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TECTONIC DENUDATION CONCEPT OF LUBLIN UPLAND MORPHOGENESIS USING THE EXAMPLE OF GIEŁCZEW HEIGHTS

Abstract: Land surface development at Giełczew Heights (central part of the Lublin Upland), especially denudational forms, has interested researchers since the 1950s due to its representativeness of the entire region. First, two planation levels and one valley level were separated. At a later stage of the study, more than three stacked levels were identified. Previous studies have proven that the denudational relief of Giełczew Heights is dependent on disjunctive tectonics. Numerous fault zones formed during the Paleogene and Neogene, which divided territories into several tectonic blocks of different rank, size and absolute height. Notably, this observation suggests a multitude of planation surfaces. Additionally, tectonic movements in the Early Pleistocene formed Giełczew Heights as an independent geomorphological region and strengthened the late Pliocene collocation of river valleys that has survived into the modern era.

Keywords: denudation relief, tectonics, morphogenesis, Neogene, Giełczew Heights, Lublin Upland

INTRODUCTION

The genesis and development of Neogene-Early Pleistocene planation surfaces (denudation levels) of the Lublin Upland are key issues related to the development of the relief of the belt of old orogens and uplands of Central Europe. Notably, this point has been presented numerous times since the 1950s (Jahn 1956; Maruszczak 1972, 2001; Harasimiuk 1975, 1980; Henkiel 1995). While A. Jahn (1956) identified three planation levels of the Lublin Upland (i.e., higher, middle and lower), he restricted his conclusions to the Giełczew Heights mesoregion. Similar levels were identified by H. Maruszczak and T. Wilgat (1956) in Roztocze. Moreover, the same levels were later recognised by H. Maruszczak (1972, 2001) and M. Harasimiuk (1975). The higher level was dated to the Lower Pliocene, while the middle level was dated to the Upper Pliocene and the formation of the lower level was connected to cooling at either the decline of the Pliocene or early (not yet glacial) Pleistocene. Using contemporary terminology and the chronostratigwraphic scale, the age of the lower level was dated to the Early Pleistocene.

Numerous geological studies undertaken in the Lublin Upland and Roztocze during the preparation of the Detailed Geological Map of Poland (1:50,000) have shown that more than three staircase-like arranged planation levels exist (Harasimiuk et al. 1988a, b; Marszałek et al. 1991, 1996, 2000; Cieśliński 1993, 2001; Albrycht, Brzezina 2000; Buła et al. 2000; Wągrowski 2001). In this context, A. Henkiel (1995) proposed a new concept of morphogenesis of the Lublin Upland. Following research in the Bełżyce Plateau area, he proposed that the higher level of this mesoregion (and the nearby Łuszczów Plateau) are abrasion surfaces (platforms) of the Paleocene sea exhumed from lower Eocene and Miocene sediments. The exposure of these surfaces was associated with several phases of tectonic uplift occurring from the Lower Oligocene to the Odranian glaciation. The other levels were assumed to be one surface dissected by faults and hypsometrically differentiated in each of the tectonic blocks.

However, geological and geomorphological studies conducted at Giełczew Heights (Fig. 1) by the authors of this paper suggest that the distribution of denudation levels is more complicated than previously assumed and that the commonly accepted model does not explain the hypsometric position of planation surfaces observed in the field. Therefore, the present study proposes a new concept of Neogene-Early Pleistocene morphogenesis of the Lublin Upland.

MATERIAL AND METHODS

To prepare a general geomorphological map of the Giełczew Heights area and analyse its geological structure and georelief, the following materials were used: 11 sheets from the Detailed Geological Map of Poland 1:50,000 (Mojski 1962; Harasimiuk et al. 1984, 1985; Marszałek et al. 1989, 1992, 1995; Cieśliński 1991, 1997; Albrycht, Brzezina 1990; Buła et al. 1994; Wągrowski 1996), geomorphological and geological drafts (Mojski 1968; Harasimiuk et al. 1988a, 1988b; Marszałek et al. 1991, 1996, 2000; Cieśliński 1993, 2001; Albrycht, Brzezina 2000; Buła et al. 2000; Wągrowski 2001) and a digital terrain model (5-m resolution and 15-cm vertical accuracy). This served as the background for thematic maps and the topographical basis for preparing morphological-geological profiles of the Giełczew Heights area. The terrain model was based on LiDAR data obtained from the Head Office of Geodesy and Cartography. Flat surfaces

