Geological Quarterly, 2023, 67: 30
DOI: http://dx.doi.org/10.7306/gq.1700

Extent of the Odranian Glaciation in the Silesian-Kraków Upland

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Nita, M., Nita, J., Andreychouk, V., Myga-Piątek, U., 2023. Extent of the Odranian Glaciation in the Silesian-Kraków Upland. Geological Quarterly, 2023, 67: 33, doi: 10.7306/gq.1700

Associate Editor: Wojciech Granoszewski

The scarcity of Scandinavian rock fragments in glaciogenic deposits and lack of well-preserved glacial accumulation forms make it difficult to determine the maximum extent of the Odranian ice sheet in the area of the Częstochowa Upland, the Woźniki-Wieluń Upland and the Silesian Upland. While the glaciogenic deposits only contain a small admixture of Scandinavian rocks, they have been enriched with local flints and gravels that are undoubtedly related to glacial transport. The distribution of flint debris suggests that within these areas, the Odranian ice sheet reached farther south than previously assumed. This question has been analysed again on the basis of archival materials, new publications and the results of field research (studies of the distribution of flints, the Połomia gravels, siderite clasts and roches moutonnées). The use of methods based on 3D visualizations via digital terrain models (DTMs) has proven very useful. Moreover, the use of computer methods (GIS) in conjunction with field surveys made it possible to delineate the Odranian Glaciation boundary more precisely in the study area. The study indicated the important role of local material for inferring the maximum extent of Pleistocene glaciations. This is particularly important in areas where typical forms of glacial accumulation have not been preserved.

Key words: Silesian-Kraków Upland, Quaternary, extent of the Odranian ice sheet, flint, limestone rocks.

INTRODUCTION

Glaciation extents in Poland have long aroused the interest of geologists and geographers alike. With more detailed data and modified research methods, views on the ranges and stratigraphic positions of the individual units have changed (Lindner, 1984, 1988, 2005; Mojski, 1993, 2005; Lindner and Marks, 1995, 2012; Marks, 2005; Bruj and Roman, 2007; Marks et al., 2016). At its maximum extent, the Odranian ice sheet reached the northern slopes of the Sudetes, entered the Silesian-Kraków Upland and the Holy Cross Mountains, and farthest to the south, it reached the upper Odranian River basin. The ice sheet front was stopped by hills, only advancing southwards via valleys. In areas where undisturbed glaciogenic deposits of the Odranian Glaciation are present on the land surface, determination of the line of maximum extent is not generally disputed. A clear picture of moraine ridges and kames that were carved out of upland hummocks by denudation made it possible to determine the extent of the ice sheet e.g., in the Silesian Rampart area (Badura and Przybylski, 2005). But, the absence of typical marginal zone forms on the Częstochowa Upland has made the determination of the maximum ice sheet extent controversial in this area for many years. Apart from the absence of clear marginal forms, another difficulty arose from different criteria that were used (Premik, 1934; Klimaszewski, 1952; Karaś and Starkel, 1958; Różycki, 1960a, 1972; Chmal and Kopański, 1978; Lewandowski and Kaziuk, 1982; Lewandowski, 1987). A further difficulty is posed by the absence or scarcity of Scandinavian rock fragments in the glacial deposits. However, sandy and gravelly deposits of residual moraines and glaciofluvial units contain a significant amount of local rock fragments, of flint, ferruginous sandstone and siderite. An example are the sandy and gravelly hills in the Przymiłowice, Czepurka, Janów and Gorzków areas, which are described as "atypical" frontal moraine forms (Karaś and Starkel, 1958; Różycki, 1960a, 1972; Lewandowski and Kaziuk, 1982). To date, though, the detailed occurrence of local rocks has not been used as an indicator of the maximum extent of the Odranian Glaciation in the area.

The first attempts to determine the extent of the Odranian ice sheet in the northern part of the Częstochowa Upland were based on the variability of lithologies in the Warta River gorge between Mirów and Mstów (Sawicki, 1921). More detailed information was obtained as a result of studies by Premik (1934) who considered the sequences of isolated sandy and gravelly hummocks along the Piasek-Ciecierzyn-Częstochowa-Wrzosowa-Koziegłowy line to be end moraines. The boundary that was situated the farthest to the south-east was determined by Klimaszewski (1952) on the basis of geomorphological criteria, but its course was only marked very schematically (Fig. 1). Różycki (1960a, 1972) classified sequences of isolated sandy and grav-

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Received: February 26, 2023; accepted: June 21, 2023; first published online: October 27, 2023

elly hummocks along the Janów-Złoty Potok-Trzebniów line as marginal forms and found glacitectonic disturbances in the Julianka area. As a result of further research, he distinguished between the Silesian and Widawka lobes, from which the Koniecpol lobe was separated, which advanced up the north-eastern slope of the Częstochowa Upland. On this basis, the boundary was shifted to the line between the villages of Gorzków-Janów-Piasek-Ciecierzyn-Wrzosowa-Koziegłowy.

When delineating the extent of the Odranian ice sheet along the Rędziny-Wyczerpy-Częstochowa-Wrzosowa-Koziegłowy-Siewierz line, Mojski and Rühle (1965) moved it back to a very distinct line of morphological forms where a large proportion of rocks of northern origin was present. According to Lewandowski (1987, 2015), the boundary of the Odranian Glaciation coincides with morphological boundaries along the Gorzków-Olsztyn-Poraj-Kamienica-Lubsza-Woźniki-Brudzowice-Tarnowskie Góry-Zabrze-Mikołów-Żory-Rybnik-Rydułtowy-Gorzyce line. This boundary was delineated on the basis of the presence of sandy and gravelly units considered to be residual end moraines in the marginal zone, as reflected by the five ice tongues that pressed into the basins of the Warta, Mała Panew, Kłodnica, Ruda and Oder rivers. According to Marks et al. (2006), the course of this boundary is similar (Fig. 1).

