of the dead ice masses: thinner on the elevations and significantly thicker in terrain depressions (mainly in large, subglacial pre-Wartian valleys). These characteristic kame ridges demonstrate that the more elevated parts of the subglacial surface had been ice free for a long time before the dead ice blocks eventually disappeared from the terrain depressions.

Key words: kame, relief, deglaciation, Łódź region of Central Poland

Introduction

Traditionally, kames have been regarded as accessory, small-scale and (by comparison with, say, large moraine ridges) of little importance in landscape analysis. However, during the last several decades, Polish geomorphologists have recognised that there are widespread landforms in those areas covered by ice during both the last and previous glaciations (Bartkowski, 1965; 1968; 1972; Niewiarowski, 1959; 1965; Klajnert, 1966; 1978; Klimek, 1962; Musiał, 1992).

The relationship between kames and other landforms of glacial and glaciofluvial origin, for example with eskers and dead-ice moraines, is still controversial, particularly when they are hybrid types.

It has been found, for example, that kames may be built from various sediments, not necessarily of fine grain, as generally believed, and that most kame deposits display a complex system of stratification.

The term „kame" is now applied to a wide variety of landforms, not only those which developed in open ice-crevasses (the traditional application of the term – Niewiarowski, 1957, 1959), but also a large family of forms which relate genetically to the dead-ice sedimentary environment – "a group of landforms fashioned in association or in contact with dead ice" (Bartkowski, 1968).

The growth of knowledge about and interest in the kames of Poland and about the relationship between their genesis and areal deglaciation of the Pleistocene ice-sheets is expressed by the many classification schemes of these landforms now published (Niewiarowski, 1959; Baraniecka, 1969; Bartkowski, 1968; Karczewski, 1971). Those include reference to a large variety of features, e.g. the horizontal and vertical positions of kame accumulation with regard to the associated ice sheet, the nature of kame material and its arrangement, the presence of ablation covers and the nature of post-sedimentation disturbance they commonly show. As an indicator of

their genesis, rather less importance is now assigned to morphological attributes of kames; even so, in detail, these features are still to be regarded as valuable indicators of origin and development of kames. The form of the kame is still commonly distinguished by the terms: hillocks, hills, ridges, plateaux and terraces. They are distinctive in a topography, that is, they are accentuated prominently on all sides. Apart from these terms, other morphometric attributes of the landforms include an altitude which may range from a few to several tens of metres and a gradient.

However, it remains problematic how kames should be classified in terms of their morphography and morphometry and the precise origin if they are prominent in a terrain from one side only, whereas from the other side they merge seamlessly with the surrounding upland. Morphologically, they may resemble solifluction lobes or tongues, or glaciofluvial deltas, as, for example, the magnificent deltas along the shorelines of the Pleistocene seas in Scandinavia, now elevated by isostatic movements. Certainly, the outlines of the deltas in plan are significantly different from those of the kame ridges.

Such highly unusual shapes of kame ridges have been observed by the Author and collaborators in the broad vicinity of Łódź (Klajnert, 1992b).

The Łódź Upland – glaciation and deglaciation

For many years now, glacial geomorphology research carried out at the Department of Geomorphology of Łódź University has concentrated on the Wartian Stage ice sheet deglaciation and the genesis of the concave landforms within the Łódź Upland, the central part of which is known as the Łódź Rampart (Dylikowa, 1973). This forms a N-S ridge which is c. 80 km long and which exceeds 200 m above sea level. To the west, north and east the ground which extends along the valleys of the Warta, Bzura, Rawka and Pilica is much lower (Fig. 1).

The Łódź Upland exerted a decisive influence on the course of deglaciation during the Warta stage of the Middle Polish glaciation. The ice flow from the NW and N met this elevated terrain near Łódź, which is underlain mostly by the Mesozoic rocks of the Łódź Synclinorium and the Kujawy–Pomeranian Anticlinorium. This caused the ice sheet divide into two lobes: the Widawka lobe in the west and the Rawka lobe in the east (Fig. 1 – Różycki, 1961; 1967; 1972a; 1972b; Klatkowa, 1972). The position of the ice margin was variously located (Galon, Roszkówna, 1961; Różycki, 1967; Baraniecka *et al.*, 1969; Baraniecka, 1984). To the north of the Łódź Upland,

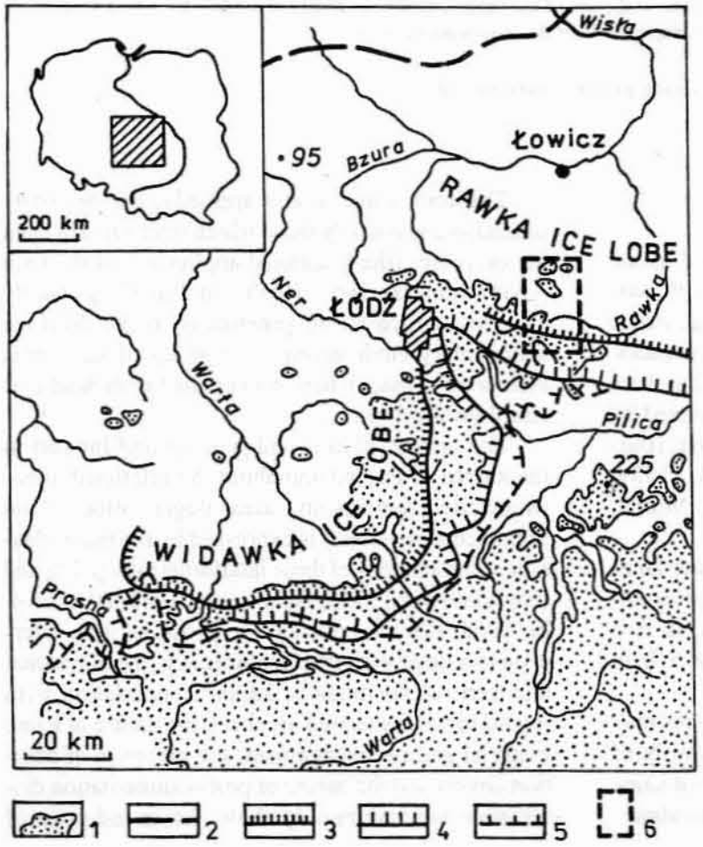

Fig. 1. The extent of Pleistocene glaciations in Central Poland (modified after Klatkowa, 1972)
1 – peninsula of the Łódź Upland (area elevated above 200 m a. s. l.); 2 – maximum extent of the Vistulian (Würm) glaciation; 3–5 – maximum extent of the Middle Polish glaciation of the Warta stage after various Polish authors: 3 – Galon & Roszkówna (1961), 4 – Różycki (1967), 5 – Baraniecka *et al.* (1969), 6 – area investigated by the Author

it is approximated by glaciotectonic forms and structures, which are particularly well pronounced in the northern zone of the Łódź Upland edge. Here, the formation of the edge steps, which descend towards the Warsaw–Berlin Pradolina, has been associated with simultaneous pushing and levelling of the ground surface by the encroaching ice sheet (Klatkowa, 1972).