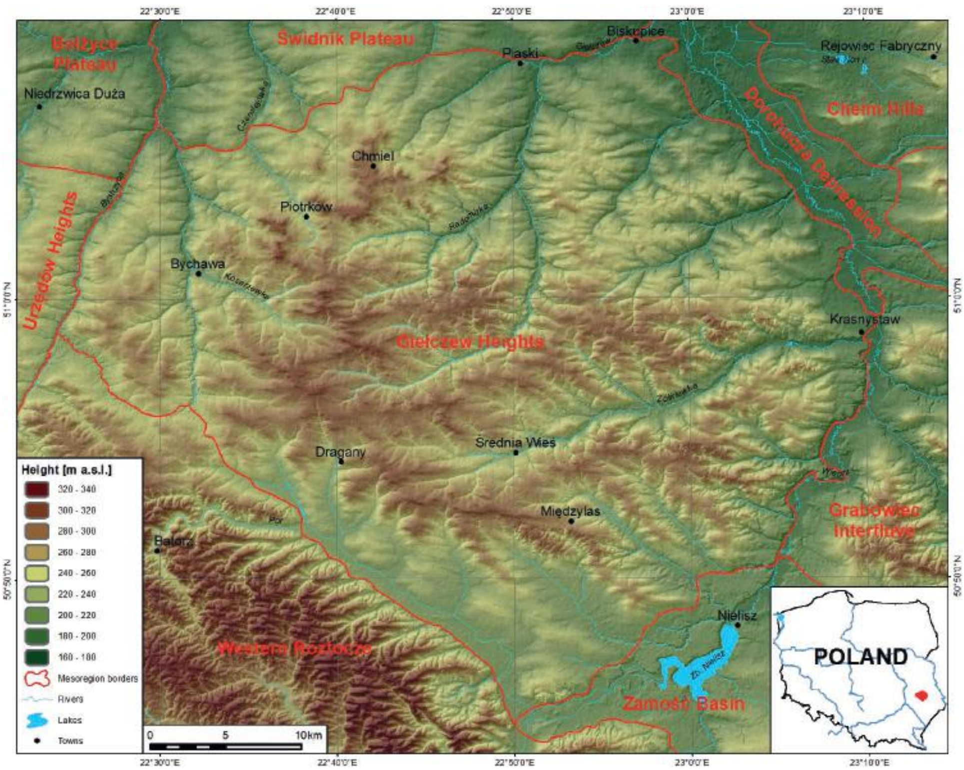

Fig. 1. Location of the study area

(up to 2° inclination) were recognised using the topographical base map with a contour interval of 2 m, based on LiDAR data. Along with the grid of assumed faults, these data facilitated the imaging of tectonic steps.

Collected archival materials from different years (with varying levels of detail) were compared and verified for compatibility. A comparative analysis of the compiled maps and cross-sections was also performed to solve the problem posed.

GEOLOGICAL STRUCTURE AND RELIEF OF GIEŁCZEW HEIGHTS

TECTONICS

Paleogene and Neogene tectonic movements in the Giełczew Heights area resulted in the creation of a dense network of normal and strike-slip faults (Dobrowolski et al. 2014). Notably, the range of downthrows and shifts is limited (up to a few dozen metres). These resulted in the formation of approximately a dozen blocks of varying size and rank, as well as a few grabens. The most important fault zones are those delimiting the elevated block and lowered fault steps of high rank. The centre of the region is an elevated rectangular tectonic block. In the north, it is delimited by a W-E fault zone ranging from the valley of Gałęzówka to the valley of Wieprz, while it is delimited by faults arranged like the coulisse of the Por graben in the south. The western border is the fault zone of Gałęzówka, while the eastern border is a SW-NE fault. On three sides of the elevated block, there are staircase-like arranged and lowered tectonic steps–one to the east, two to the west and four in the north (Fig. 2).

On the tectonic plan of Giełczew Heights, visible fault zones are connected to the Wieprz, Por, Bystrzyca, Kosarzewka, Czerniejówka, Giełczew, Radomirka and Żółkiewka river valleys. Among others, in the Czerniejówka valley, there is a 30 m vertical shift in the base of Paleocene sediments in comparison to the opposite side of the valley (Marszałek et al. 1996). In the Bystrzyca and Gałęzówka valleys, the faults are rectilinear, delimiting a triangular block. Meanwhile, the Giełczew, Radomirka and Żółkiewka valleys are broken by a sequence of dislocations. In some places, the faults radiate from tectonic loops (e.g., near Piaski). At other places, the faults delimit parallelogram-shaped blocks (e.g., in the Żółkiewka river valley) (Fig. 2). In certain places, fault zones refer to the Palaeozoic tectonic plan (Harasimiuk 1980; Harasimiuk et al. 1988a).

Joint fissures of opokas and gaizes are also significant in the development of the relief because they influence the azimuths of the valleys. Notably, two trends dominate the region: NW-SE and perpendicular SW-NE (Harasimiuk, Henkiel 1975; Harasimiuk 1980).

In the south-western part of Giełczew Heights, Cretaceous rocks are slightly folded. Part of the region comprises the south-eastern outskirts of the Wilkołaz-Zakrzówek anticline, which is a flat formation with a relatively low inclination of the layers (up to 12°) and an axis orientation adhering to the Lublin direction (WNW-ESE) (Jahn 1956). Close to the terrain surface, there are folded opokas and marly opokas of the Lower Maastrichtian (Cieśliński 1993).