The application of GIS to geological studies has reopened the discussion regarding the maximum extent of the Oder Glaciation on the Silesian Upland and the Kraków-Częstochowa Upland. Where field data are insufficient for clear interpretation, modern geological surveys commonly use computer software to solve the resulting problems. Particularly useful are surface geological structure models produced on the basis of digital geological maps and models, e.g., DEM (Digital Elevation Model), DTM (Digital Terrain Model), SRTM (Shuttle Radar Topographic Mission), ALS (Airborne Laser Scanning), produced with the use of aerial and satellite imagery as well as

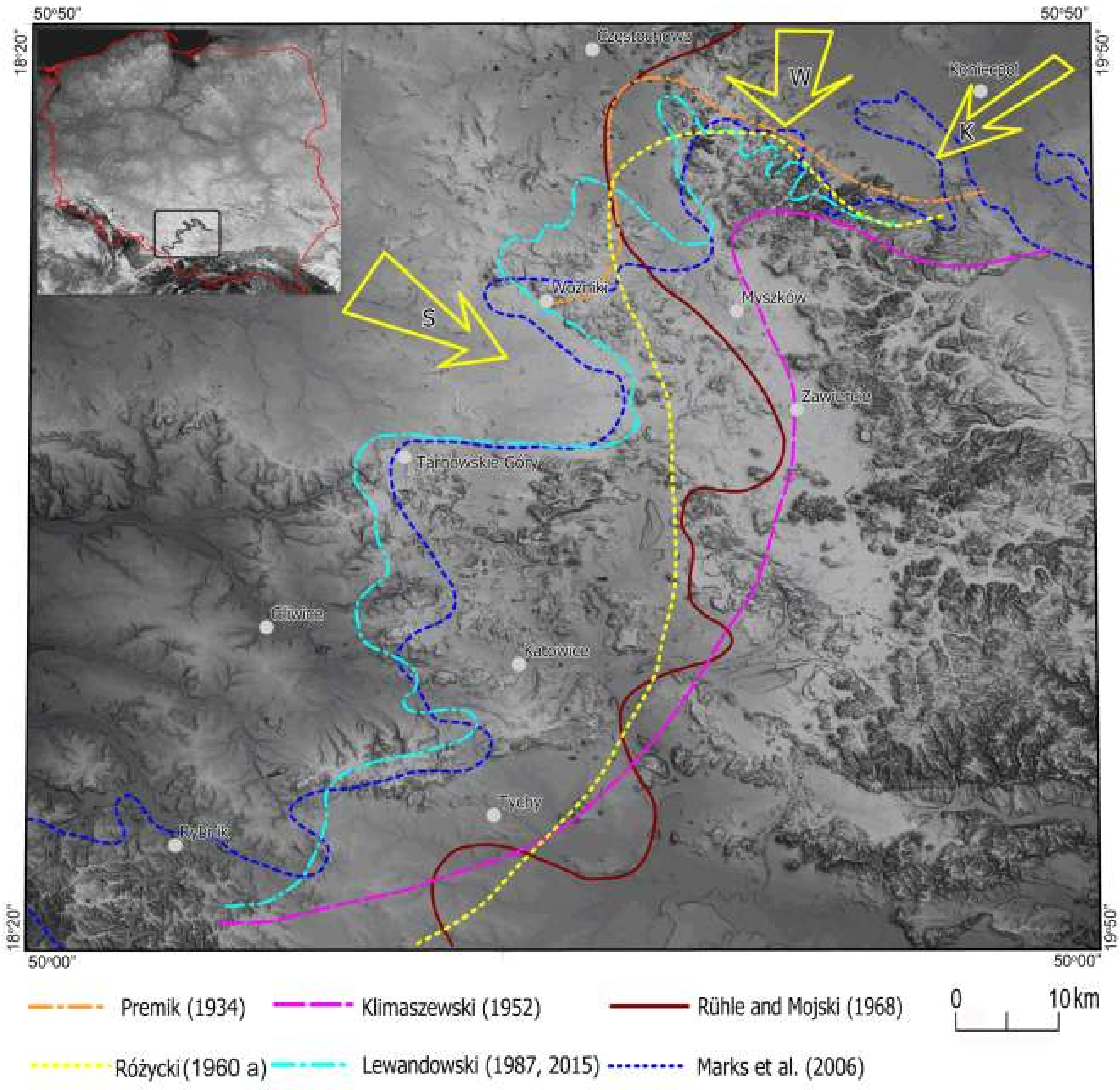

Fig. 1. Odranian Glaciation ice sheet extent boundaries according to various authors superimposed on a DTM (Digital Terrain Model)

Yellow arrows show ice lobes (S – Silesia, W – Widawka and K – Koniecpol) according to Różycki and Lamparski (1967) land surface visualization technologies, which give a clear picture of terrain relief (e.g., shading, slope gradient, topographic index, gradient modelling and 3D intersection) (Dikau, 1989; Irvin et al., 1997; Sedlák, 2002; Ostaficzuk, 2003; Nita and Małolepszy, 2004; Schmidt and Hewitt, 2004; Nita et al., 2007; Minár and Evans, 2008; Piętkowski and Zachwatowicz, 2008; Wieczorek and Żyszkowska, 2011; Doneus, 2013; Biland and Çöltekin, 2017). 3D visualisations make it possible to view a geological object from different perspectives (Arens et al., 2005; Wu et al., 2005), and thus they are ideal for reconstructing maximum glaciation extents (Clark, 1997; Clark et al., 2004; Rosentau et al., 2004), especially where glacial landforms are poorly discernible.

The use of these computer methods in conjunction with field studies is particularly important in areas such as the Silesian-Kraków Upland, where typical forms of glacial accumulation are not found. The application of these methods enabled more precise identification of the extent of the Odranian Glaciation boundary in the study area, as described in the present study.

STUDY AREA

The study area is located in the Silesian-Kraków Upland (Solon at al., 2018; Nita and Myga-Piątek, 2021) and lies within the Silesian-Kraków monocline and the Upper Silesian basin (Dadlez et al., 2000; Żelaźniewicz et al., 2011). In the area of the monocline, the sub-Quaternary substrate consists of Triassic and Jurassic formations (Fig. 2). Upper Jurassic rocky limestones are especially characteristic, and make up the upper