In contrast to the edge zone, kames are common in the areas situated in the central parts of the Rawka and the Widawka lobes. These clearly indicate an areal type of deglaciation. The above view onto the ice sheet disintegration and decay in the middle part of the Widawka lobe is derived from the extensive researches of Baraniecka (1971), Baraniecka *et al.* (1969), Gawlik (1970), Klatkowa (1972), Krzemiński (1974), and Wasiak (1979).

With regard to the eastern part of the Rawka lobe, between the Bzura and the Pilica (Fig. 1), earlier opinions concerning the frontal recession of the Wartian ice sheet (Balińska-Wuttke, 1960; S. Z. Różycki, 1961; 1972a) became replaced by a newer concept that glacial relief in this area was formed essentially by areal deglaciation, which includes many kames (Klajnert, 1966; 1978; 1984; 1992a; Klajnert, Rdzany, 1989; Klajnert, Wasiak, 1989; Klajnert, Świdrowska, 1992; Rdzany, 1997; Kobojek, 2000).

The Skierniewice Interfluve (the N part of the Łódź Upland) Spatial distribution of kames

A detailed analysis of the internal composition of kames, in particular of the ice-contact deposits and structures, has permitted a reappraisal of the processes of ice-sheet disintegration and of the thinning and decay of stagnant ice blocks in several parts of the Skierniewice Interfluve. Skierniewice is situated south of Łowicz, about half way between Warsaw and Łódź (Fig. 1.). A survey of dips and strikes of laminae of glaciofluvial sands and gravels in a vertical sequence of bedded kame material has introduced a new dimension to studies of areal deglaciation dynamics in the Łódź region (Klajnert, 1966, 1969, 1978, 1984, 1992a, 1992b). It has been determined that the configuration of the underlying topography had a controlling effect on the directions of meltwater flows during the deglaciation, and therefore, indirectly, on processes governing the accumulation of kame deposits. This influence has been recognised both in the wider context of the vast, long subglacial slopes of the Łódź Upland, which are generally inclined towards the glacier (i.e. towards NW, N and NE), and at a smaller, regional scale. In the latter case, it was found that the directions of the meltwater flows responsible for the kame material deposition corresponded with local gradients of fragments of the subglacial interfluve. The surfaces of these fragments are inclined, as are contemporary interfluve areas, towards the adjacent river valleys, i.e. towards "subglacial valleys", which, despite of being filled with substantial masses of dead ice, served as important drainage routes (Fig. 2). Not surprisingly, the majority of the kames are now situated in contemporary river valleys, and also below a variety of benches or edge steps. The thickness of kame deposits increases towards the lower-lying areas, hence the heights of these kame ridges tend to increase commensurately. With respect to the unusual shapes of these landforms, the terms "kame tongues" and, in the cases where several tongues possess a wide common base, "kame paws" are proposed as the most appropriate to describe these features.

Kame tongues. Morphology and internal structures

The Rogoźno Ridge, which descends diagonally towards the axis of the Bobrówka valley floor near Łowicz, is an excellent example of a kame tongue (Fig. 3). It begins as a small mound on the south, outside the valley, but, further northwards, near Lake Okręt in the Bobrówka valley, changes into a narrow, sharply defined landform, which is elevated about 15 m above the surroundings. Interestingly, the arcuate line of the ridge axis reflects a similar form of an ice crevasse in stagnant ice.

Many kame ridges possessing features of kame tongues have been found in the basin of the Upper Rawka valley, west of Rawa Mazowiecka. During the period of areal deglaciation, the upper Rawka valley, 5 km wide, was filled with stagnant ice. Gradual downwasting of the ice formed conditions suitable for the ponding of glacial lakes. The slow melt water

Fig. 2. Scheme of morphologic situation of kame ridges on Łódź Upland. The arrows indicate predominant direction of dips of laminae of the glacifluvial sediments. Note the increase in thickness of kame sediments and in relative altitude of the ridges towards the river valleys

flow through the lakes resulted in the accumulation of paraglaciolacustrine silty-sandy deposits, but in later, more turbulent, phases, glaciofluvial sands and gravels accumulated. These sediments build kame terraces in the Rawka valley, which are often arranged in a staggered sequence (Klajnert, Rdzany, 1989; Klajnert, Wasiak, 1989; Rdzany, 1997).

Kame tongues of various length and width are particularly frequent at the edge of this broad valley, i.e. in the transition zone between the valley and flat