Notably, some existing research overestimates the number of faults in Cretaceous rocks, putting them in the axes of major rectilinear valleys. However, these valleys can be related to joint fissures. However, S. Cieśliński (1993) claimed that no faults exist in the south-western part of Giełczew Heights.

PRE-QUATERNARY SURFACE ROCKS

Giełczew Heights comprises marine rocks dated to the Cretaceous (opokas, marly opokas, marlstones, chalkstones, limestones), Paleocene (gaizes), Eocene (sands with glauconite) and Miocene (Sarmatian) (silica sandstones,

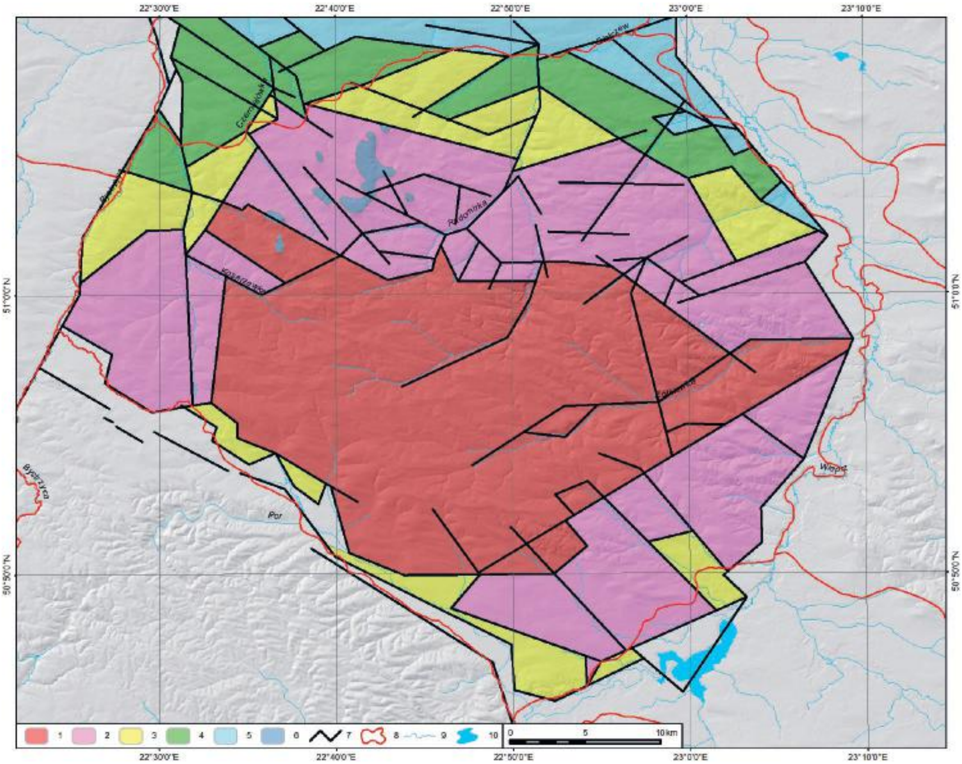

Fig. 2. Main morphotectonic elements of Giełczew Heights. Faults compiled according to J.E. Mojski (1968); M. Harasimiuk et al. (1988a); S. Marszałek et al. (1991, 1996, 2000); S. Cieśliński (1993, 2001); A. Albrycht and R. Brzezina (2000); S. Buła et al. (2000); A. Wągrowski (2001); (complemented). 1 – central tectonic horst, 2 – tectonic step I, 3 – tectonic step II, 4 – tectonic step III, 5 – tectonic step IV, 6 – quartz sand tablelands, 7 – assumed faults, 8 – mesoregion borders, 9 – rivers, 10 – lakes and water bodies

sands) (Fig. 3). The largest area is occupied by opokas and marly opokas from the Upper Maastrichtian (Upper Cretaceous). These rocks are of biomorphic structure and their main part is marl-silica material binding coccolith detritus. The granular components include quartz, glauconite, mica, pyrite and organic remains. Calcium carbonate content varies from ca. 50 to 80% (Marszałek et al. 1996). Marlstones and chalkstones also feature microremains of coccoliths, which make up the majority (up to 90%) of the mass of these rocks. Marlstones with layers of chalkstone are found in a narrow area on the southern outskirts of Giełczew Heights (Fig. 3). Limestones are present as thin layers between the opokas. These rocks comprise mainly organic remains distributed within carbonate micrite mass. Notably, the calcium carbonate content in these rocks can be up to 90% (Wyrwicka 1980).