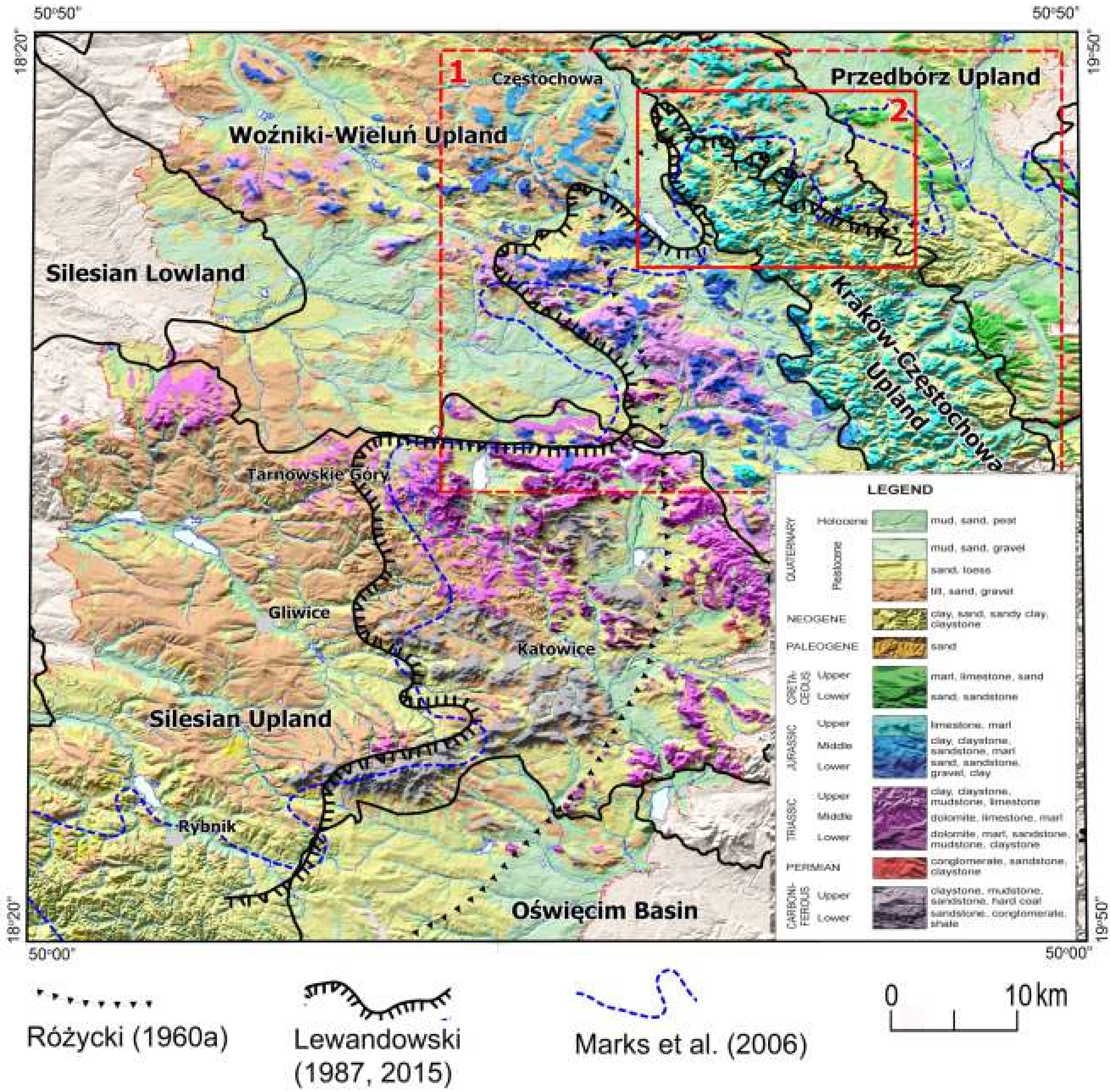

Fig. 2. Geological map of the study area (Nita and Małolepszy, 2004 based on the Geological Map of Poland, scale 1:200 000, sheets: Kluczbork (Haisig and Wilanowski, 1976), Częstochowa (Biernat et al., 1978), Gliwice (Kotlicka and Kotlicki, 1977), modified)

Red frames: **A** – study area of flint debris covers; **B** – distribution of roches moutonnées in limestone, and of limestone terrain lacking these topographic features parts of the hills in the Kraków-Częstochowa Upland, reaching a maximum height of 512 m a.s.l. (Góra Zamkowa in Podzamcze). In the depressions, platy and chalky limestones (Upper Jurassic) are exposed. The main features of the structural relief were formed in the Neogene. In the Neogene, structural relief (cuestas and subsequent valleys) began to form, with the main period of development occurring in the Miocene (Lewandowski, 2015). Rocky monadnocks, which are characteristic of the landscape of the Kraków-Częstochowa Upland and are made of rocky limestone, are among the oldest formations in the relief of the area (Lewandowski, 2015). Quaternary deposits do not form a continuous cover and are of variable thickness (from several to over 70 m). The greatest extent is observed for the deposits of the Odranian Glaciation. These mostly comprise glacial sands and gravels, marginal silts and glacial till (Heliasz et al., 1982; Haisig et al., 1983; Bardziński et al., 1986; Heliasz, 1994; Kurkowski, 2015; Romanek, 2020).

The Upper Silesian Basin is a wide basin filled mainly with coal-bearing Carboniferous formations and Miocene molasse formations (Racibórz Basin). On the surface, there is a discontinuous cover of Pleistocene deposits, the thickness of which reaches locally 100 m, in river valleys (Haisig and Wilanowski, 2003; Wilanowski, 2016).

RESEARCH METHODS

The basis for interpreting the extent of the Odranian Glaciation was the results of field surveys, which were conducted in 1990–2003, during the autumn and early spring, when farmland was freshly ploughed. They focused on the presence of clasts of local rocks (mainly of flint, ferruginous sandstone and siderite) in surface glacigenic deposits. The proportion of flints in these deposits is highly variable even over small areas. Ground surfaces with a high concentration of flint debris are referred to as “flint debris covers” for the purposes of this paper (Fig. 3). Accumulations where at least 10 clasts >2 cm in size per square metre were present, and flint accounted for at least 50% of the number of all clasts of this fraction, were considered to be flint debris covers. The minimum area so defined could not be <100 square metres. The fieldwork yielded contour maps of these flint covers, of which some 120 with areas of 1–150 hectares were analysed in detail. The selection of sites for detailed statistical analysis required identification by complementary field methods within the previously contoured area. Depending on the area of the cover, several 100 square-metre calculation fields were selected, considered to be typical of the cover. Similar studies, but at a smaller scale, were carried out for ferruginous sandstone and siderite clasts, such as found in the residuum of the Woźniki limestone.

In the Częstochowa Upland, limestone rocks and hills were also of interest, which were inventoried because they had been affected by *roche moutonnée* processes (Fig. 4).

The data obtained from field surveys were visualised using GIS software (*ArcInfo, Global Mapper, QGIS, SAGA*). The basis for the development of the DTM (*Digital Terrain Model*) were DTED 2 (*Digital Terrain Elevation Data*) digital data with a terrain pixel size of 30 × 40 m, and DTM data (*PL-EVRF2007-NH* with a resolution of 1.0 m), DTM LAZ survey data (4 points per square metre, 2017 and older) as well as LIDAR (*Light Detection and Ranging*) data from ALS (*Airborne Laser Scanning*). The study also used data derived from DTM LIDAR measurements to identify lithological and tectonic lineaments using gradient modelling parameters (Ozimkowski, 2010; Höfle and Rutzinger, 2011; Coblentz et al., 2014; Różycka, 2015; Mayoral et al., 2017). In the area in question, this analysis did not yield conclusive results and thus it was only used as an auxiliary tool in locations where Triassic and Jurassic cuestas are present. To trace ice sheet extent and maximum elevations, the TPI (Topographic Position Index) was used as a way of representing terrain variation (roughness) and its anomalies caused by glacial erosion (Tagil and Jenness, 2008; De Reu et al., 2013).