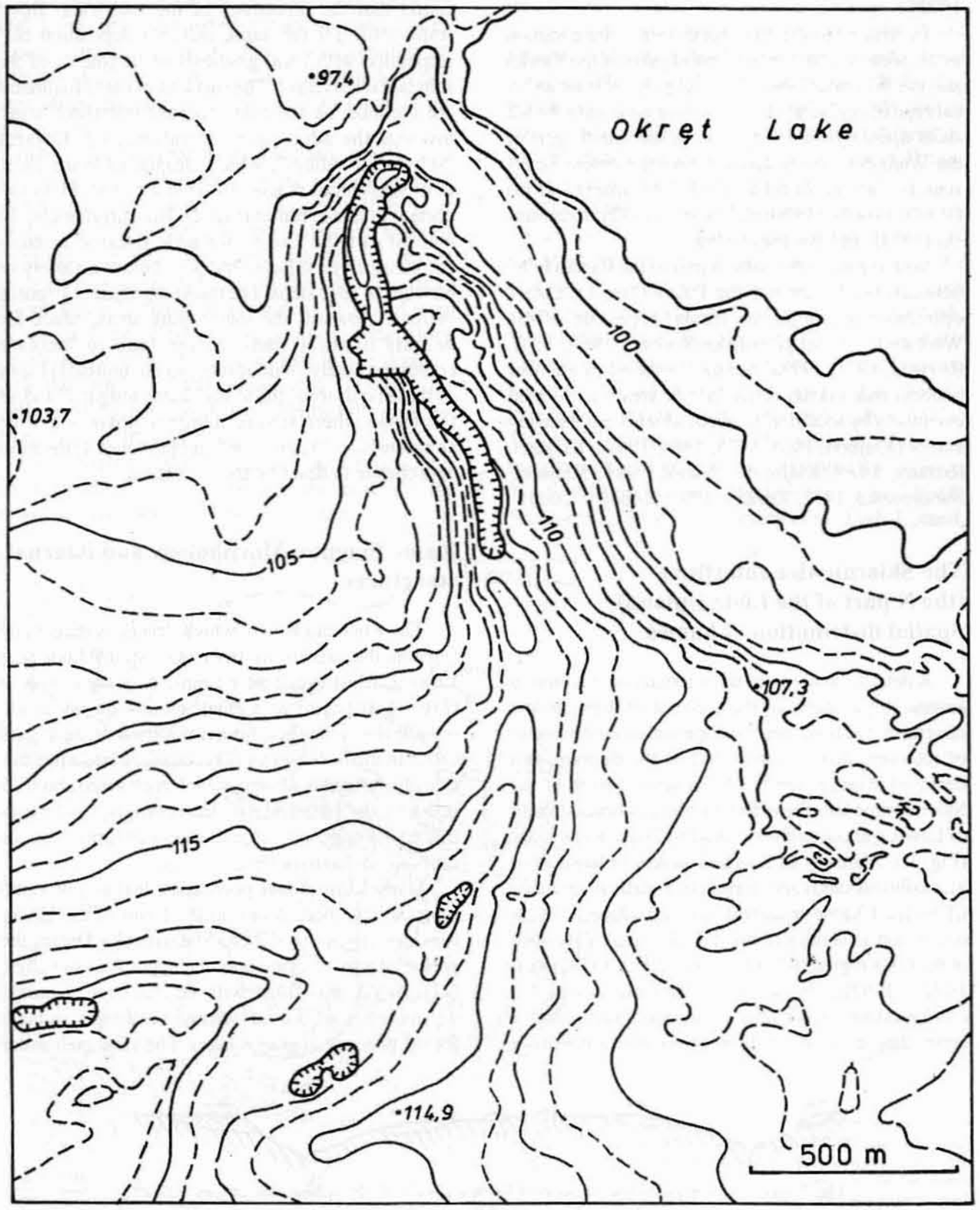

Fig. 3. The Rogoźno Ridge – a kame tongue with a curving morphologic axis

interfluves. In this area, the kame tongue at Tatar on the outskirts of Rawa Mazowiecka (Fig. 4) was examined most thoroughly. Traditionally, this landform had been described as a frontal moraine ridge (Balińska-Wuttke, 1960). Later, it was interpreted as a kame (Makowska, 1971; Klajnert, 1984; Klajnert, Rdzany, 1989).

A more detailed analysis of this landform has recently been carried out by Rdzany (1997). The ridge has the shape of a typical kame tongue and is about 700 m long and 300–400 m wide. It is situated on the northern slope of the Rawka valley. From the side of the interfluve, built here from till, the ridge connects smoothly with the surrounding side slopes; by contrast, on the other side, near the valley bottom, its height increases to 30 m (Fig. 4). A 10 m-deep exposure in its southern part displays bedded silts, sands and gravels deposited in the shape of a glaciofluvial delta in a narrow stretch water, between the blocks of dead ice which once filled the Rawka valley. The material was supplied from the NW, from the interfluve area, an elevated portion of the ice sheet base (Rdzany, 1997, see Fig. 4). It must be emphasised that, in marginal parts of this kame tongue, sandy-pebble-till ablation sediments were observed to cover gravitational disturbances of an ice-contact type.

Also, a well developed, large kame tongue is present further westward in the upper Rawka basin, near Góra and Kochanów (Fig. 5). This is over 3 km long and, in places, as much as 1 km wide; it is aligned almost parallel with the Rawka valley axis. The tongue begins at Góra, where its broad, domed base merges with the interfluve area. At the other end it is elevated about 20 m above the valley floor. North of the lobe,