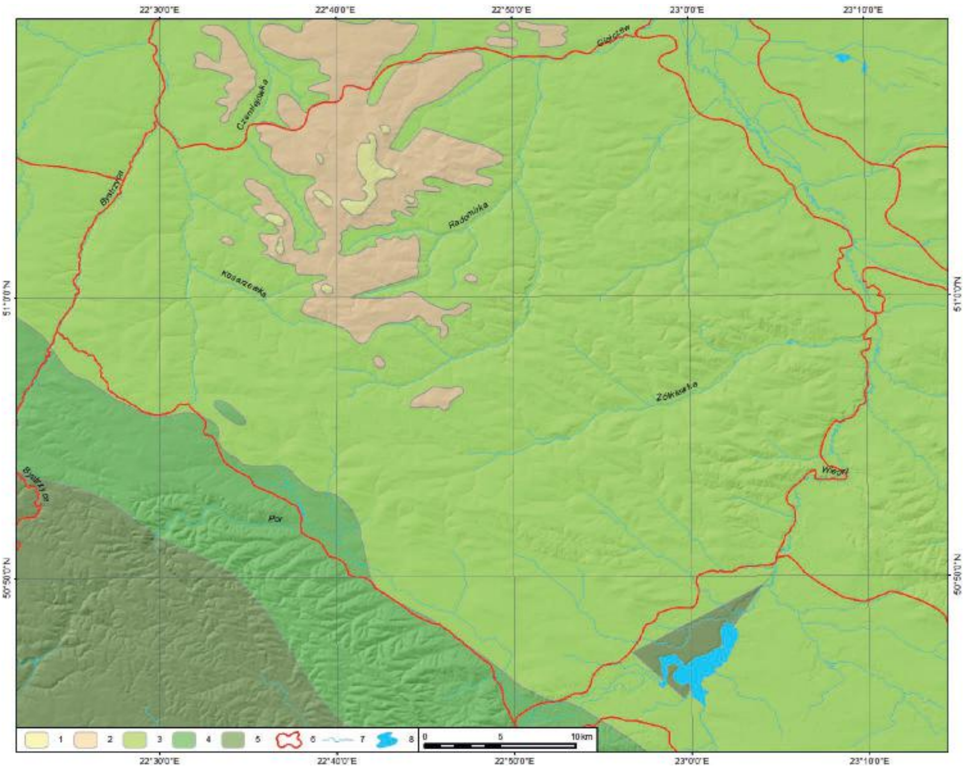

Fig. 3. Mesozoic-Cenozoic rocks (without the Quaternary sediments of Giełczew Heights); compiled according to J.E. Mojski (1968); M Harasimiuk et al. (1988a); S. Marszałek et al. (1991, 1996, 2000); S. Cieśliński (1993, 2001); A. Albrycht and R. Brzezina (2000); S. Buła et al. (2000); A. Wągrowski (2001). 1 – silica sandstones and quartz sands (Sarmatian, Tertiary); 2 – silica and marly gaizes with insertions of grey limestones (Paleocene, Tertiary); 3 – opokas, marly opokas, marlstones with layers of chalkstone (Upper Maastrichtian, Upper Cretaceous); 4 – marlstones (Lower Maastrichtian, Upper Cretaceous); 5 – marly opokas, opokas, limestones and marlstones (Upper Campanian, Upper Cretaceous) 6 – mesoregion borders; 7 – rivers; 8 – lakes and water bodies

In the central and northern part of Giełczew Heights, there are silica and marlstone gaizes from the Paleocene with insertions of grey limestone. These rocks are hard since they feature a skeleton composed of silica organic remains, quartz grains and calcium carbonate (up to 50%). On the surface, it is evident that the gaizes have undergone decalcification (Marszałek et al. 1996).

Eocene sands with glauconite can only be found in two locations: on Chełmiec hill and in Kolonia Skrzynice village. Small areas at these locations contain Sarmatian sandstones, which can be found on island hills