Fig. 3. Flint debris covers

A – Potok Złoty-Dworskie (south of Aleja Klonowa), **B** – Piasek, **C** – Biskupice (photos by J. Nita)

Fig. 4. Rock muton according to Różycki and Lamparski (1967)

Przymiłowice (photo by J. Nita)

STUDY RESULTS

Flints are a common component of surface sandy and gravelly deposits in the northern part of the Częstochowa Upland which found itself within the range of the Odranian Glaciation (Fig. 4). They are the result of the weathering and karstification of local platy and chalk-like limestones, in which they are present as flint nodules (Różycki, 1960b). Once "released" from the limestone, these nodules are rarely preserved whole, most often disintegrating into clasts of different sizes. These reach a maximum of 20 cm in size, but 2–5 cm fragments predominate.

In the northern part of the Częstochowa Upland, the presence of flint clasts commonly does not coincide with the platy and chalk-like limestone outcrops. Although these rock outcrops are found in the lower parts of the slopes, flint debris covers have also been observed much higher, in their upper parts, which consist exclusively of rocky limestones. It turns out that locally, flint debris covers reach up to 400 m a.s.l., while outcrops of platy and chalk-like limestones with *in situ* flints occur at most up to 370 m a.s.l. Flints occur very rarely (only sporadically) within rocky limestones, and thus their presence within these rock outcrops, and additionally in the upper parts of the slopes, can only be explained by their transport by the ice sheet. Another argument that suggests displacement is the flints' state of preservation. Those flints that are present on the upper slopes are generally fragmented, in contrast to the nodules that accumulated in sinkholes during the karstification of limestone, which are preserved whole (Błaszak, 1970; Gilewska, 1971; Głazek, 1973; Lewandowski and Ciesielczuk, 1997).

The shape of flint debris covers often mirrors that of the landforms within which they occur. In the vicinity of Piasek, Czepurka and Suliszowice, oval-shaped covers reflect the outlines of hummocks consisting of glacigenic deposits. Large flint debris covers within sands and gravels can be found on broad, flat valley bottoms and also on slopes with gradients of up to 5°. Covers that include small flint clasts, which occur at the mouths of depressions and valleys, have the most irregular shapes. In sandy deposits, minimal amounts of Scandinavian rocks fragments are present, in places accompanied by small patches of till and residual clay (e.g., in the area of the Piasek, Janów and Gorzków). Flint debris covers can be found up to a line joining the towns of Przybynów, Suliszowice, Siedle and Trzebniów (Fig. 5).

In the northern part of the Częstochowa Upland, in the vicinity of forms traditionally considered marginal (e.g., south-west of the Olsztyn-Janów road), limestone rocks are present in the shape of flattened domes and mounds, and hill slopes are gentle (Heliasz et al., 1982; Różycki, 1982). These forms are similar to those from the Olsztyn area, which Różycki (1982) considered to be *roches moutonnées*. Rocks with these rounded shapes and similar *moutonnée* forms are also present, for instance, in the vicinity of Krasawa, Zrębice, Pabianice, Siedlec and Gorzków, farther south of the line of the maximum extent of the Odranian Glaciation determined by many researchers (e.g., Marks, 2005; Lewandowski, 2015; Marks et al., 2016; Fig. 6). In the northern part of the Częstochowa Upland, limestone terrain lacks the soaring spires, towers and crags that are typical of the central and southern parts of the Upland, which lay beyond the reach of the Odranian ice sheet.

On the Woźniki-Wieluń Upland, siderite clasts play a role similar to flints. These are situated at a considerable distance to the south from their *in situ* location. Their clusters are not as distinctive and numerous as in the case of flints, and although their presence is indicative, there are no locations where siderite fragments dominate the gravel fraction.

On the Woźniki-Wieluń Upland and in the northern part of the Silesian Upland, glaciogenic deposits that include fragments of northern rocks also include local gravels. A large amount of these loose rock fragments come from the Połomia and Helenów beds as well as from the Kościelisko beds. These gravels consist mainly of quartz and occasionally contain siderite or flint. Their presence creates considerable confusion, since it is not possible to unequivocally determine whether or not they represent sediments transported by the ice sheet. Therefore, sand and gravel outcrops that do not contain fragments of Scandinavian rocks are generally considered to be *in situ*. However, it appears that some of them may be remnants of moraine ridges and outwash plains formed as a result of the presence of local glacial lobes and the impact of their meltwater.

The loose local material probably originated from the Miocene "Sośnicowice gravels", which are present in the Racibórz Basin region (Silesian Plain) and on the Rybnik Plateau (Dyjor et al., 1978; Lewandowski and Kaziuk, 1982). The presence of significant amounts of loose local rocks in the glacier's path may