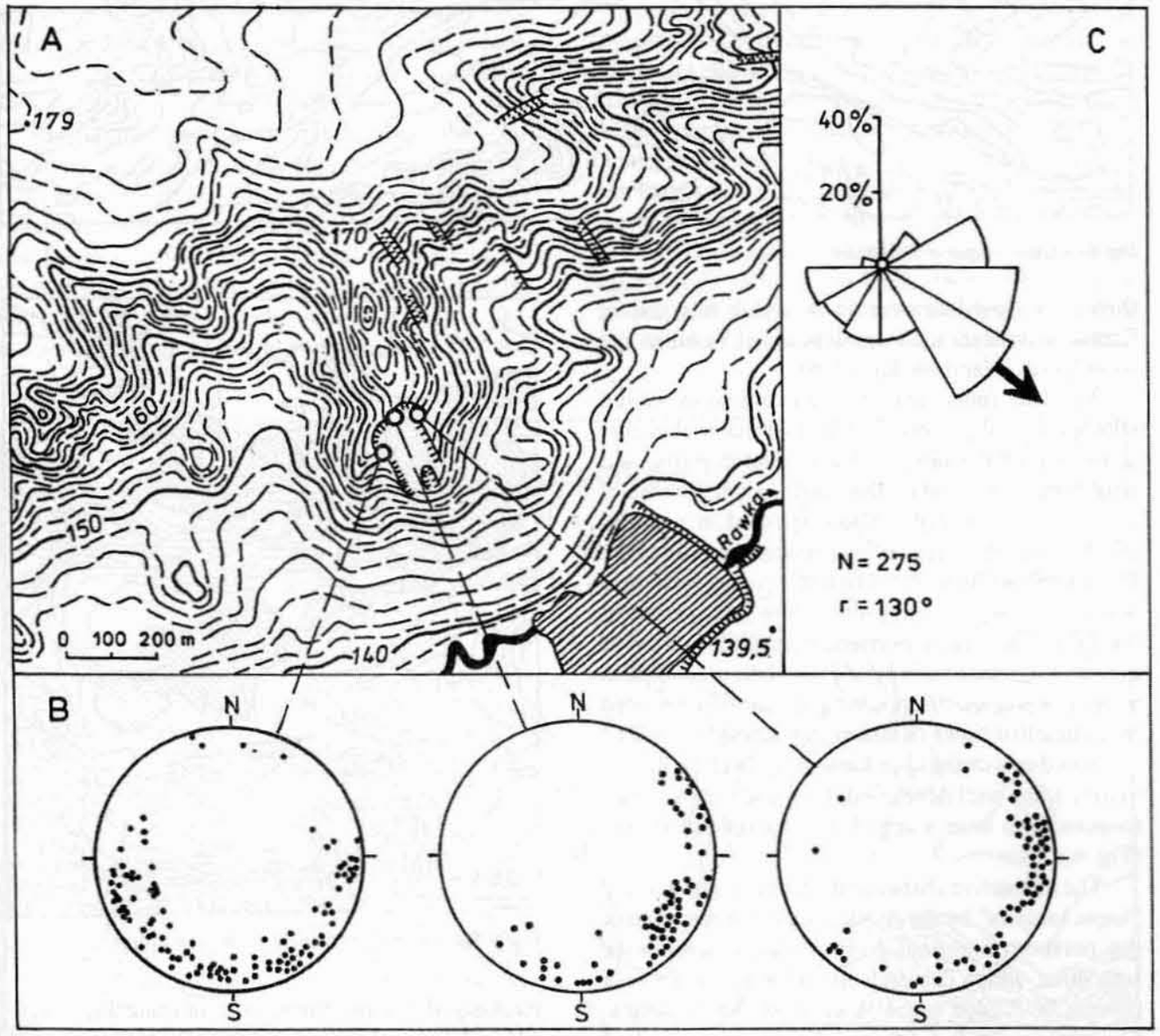

Fig. 4. A kame tongue at Rawa Mazowiecka (modified after Rdzany, 1997)
A – contour map, B – dips of silt, sand and gravel laminae, C – dips of laminae – collated diagram; N – number of measurements, r – azimuth of resultant vector

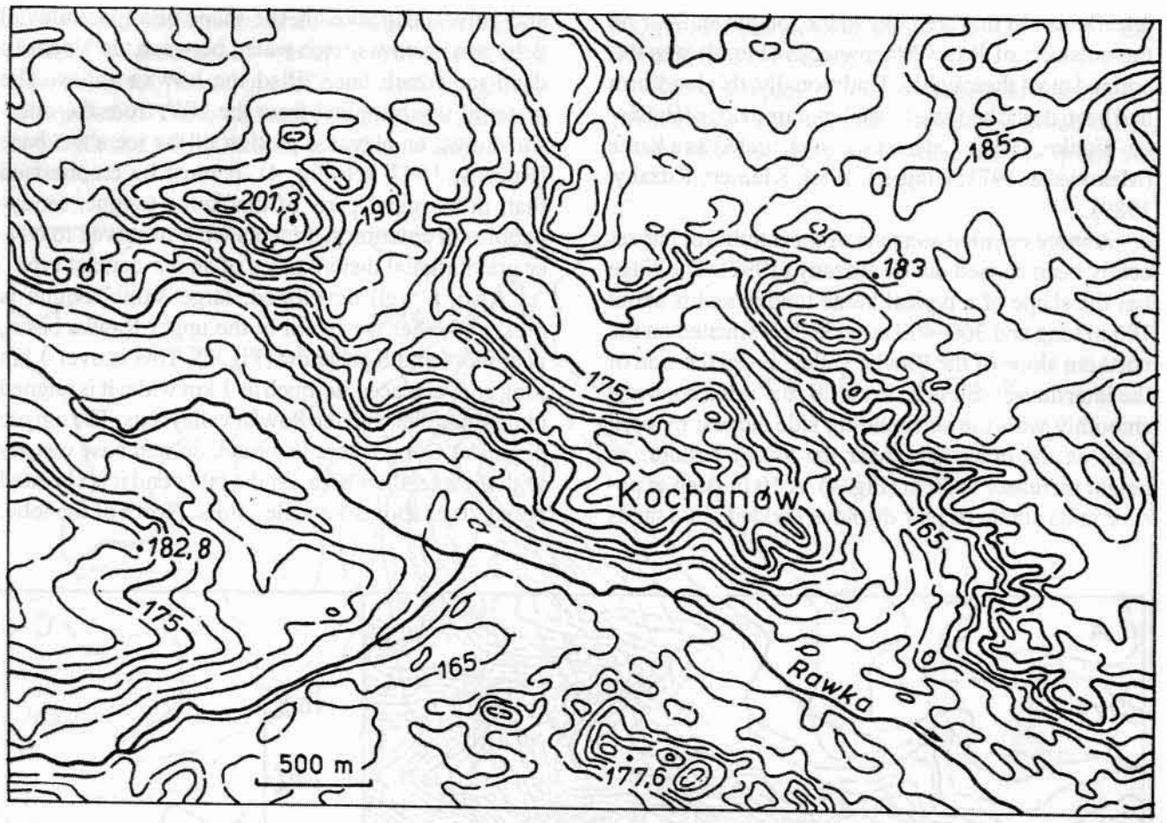

Fig. 5. A kame tongue at Kochanów

there is a closed depression in which interglacial Eemian sediments and slope deposits of Vistulian age were found (Manikowska, 1966).

The kame tongue at Kochanów consists of layered silts, sands and gravels. The coarser material occurs at the top of the tongue. Ice-contact deposits and structures are present on the slopes. As in the case of the tongue at Tatar, this also originated in a glacial lake between the stagnant ice masses which filled the Rawka valley at that time. The lower part of the tongue was formed when a very slow flow was present in the lake. The upper portion, composed partly of gravel, was formed in a period when the glacial lakes were changing and disappearing, finally to be replaced by channelled flows (Klajnert, Świdrowska, 1992).

Together with the huge kame tongues in the Rawka valley, many well developed, long and narrow kame tongues have been mapped, for example at Byliny (Fig. 6.)

The distinctive shapes of the kame ridges, termed "kame tongues" by the Author, are often observed in the northern marginal zone of the Skierniewice Interfluve, which descends northwards and forms a distinct W-E edge to the Warsaw–Berlin Pradolina. The vicinity of Pszczonów, about 10 km west of Skierniewice, provides a good example of the irregular topography of the interfluve edge zone. The flat

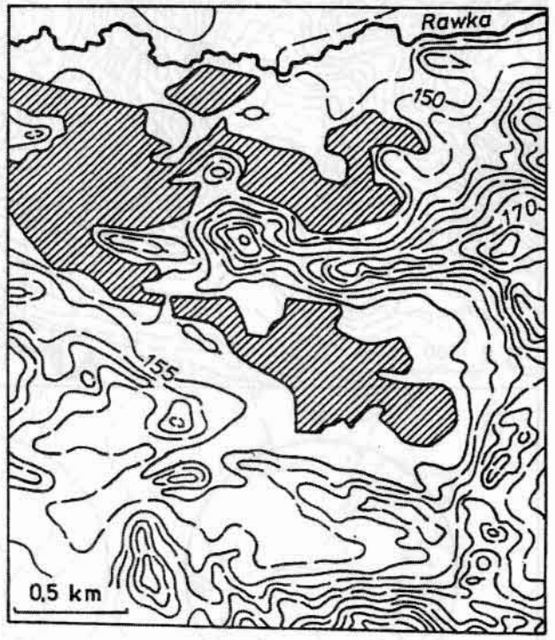

Fig. 6. Narrow kame tongues in the Rawka valley

foreland of the interfluve, at an altitude about 120–125 m a.s.l., contrasts here with an edge zone with hillocks, and, slightly southwards, with the northern part of the Skierniewice Interfluve at altitudes above