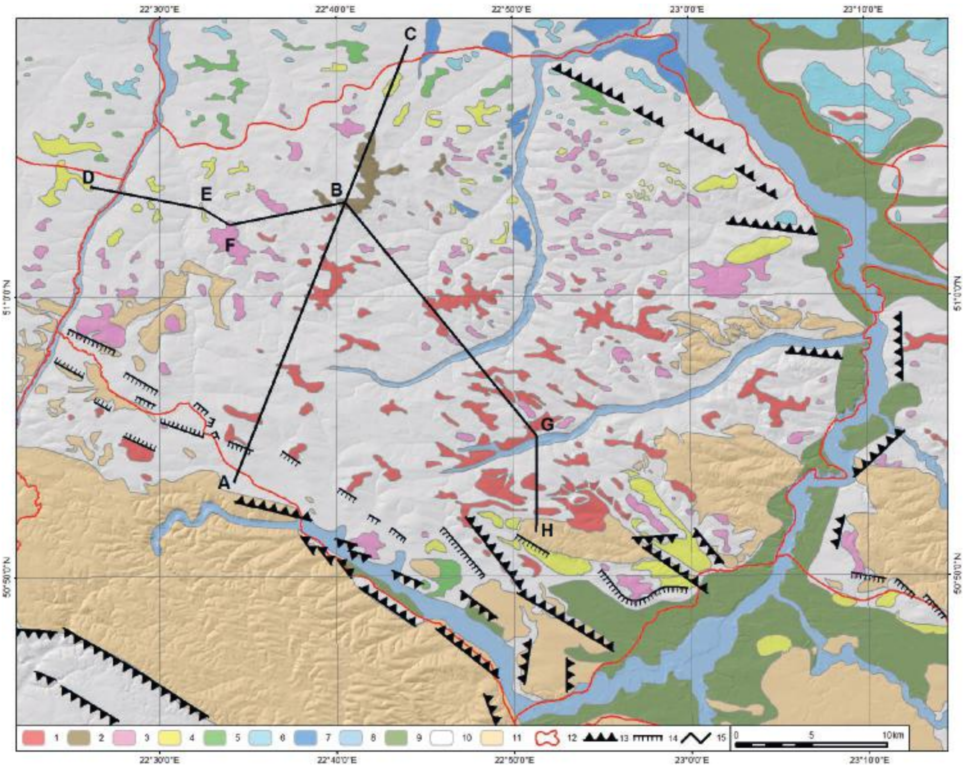

Fig. 4. Geomorphological sketch of Giełczew Heights; compiled according to J.E. Mojski (1968); M. Harasimiuk et al. (1988a); Marszałek et al. (1991, 1996, 2000); S. Cieśliński (1993, 2001); A. Albrycht and R. Brzezina (2000); S. Buła et al. (2000); A. Wągrowski (2001); (complemented). 1 – hilltop denudation level – peneplain; 2 – resistant denudation island hills; 3 – step I of the lowered peneplain; 4 – step II of the lowered peneplain; 5 – step III of the lowered peneplain; 6 – step IV of the lowered peneplain; 7 – valley denudation level; 8 – floodplain; 9 – Pleistocene terraces; 10 – hillsides and valley slopes; 11 – loess plains and valley slopes; 12 – mesoregion border; 13 – scarp with tectonic origin; 14 – cuesta; 15 – lines of morphological-geological cross-sections

near Piotrków, Chmiel and Bychawa. They comprise medium- and coarse-grained quartz sand cemented with quartz, silica-ferruginous and – in certain places – silica-ferruginous-silt binding material (Huber 2013), which form layers in loose sands (Marszałek et al. 1996). On the slopes and hilltops, marine rocks are predominantly covered with a thin layer of Quaternary continental deposits (eluvial, deluvial and glacial sediments). High fluvial sediment thickness is only present in the river valleys, while two patches of deep loess can be found along the Żółkiewka and Werbka rivers (Fig. 4).

GEORELIEF

The relief of Giełczew Heights is diverse in terms of genesis and age. The largest area is occupied by denudation forms, the oldest of which are fragments of the denudation surface (peneplain). They are situated in the central and southern part of Giełczew Heights, at an elevation of 270–280 m above sea level. In certain locations, island hills composed of gaizes, opokas and sandstones rise above that surface. These sandstone hills are extensive and sometimes have a flat top representing an accumulation bottom of the Sarmatian Sea, at an elevation of 280–290 m above sea level. Fragments of the aforementioned planation surface of four tectonic steps lie below the central planation surface. Fragments of tectonic escarpments are sporadically preserved at the front of denudation spurs. Primary planation surfaces are dissected by a dense network of valleys: dry basin valleys, dry flat-bottomed valleys and river valleys. The axes of these valleys typically have a NW-SE or SW-NE direction (Harasimiuk 1980). In the north-eastern part of the region, near Biskupice, there is a large cluster of karst sinks (Harasimiuk et al. 1988b; Fig. 4).

Notably, fluvial forms such as terrace levels from the Vistulian, flood terraces and river beds exist at the bottom of river valleys. In the vicinity of Piotrków and Biskupice, the remains of kame terraces can be found (Marszałek et al. 1996; Harasimiuk et al. 1988b). Moreover, the remains of glacial forms (moraines) are preserved in the Stawek river valley (Harasimiuk et al. 1988b).

STAGES AND CONDITIONS OF THE NEOGENE-EARLY PLEISTOCENE MORPHOGENESIS OF GIEŁCZEW HEIGHTS

The Neogene-Early Pleistocene morphogenesis of Giełczew Heights is framed between two events: the regression of the Sarmatian Sea and severe river erosion in late Early Pleistocene (1.4 million years ago, according to J.E. Mojski (2005)). The Sarmatian Sea likely formed a sea bay in part of the region, where sands were deposited and subsequently hardened with silica (Turnau-Morawska 1950). Sarmatian silica sandstone presently forms resistant island hills (Figs 3, 5). However, the relief of this portion of the region, which was not flooded by the Sarmatian Sea, has an older Palaeogene assumption.