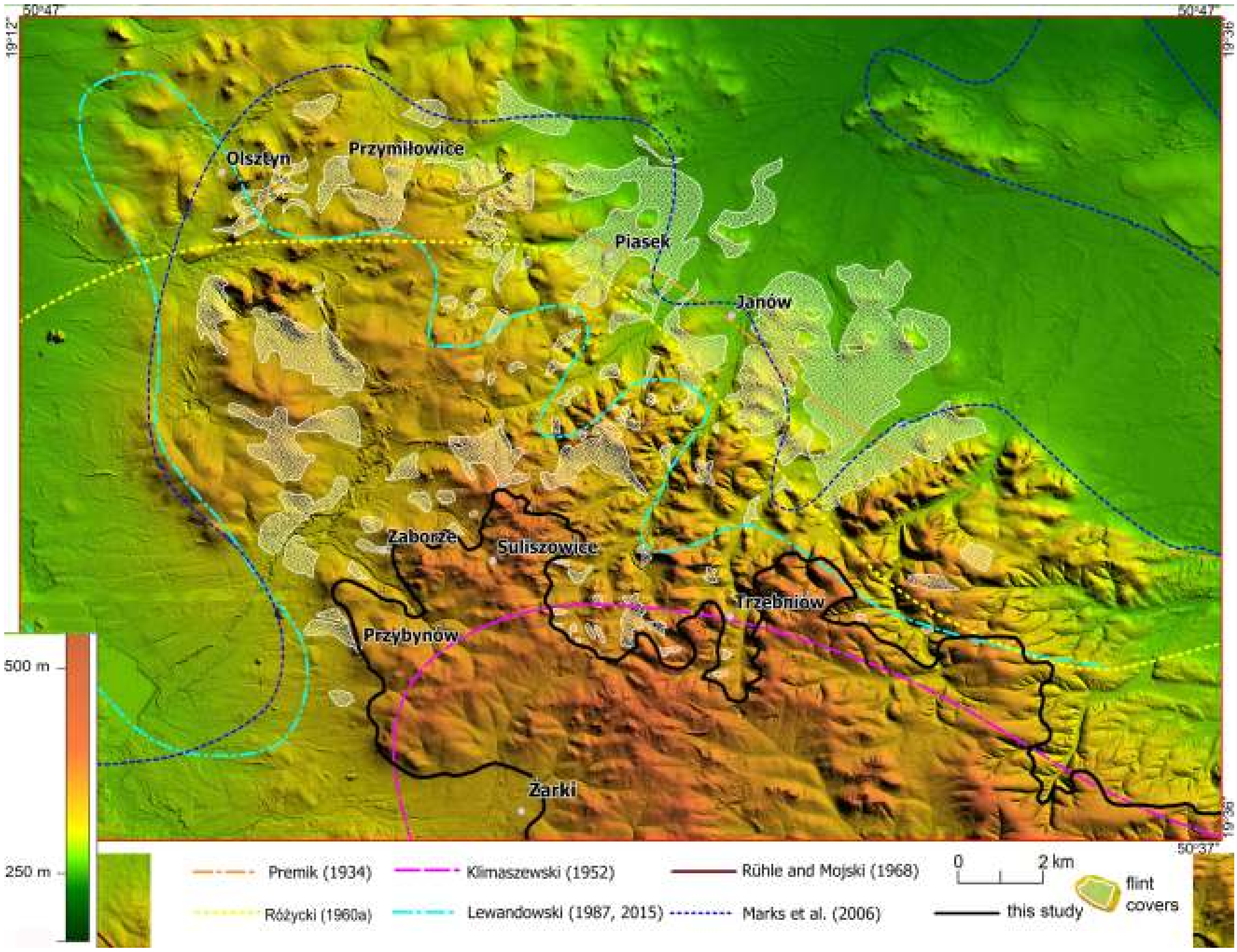

Fig. 5. Distribution of flint debris covers in the northern part of the Częstochowa Upland, superimposed on the DTM

The black line shows the extent of the Odranian Glaciation determined by the occurrence of flint debris covers

have considerably increased the compositional variation of the rock material carried by the ice sheet.

The introduction of a digital terrain model into this study of the extent of the Odranian Glaciation demonstrates the complex bedrock structure and its impact on the formation of local lobes in the area. The sub-Quaternary relief of the substrate over which the Odranian ice sheet moved is varied. It includes a number of deep valleys and depressions, which determined the course of the glacial advance in the area to a significant extent (Dyjor et al., 1978; Kotlicka, 1981; Lewandowski and Kaziuk, 1982; Kryza, 1987; Piotrowski, 1991; Lewandowski, 1993, 2007). In the area of the Częstochowa Upland, the ice sheet encroached on the relatively "soft" Lower and Middle Jurassic formations (silts and mudstones as well as sands and sandstones), and subsequently advanced farther up the valleys into the Upland, coming into contact with "hard" Upper Jurassic limestones. Broad, flat valleys are present here, which probably formed as a result of erosion by small drainage glaciers (Fig. 7), which extended 10–20 km farther south than the line of ice sheet extent determined by Lewandowski (2015). The largest and most typical valley of this type is the one that runs through the northern part of the Częstochowa Upland along the Ostrężnik-Czatachowa-Zawada-Żarki line. Similar valleys are also present east of Trzebniów, west of Zaborze and in the area of Niegowa.

Deep depressions surrounded by cuestas forced ice sheet movement into a specific direction. The monoclinal bedding of the Triassic and Jurassic formations as well as the presence of horst and graben structures meant that the direction of ice sheet transgression changed from north to north-west and even west in places (Różycki, 1972; Fig. 8). Local depressions oriented towards the east or south-east allowed the passage of small local glaciers. The impact of bedrock relief on the movement of the ice sheet is well documented in the upper reaches of the Warta River valley. The distribution of thickness of Quaternary deposits in the boreholes suggests that the Warta River ice-marginal valley shifted farther south, coming into the vicinity of the Middle and Upper Jurassic cuesta. This indicates intense erosive action by water near its structural edges. The modern valley of the Warta River has been largely overlain by sandy and gravelly deposits. The thickness of Quaternary deposits in its northern part exceeds 80 m, while it rarely reaches 50 m in the southern part. A comparison of the distribution of glacial deposits and area morphology demonstrates that the main system that drained water from the glaciated area was the present Przemsza River network, transporting water to the lower reaches of the Vistula