160 m a.s.l. (Fig. 7). In the edge zone, numerous arcuate kame ridges are present. They are from several hectometres to over 1.5 km long. The landforms exhibit a common feature: in the southern part, as with the kame ridges described above, they seamlessly grade into the interfluve, while, at the northern end, their heights increase to 20 m.

The kames are directly underlain by till, the surface of which is irregular under the ridges. In the structure of the kame tongues, a regular sedimentary sequence was observed: from clayey silts at the bottom, passing upwards into silty and fine sands with ripplemarks, to gravels which fill erosional channels of various size, incised in the underlying sand (Fig. 8, 9). The vertical order of the kame material, termed "the ascending order" by the Author (Klajnert, 1978), shows the transition from the still water glaciolacustrine accumulation of the earlier phases of the ridge formation, to the more energetic sedimentation conditions in the ablation river channels, which is indicated by erosional channels which were later filled with gravel.

The largest kame tongue in the Łódź region – the Domaniewice Ridge – is the biggest landform in the Domaniewice Hills. This has been described by Lencewicz (1927), and later Balińska-Wuttke (1960) and Różycki (1972a) as a frontal moraine of the Wartian stage of the Saalian. As the result of detailed investigations in the Domaniewice Hills, the Domaniewice Ridge has now been reinterpreted as a kame of glaciofluvial type, which accumulated the wide spaces between stagnant ice blocks (Fig. 10). This notion is supported by the bedded nature of the sands and gravels which constitute the ridge, and also by very well preserved ice-contact deposits and forms found on the kame slopes (Klajnert, 1966, 1969).

The Domaniewice Ridge, over 7 km long and as much as 3.0 km wide, is located on the slope of the Skierniewice Interfluve, which descends towards the axis of the Warsaw–Berlin Pradolina, in the Bzura valley (Fig. 1). Southwards, the ridge merges along a wide base into the interfluve, whereas, at the northern end, its relative altitude reaches 50 m in places.

Kame paws and inter-kame valleys

The term "kame paw" is proposed for the landform comprising several kame tongues which are joined together at a common base. The landform at Płyćwia, about 10 km south-west of Skierniewice, is a typical example (Fig. 11). In the south-east, the kame ridges merge seamlessly with an interfluve composed of till. On the north-west side, they are separated from each other and splay in a radial pattern. Their frontal parts are raised steeply about 20 m above the neighbouring terrain. The kame "fingers" separate "inter-kame valleys" of meltout origin. Undoubtedly, these valleys as well as the kame paws have been transformed by post-Wartian mass movements and slope wash, which

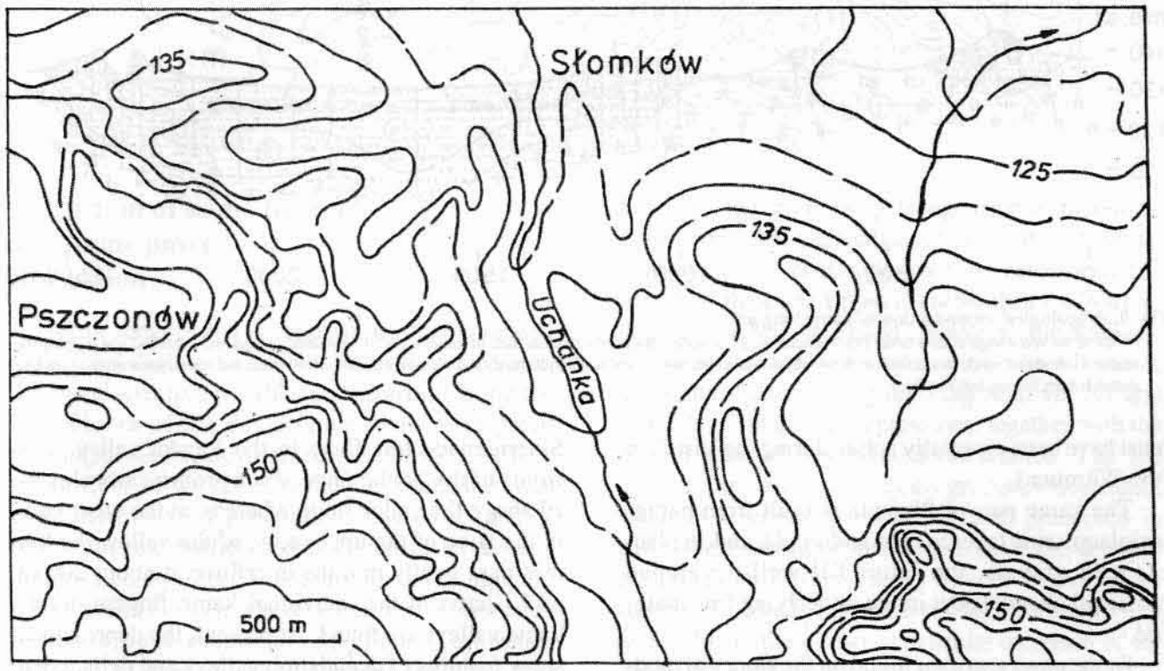

Fig. 7. Kame tongues within the zone of the northern edge of the Skierniewice Interfluve near Pszczonów and Słomków