After the regression of the Sarmatian Sea, the uncovered land began to undergo (mainly chemical) erosion, denudation and fluvial processes. Rocks containing calcium carbonate (i.e., marlstones, chalkstones and marly opokas) were especially prone to chemical erosion, while opokas and gaizes were less prone and Sarmatian silica sandstones were immune to the chemical

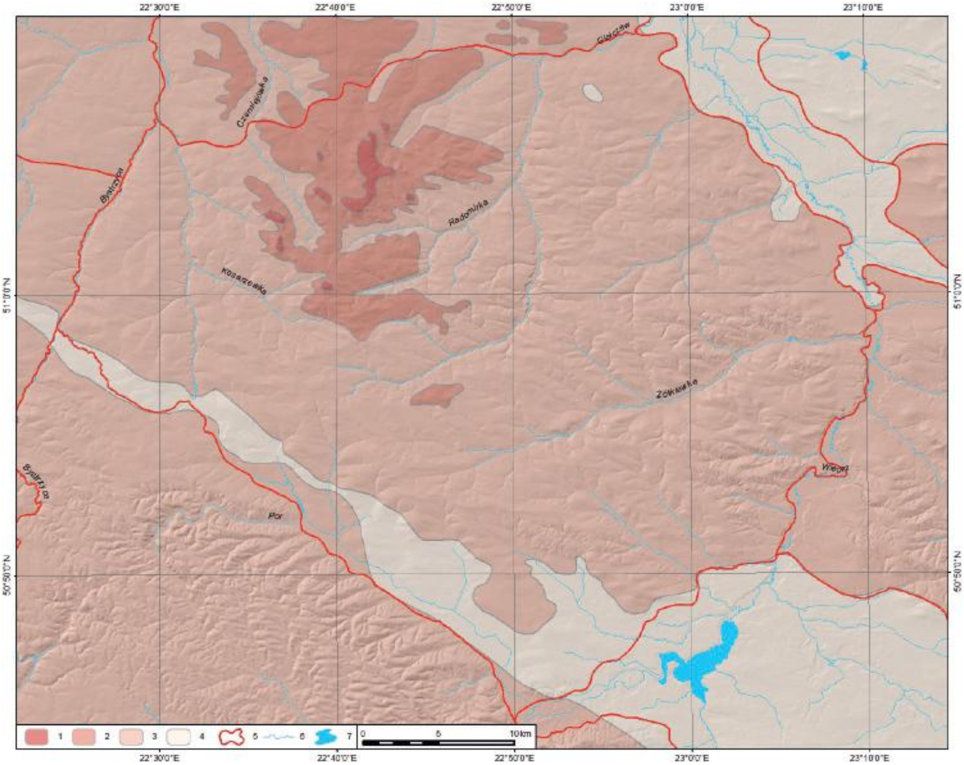

Fig. 5. Differentiation of Cretaceous and Tertiary rock hardness of the Giełczew Heights area. Lithology and rocks range according to J.E. Mojski (1968); M. Harasimiuk et al. (1988a); S. Marszałek et al. (1991, 1996, 2000); S. Cieśliński (1993, 2001); A. Albrycht and R. Brzezina (2000); S. Buła et al. (2000); A. Wągrowski (2001). 1 – very resistant rocks (quartzite sandstones); 2 – resistant rocks (gaizes); 3 – medium resistant rocks (opokas, marly opokas, limestones); 4 – low resistant rocks (marlstones, chalkstones); 5 – mesoregion borders; 6 – rivers; 7 – lakes and water bodies

erosion process. H. Maruszczak (2001) estimates that the vulnerability of opokas to chemical erosion is approximately 7 m/Ma. Assuming that the rocks were exposed to intensive chemical processes until the Messinian Event (i.e., a period of approximately 5 million years), a layer 35 m thick would have undergone erosion and removal. This value is not credible since, according to W. Pożaryski (1956), opokas of the Upper Maastrichtian are less vulnerable to erosion than gaizes with insertions of limestones and marlstones from the Danian. In summation, a flat planation surface with island hills (peneplain) emerged in the Giełczew Heights area during the Pannonian and Pontian. A similar hypothesis was proposed by L. Sawicki (1925), who claimed that a vast destruction surface ("middle-Polish quasiplain") was formed on the Polish Uplands during the Tortonian. Tectonic movements that likely occurred during the Pliocene caused fragmentation of the peneplain. Another view is represented by A. Henkiel (1995), who claimed that the highest planation level on the Lublin Upland is the exhumed abrasion surfaces of Eocene sea and partly the Sarmatian Sea. Only the south-western part of Giełczew Heights likely had such a genesis. Some research has denied the possibility of a few planation surfaces developing in the Carpathians. According to W. Zuchiewicz (2011), the relief could develop continuously.