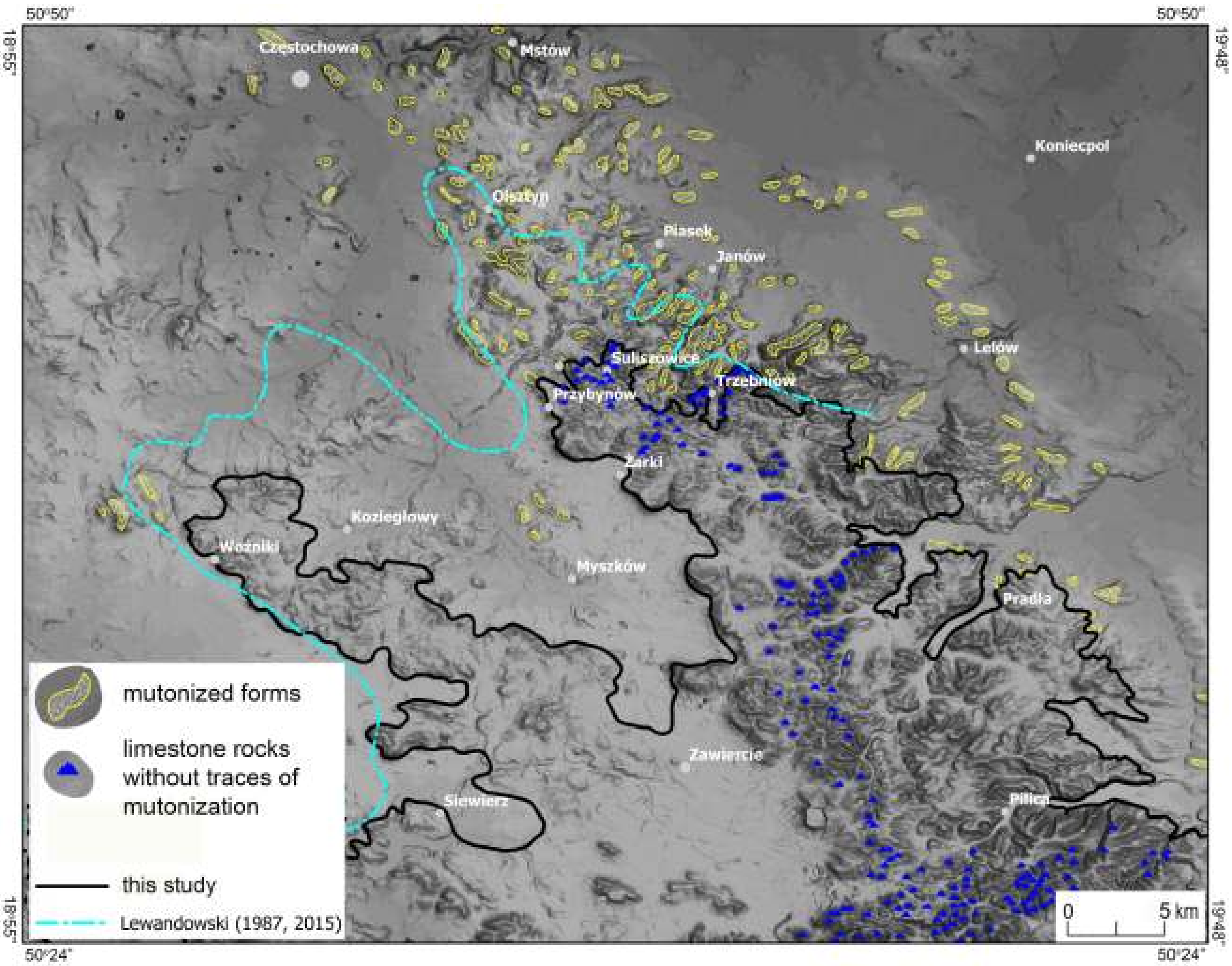

Fig. 6. Boundary of the Odranian ice sheet, vis-à-vis the distribution of roches moutonnées and areas lacking these topographic features, in limestone terrain

River valley, as established by Lewandowski and Zieliński (1990) and Lewandowski (1996).

The visualization of outcrops of glacial tills as well as of glaciofluvial sands and gravels on a digital terrain model is important for tracing the maximum extent of the ice sheet in the northwestern part of the Silesian-Kraków Upland. This makes it possible to distinguish areas where glaciogenic deposits clearly prevail, within which areas the line of the maximum extent of the Odranian ice sheet can be reconstructed. Figure 9 shows that the southern area is almost entirely covered by glacial deposits, in which erosional cuts are clearly visible, while the northern area is heavily altered. Glacial deposits within this area are more scattered, and loose rocks belonging to the older bedrock can often be found on the surface.

DISCUSSION

In considering the course of the maximum extent of the ice sheet, it is important to distinguish whether the deposits studied were carried directly by the ice sheet or by meltwater flowing from the glacier. In the case of flints, the statement that they do not occur *in situ* is unlikely to raise any doubt. Most of them occur in the study area within eluvial deposits of glacial till of the Odranian Glaciation, as identified by Heliasz et al. (1994). A characteristic feature of such covers is the high proportion of large flint fragments (8–20 cm) and their occurrence on the tops of hills and smaller mounds. However, there may be some doubt regarding those covers which consist mainly of small flint fragments (up to 2 cm), with few larger pieces, which are generally located in extensive valley depressions and mimic their shape. It can be inferred that such flint concentrations are the result of glaciofluvial rather than glacial transport. However, such a distinction is not always possible. Taking this into account, the proposed line of maximum extent has been determined by the presence of covers whose displacement by the glacier is not in doubt. South of this line, flint covers are sparse and consist of very small flint fragments. Corroboration of such a boundary can also be seen in the course of the line that separates the area of occurrence of terrain with *roches moutonnées* and terrain lacking these features.

The situation is slightly different for the gravels which were sourced from the Połomia and Helenów as well as from the