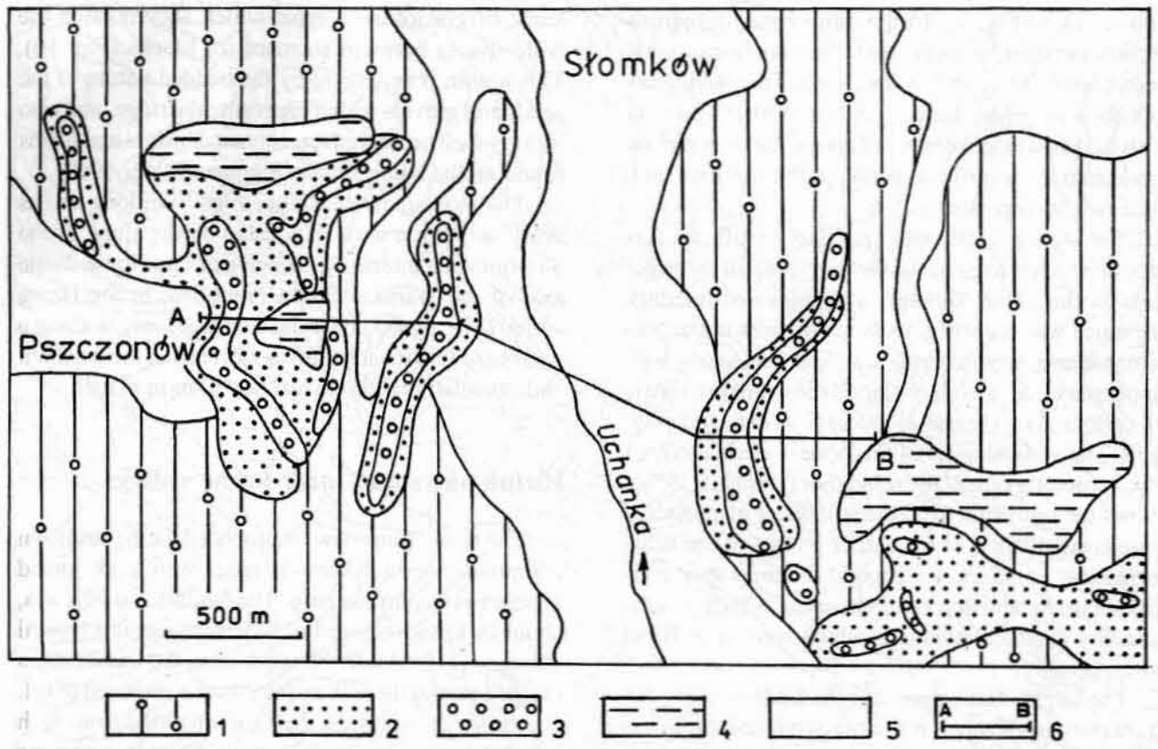

Fig. 8. A geological map of the kame tongues near Pszczonów and Słomków

1 – till, 2 – fine-grained and silty glaciofluvial sands with ripplemarks, 3 – gravel in erosional channels, 4 – silts of small glacial lakes, 5 – alluvium in the Uchanka river valley, 6 – (A – B) – geological cross-section line (see Fig. 7)

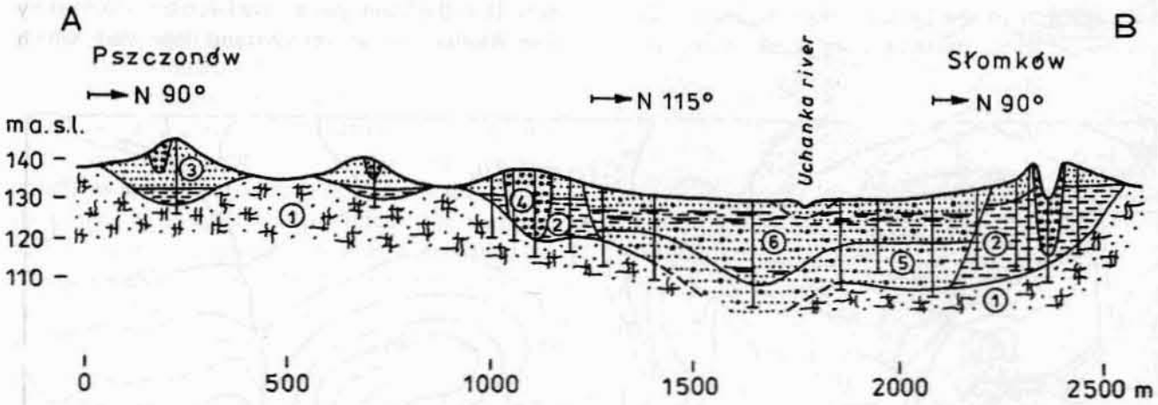

Fig. 9. A geological cross-section of kame tongues

1 – till of the Warta stage of the Middle Polish glaciation; 2 – stratified clayey silts (bottom parts of kame ridges); 3 – stratified fine-grained sands and silts (ripplemark sands); 4 – stratified poorly sorted sands with gravels; 6 – varied-grained alluvial sands with gravels and silt intercalations (in the bottom and top – intercalations of organic materials from Eemian and Vistulian)

must have been especially active during the Vistulian (the Würmian).

The kame paw at Płyćwia is built from paraglaciolacustrine layered silts and sands, and,in places, with gravels; the latter fill well-developed erosional channels cut in the underlying fine material.

Kame paws are often found on the slopes of modern river valleys, as, for instance, at Sabinów on the Skierniewice Interfluve in the Rawka valley. The fronts of the "kame fingers" are prominently elevated above the valley floor, whereas, at the other end, in the zone of the upper edge of the valley, the kames pass gently into the interfluve at about 200 m a.s.l. Between the individual kame fingers, inter-kame valleys are found. At present, the depressions show features of denudation valleys and dells, open towards the axis of the Rawka (Fig. 12).