Towards the end of the Pontian, in semi-arid and arid climates (Maruszczak 2001), the types of morphogenetic processes had changed. During this period, physical weathering, gravitational processes and aeolian erosion primarily occurred. At that time, the area of Sarmatian silica sandstone and hills composed of Cretaceous rocks were intensively destroyed. Due to lateral slope retraction (pediplanation), the hills gained concave, steep slopes with pediments formed at their feet. The previously homogeneous destruction surface became polygenetic. Sandstone debris on the surface of pediments survived until the modern era, largely due to hardening opal desert varnish formed during the Messinian Event. Thus, due to a reduction in the total area composed of highly resistant rocks (Fig. 5), pediments joined the peneplain. Similar conclusions were presented by H. Maruszczak (2001), who maintained that the oldest island hills of Giełczew Heights were formed in the desert landscape, accenting the litho-structural features of the area.

A short period of the early Pliocene (Dacian) and its climate conditions was not favourable for the intensive transformation of the terrain relief. The peneplain, island hills and pediment surfaces did not undergo any significant changes and survived until the block movements of the late Pliocene (late Romanian). These movements resulted in a separation that remains continuous, whilst the surface of the peneplain separated into blocks and tectonic steps of various sizes and shapes. The central area of Giełczew Heights is elevated as a rectangular block, while four staircase-like descending and inclined tectonic steps exist to the north (Fig. 2): I (240–250 m a.s.l.), II (230–240 m a.s.l.), III (220–230 m a.s.l.) and IV (210–220 m a.s.l.). The height of the downthrows is small (10–20 m). Similar values were noted by other researchers (Harasimiuk et al. 1988a; Maruszczak 2001). This course of events is further supported by the identical terrain relief of the lowered levels and the central portion (i.e., a flat surface with island hills). This was previously noted by A. Jahn (1956), who noted that the middle level is a basement surface with island hills that was formed as a result of denudation processes over a long period under semi-arid climate conditions in a landscape of steppes or waning deserts. Another piece of supporting evidence is that both the surface of the central block and the lowered levels dissect rocks of varying resilience (Figs 6, 7).

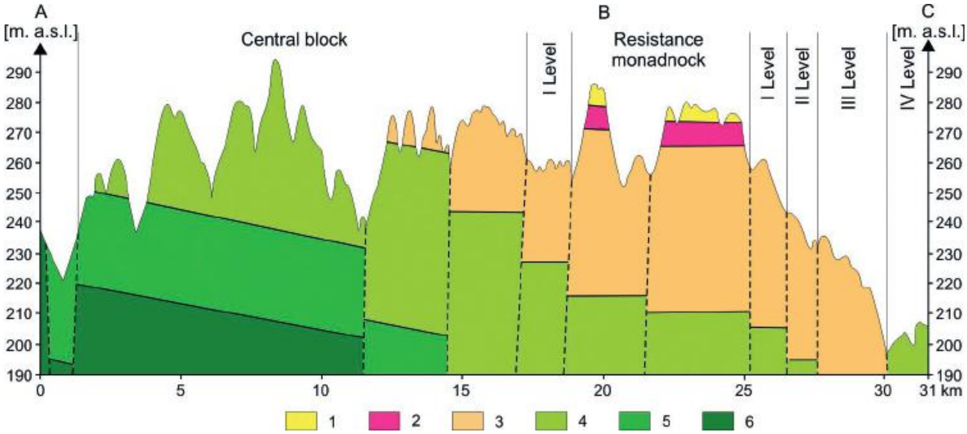

Fig. 6. Geological cross-section A–C of Giełczew Heights. Rock lithology according to S. Marszałek et al. (1992, 1996); S. Cieśliński (1997, 2001). 1 – silica sandstones; 2 – diatomites; 3 – gaizes; 4 – opokas; 5 – marlstones; 6 – chalkstones

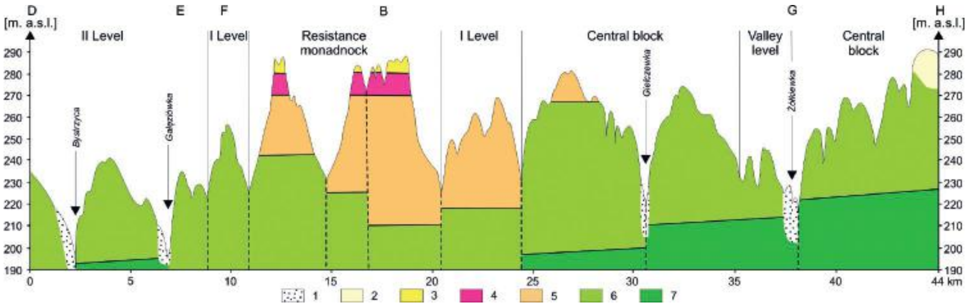

Fig. 7. Geological cross-section D–H of Giełczew Heights. Rock lithology according to S. Marszałek et al. (1989, 1991, 1992, 1996); A. Albrycht and R. Brzezina (1990, 2000), S. Cieśliński (1997, 2001). 1 – Quaternary sediments; 2 – loess; 3 – silica sandstones; 4 – diatomites; 5 – gaizes; 6 – opokas; 7 – marlstones