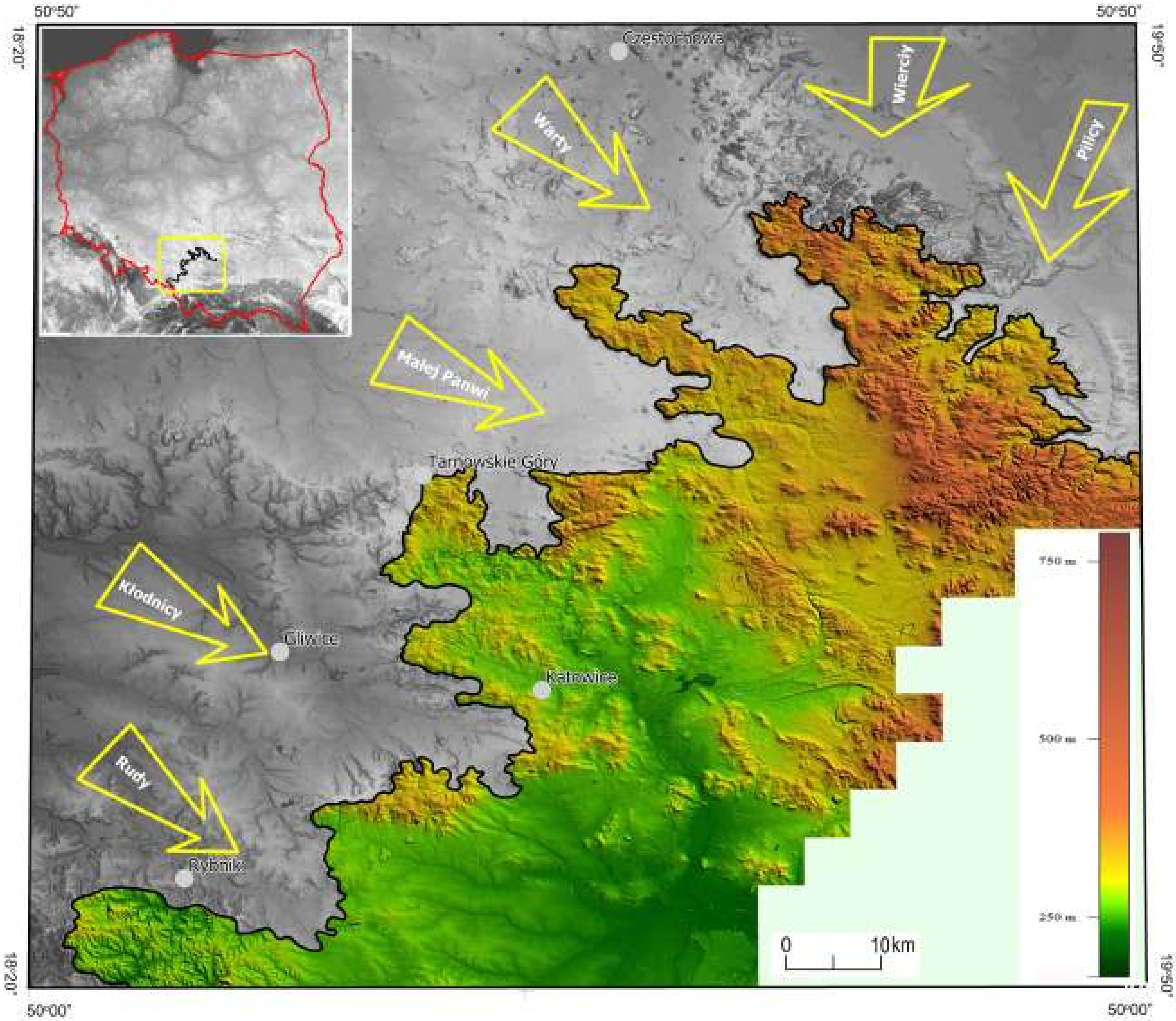

Fig. 7. Boundary of the Odranian ice sheet superimposed on the DTM

Yellow arrows show ice lobes

Kościelisko beds. Their presence creates considerable confusion, since it is not possible to unequivocally determine whether they arose as sediments transported by the ice sheet. Therefore, sand and gravel outcrops that do not contain fragments of Scandinavian rocks are generally considered to be *in situ*. However, it appears that some of these may be remnants of moraine ridges and outwash plains formed as a result of the presence of local glacial lobes and the impact of their meltwater.

For most researchers studying the maximum extent of the Odranian ice sheet on the Częstochowa Upland, the 300-metre contour line was an important boundary, since no clear forms left by this glaciation had been found above this height (Galon and Roszkówna, 1967; Różycki, 1972; Knopik, 2011). However, when comparing more recent field data (the vertical extent of flint debris covers), elevation models with slopes and terrain indices interpreted, and 3D models of geological surfaces, it can be concluded that the maximum height reached by the ice sheet in the area of Suliszowice, Trzebniów, Gorzków and Góra Włodowska reached 380 m a.s.l., and in certain places it may have reached as high as 400 m a.s.l. (Fig. 6). In the eastern part of the Upland, the ice sheet reached an elevation ~20 m higher than at the same latitudes in its western part. Jurassic escarpments stopped the transgression of the ice sheet at elevations ranging from 325 to 350 m a.s.l., Upper Triassic escarpments stopped it at 300–325 m a.s.l., and Carboniferous rock escarpments in the south at 270–300 m a.s.l. Valleys up to 100–200 m deep, which formed in the area before the Quaternary, significant impeded ice sheet movement. Another significant factor determining the extent of the glaciation was that the ice sheet reached the climatic limit of its expansion, which caused its thickness to be reduced to 200 or even to 50 m (Mojski, 1993).