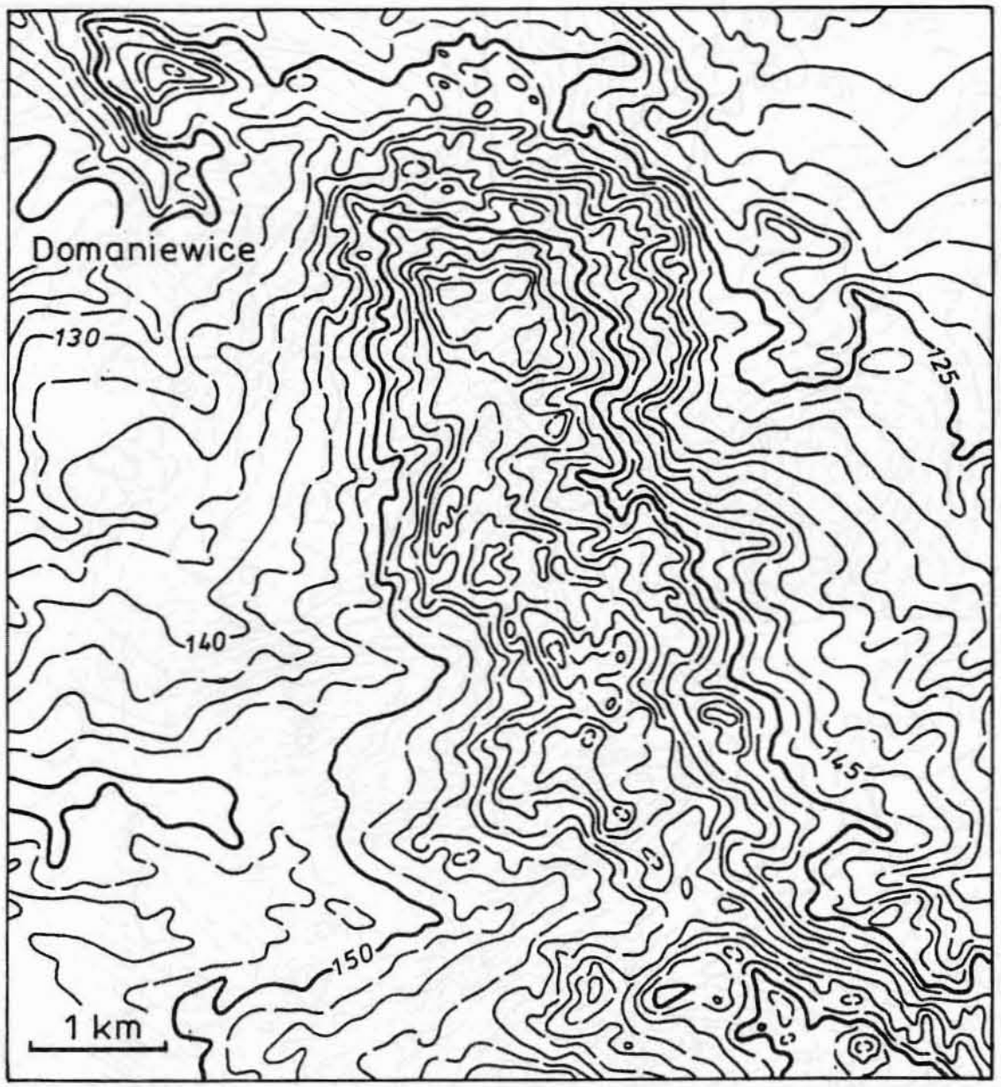

Fig. 10. The Domaniewice Ridge – the largest kame tongue in the vicinity of Łódź

The origin of kame tongues and kame paws Discussion

Kame tongues and kame paws are clearly related to the areal deglaciation of the Warta stage ice sheet, the last glacier to have affected this area. During the final phases of the deglaciation, with widespread thinning of the ice, crevasses reached from the surface to the floor of the ice. The flow of meltwater was controlled only by gravitation. The directions of the meltwater outflow must therefore have been determined by local gradients of the subglacial interfluves (Fig. 2). These areas must have been inclined towards subglacial valley floors, i.e. towards pre-Wartian river valleys, as the configuration of the underlying topography closely resemble the present-day relief. In term of the palaeogeography, therefore, it is inferred that the spatial pattern of the interfluve areas and of the contemporary river network in this portion of the Łódź Upland is older than the Wartian stage of the Middle Polish glaciation (the Saalian). At the time when the deglaciation was advanced, meltwater drained along the subglacial valleys and all kinds of subglacial depressions, together with the stream load which formed the kames. The ice thickness on terrain elevations gradually decreased, whereas it remained relatively well preserved in valleys and terrain depressions. Hence, the depth of crevasses and other empty spaces between the stagnant ice blocks expanded towards the lower lying areas. Where there were substantial increases of the subglacial surfaces, i.e. along the upper edges of the valley slopes and at interfluve steps, conditions