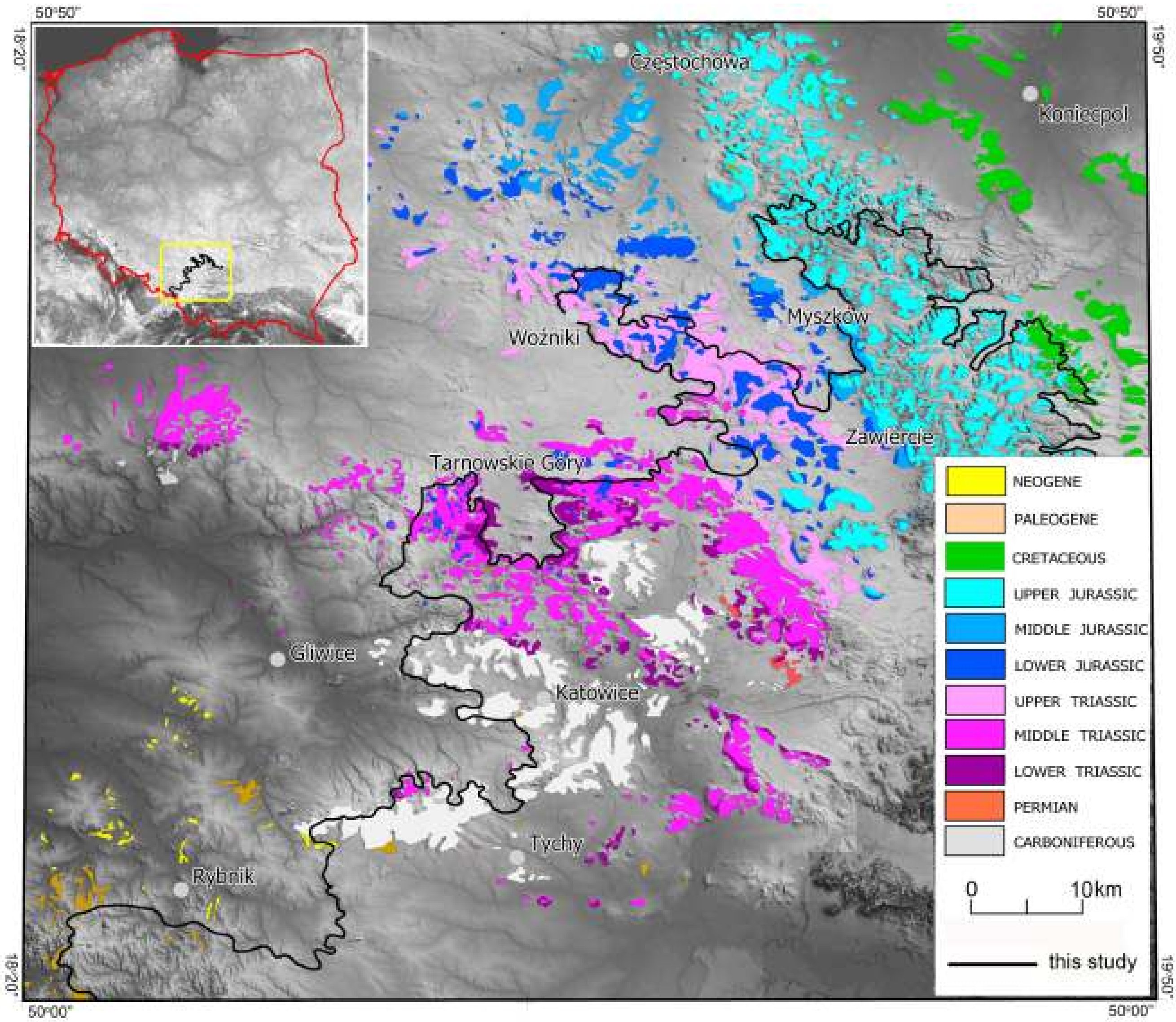

Fig. 8. The Odranian Glaciation boundary on a map of outcrops of older rocks

CONCLUSIONS

The authors' field studies have confirmed the link between the occurrence of glacial forms and the significant presence of fragments of local rock, such as flints and Jurassic gravels (e.g., from the Połomia beds). The analysis of the distribution of local clusters of flint clasts using a digital terrain model proved useful in determining the extent of the ice sheet in its marginal zone where no glacial forms have been preserved and Scandinavian rocks are virtually absent from the deposits. The distribution of flint debris covers, the presence of limestone rocks resembling flattened domes and mounds as well as gentle hill slopes and flat river valleys clearly suggest that the Odranian ice sheet reached farther than previously thought within the Częstochowa Upland. This boundary is located ~10–20 km farther south and south-east compared to the one adopted by Lewandowski (1987, 2015) and Marks et al. (2006), running through Moczydła, Trzebniów, Ostrężnik, Suliszowice and Zaborze as well as Przybynów and Włodowice along the Upper Jurassic cuesta (Figs. 5, 6 and 8). On the Woźniki-Wieluń Upland, the proposed ice sheet boundary, as determined by the presence of siderite clasts and gravels from the Połomia beds, runs in the vicinity of Mrzygłód, Będusz, Koziegłówki, Woźniki, Cynków and Brudzowice. The movement of the ice sheet within the Silesian Upland was heavily influenced by cuestas, since these divided the ice sheet masses coming from the north-west into local lobes, which reached deep into the valleys. The presence of these escarpments undoubtedly im-

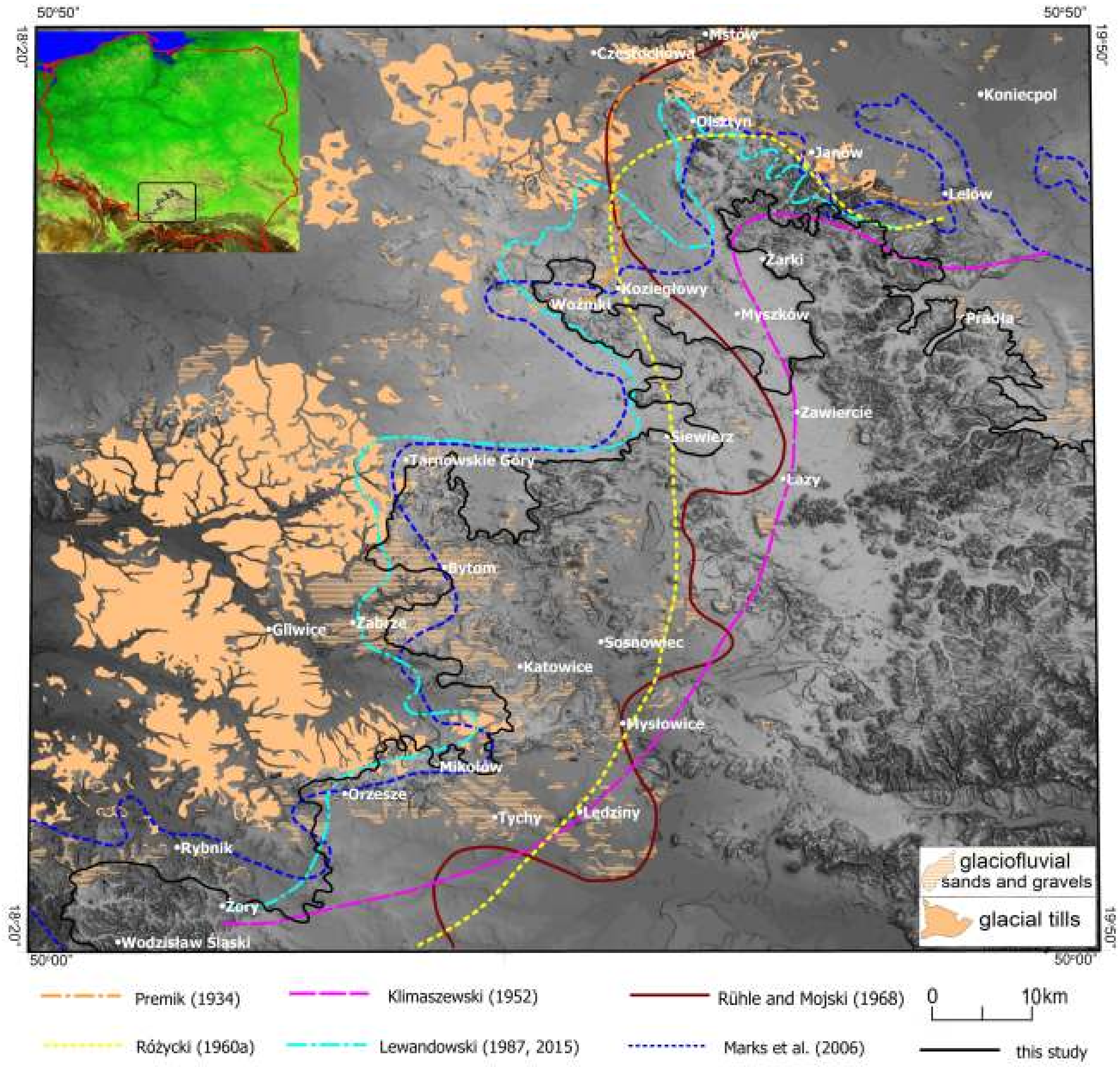

Fig. 9. Occurrence of tills as well as sands and gravels of glacial and glaciofluvial genesis superimposed on a DTM (based on the Detailed Geological Map of Poland and the authors' observations)

pacted the development of river valleys within the Oder-Warta-Liswarta, Mała Panew, Kłodnica, Ruda and Olza river basins. Stopped by the Jurassic, Triassic and Carboniferous escarpments, the Odranian ice sheet did not reach as far east as Klimaszewski (1952), Mojski and Rühle (1965) and Różycki and Lamparski (1967) postulated. In many locations on the Silesian Upland, its maximum extent coincided with that shown by Lewandowski (2015) and Marks et al. (2006), although in some areas it probably reached slightly farther east and south-east. The boundary of maximum ice sheet extent may have run in the area of Sączów, Rogoźnik, Piekary, Tarnowskie Góry, Bytom, Ruda Śląska, Mikołów, Orzesze, Żory and Rybnik (Fig. 9).

Acknowledgements. The authors would like to thank the reviewers for their discerning analysis of this manuscript. Their suggestions were valuable and contributed to significant improvement of the paper.

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