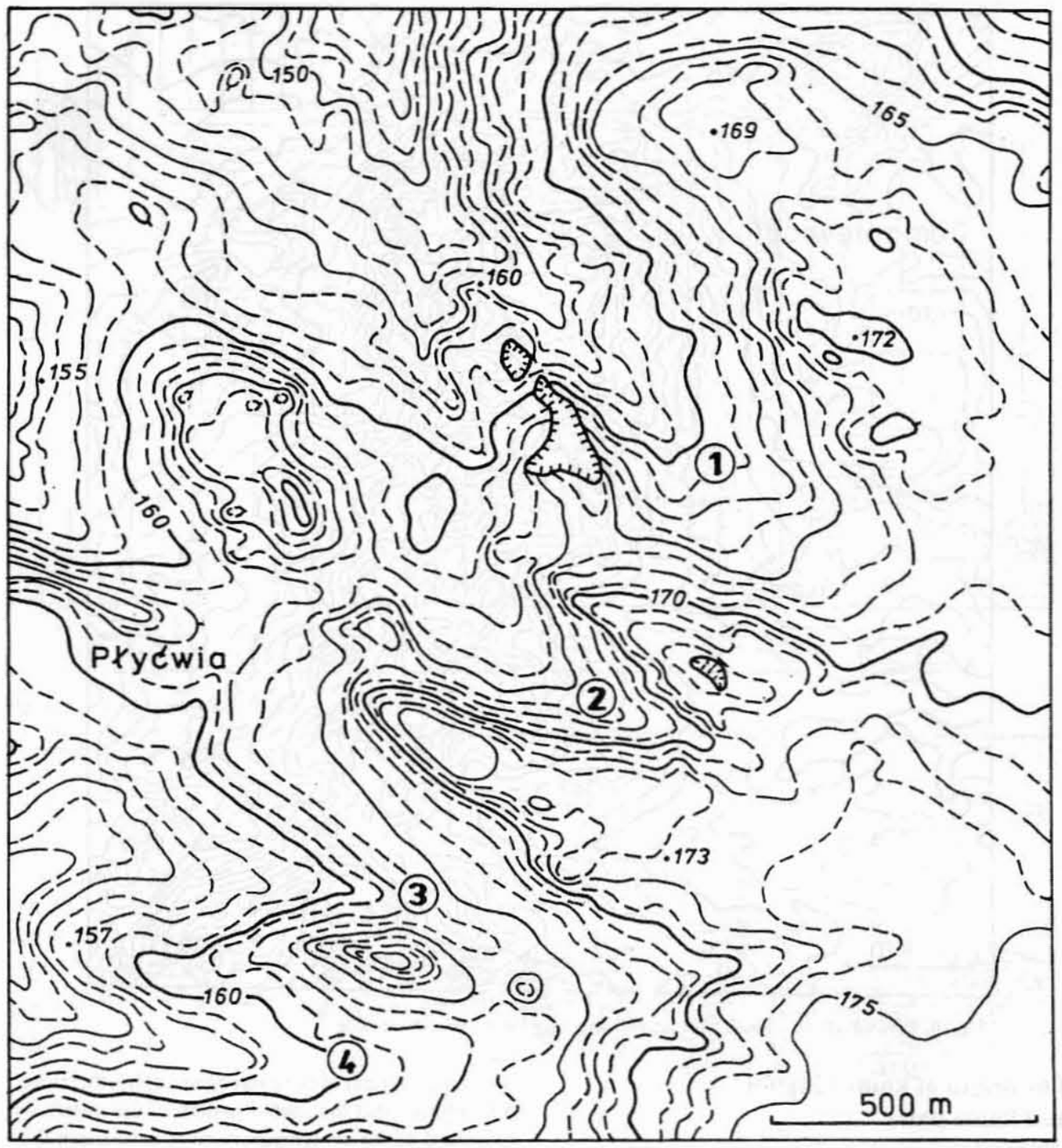

Fig. 11. A kame paw at Płyćwia. A flat base of the kame tongues – fingers (in the lower-right corner) is built from till
1–4 – inter-kame valleys

favourable for the deposition of silt, sand and gravel in glacial lakes appeared and lacustrine or deltaic sedimentation ensued. The laminae of kame material were inclined towards the deepening crevasses and inter-lobe spaces. In the same direction, the deposits grew in thickness.

The gentle integration of kame lobe bases and kame paws with the more elevated interfluve areas indicates that, in a given period of deglaciation, the ice thickness in the centre of interfluve was negligible (or non-existent). Therefore, the spaces between dead ice blocks were surrounded by ice on only three sides. The remaining side was ice free and opened towards the elevated interfluves. It is assumed that these empty spaces may also have been entered by water (and transported sediment) which did not directly relate to the ice sheet thaw.

After the ice walls had finally melted out (ice-contact deposits and structures then developed), the kame ridges with an asymmetric longitudinal profile formed, which resulted in their distinctive forms of kame tongues and paws. These kinds of kames may

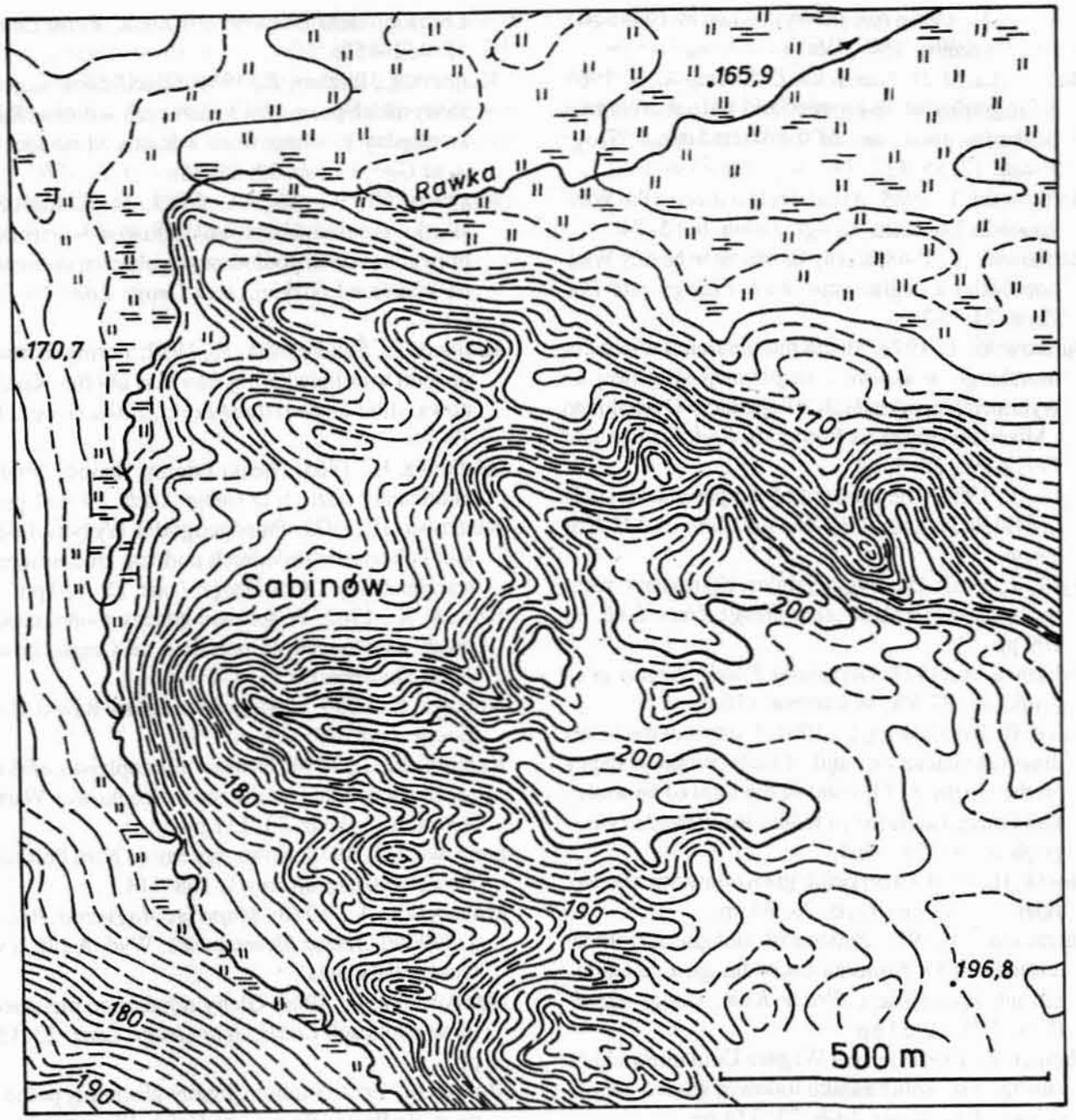

Fig. 12. A kame paw at Sabinów in the Rawka valley. The base of kame tongues (fingers) – is built from till

be regarded, therefore, as indicators of varying thickness of stagnant ice masses, and, in particular, of an increase in ice thickness towards terrain depressions.

The kames in the Łódź Upland underwent transformation by post-Warta stage denudation processes, which lowered and smoothed their slopes. In consequence, these landforms are, of course, polygenetic. However, they have an essential component of glacial deposits. The "inter-kame valleys" of meltout origin were particularly strongly modified by the development of denu-dation dells and dry denudation valleys, i.e. the landforms characteristic of the periglacial landscape of Central Poland (Dylik, 1952, 1953; Klatkowa, 1965).

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