From tectonic escarpments towards the springs, rivers cut into their bottoms, thereby deepening the valleys and subsequently widening them during the period of tectonic tranquillity. As emphasised by A. Jahn (1956, p. 292), "Valleys dissect the escarpment in a relatively small area, they do not cause frontal retraction, but rather break its integrity. Erosion valleys are an alien element in this complex of landforms". The fluvial valley level was thus formed at varying heights, depending on the height at which each tectonic step occurs. It is the most elevated on the central block, in the Radomirka, Giełczew and Żółkiewka valleys (ca. 250 m a.s.l.), and the least elevated on block IV (180–190 m a.s.l.). These facts suggest that the valleys of contemporary rivers were formed as late as the Romanian. Also, R. Dobrowolski et al. (2014) suggested that the hilltop planation surface was dissected during the early Romanian. Furthermore, A. Jahn (1956) believed that their foundations were much earlier, representing surviving Sarmatian hydrographic lines.

While there is no direct evidence for the aforementioned dating of the tectonic forms of Giełczew Heights, they can be correlated with tectonic phases by "backwards counting". High-intensity erosion in the river valleys is unequivocally dated to Early Pleistocene (Celestynów Interglacial, ca. 1.4 million years ago). This erosion was connected to intensive tectonic movements. Forms older than deep valleys constitute preserved fragments of the valley level covered by the lower parts of the sediments of the Kozienice series (Jahn, Turnau-Morawska 1952). This series was accumulated by rivers 2.6–1.4 million years ago (Mojski 2005). This level is a rocky erosion bottom of wide valleys with a slight inclination that was formed by dissection of the peneplain and pediplain during uplift movements and subsequent side erosion and denudation. However, it remains unknown whether these movements occurred in the Early Pleistocene or Early Romanian (Pliocene). In the Carpathians, the valley level was formed in the early Pleistocene, while the upland level was formed in the Romanian (Starkel 1969, 1972; Baumgart-Kotarba 1983; Zuchiewicz 1985, 1992). The Young-Tertiary (Pliocene) tectonic phase in the Lublin Upland area was also assumed by A. Jahn (1956). He considered the formation of this region and its current morphological traits to be connected to this phase. Therefore, we hypothesise that the fluvial valley level was formed at the beginning Early Pleistocene, during the period of tectonic tranquillity. The deposition of the Kozienice series can also be dated to this period. A similar view on the period of the deposition for these series is presented by S. Dżułyński et al. (1968) for the Sandomierz Basin area. In some regions, two valley levels were formed before the Celestynów Interglacial. Such formations have been observed in Roztocze (Buraczyński 1997), Horodło Perch (Dolecki 1992) and the Carpathians (Zuchiewicz 1998).

During the Celestynów Interglacial (ca 1.4 million years ago), the Lublin-Volhynia Uplands and Roztocze block were uplifted by approximately 100 m in relation to the northern forefield (Mojski 2005). The rivers of Giełczew Heights dissected the valley level, deepening most valleys by ca. 15–45 m, while the Wieprz river valley was deepened by up to 100 m (Harasimiuk et al. 1988a). Subsequently, likely at the decline of the Early Pleistocene and beginning of the Narewian glaciation, the valleys were almost completely covered in sediments of the Krasnystaw series. These series comprise gravels merging into sand and dust towards the ceiling, which represents evidence of changes in river regimes due to climate change. Further evidence of the deposition of these series in a cooling climate is provided by data on taiga forests (Janczyk-Kopikowa 1981) and permafrost structures found in the sediments (Harasimiuk et al. 1988a).

CONCLUSIONS

1. The highest planation surface of Giełczew Heights was developed in a climate that was changing from hot and wet to hot and arid. Essentially, part of this surface is a peneplain, while the other part is a pediplain. However, it is also possible that exhumed abrasion surfaces of the Sarmatian Sea were preserved.
2. Giełczew Heights comprises tectonic blocks varying in both size and age. Some of these blocks were formed before the transgression of the Sarmatian Sea, while others were formed at the end of Pliocene (late Romanian) and beginning of the Early Pleistocene.
3. In the Neogene, only one hilltop planation surface was present in the Giełczew Heights area. The Pliocene and Pleistocene tectonic movements broke it into several lowered steps, which suggest the existence of separate hilltop planation surfaces.
4. Erosion valley levels are present at various elevations since their bases were foothills of the lowered blocks. However, they were simultaneously formed at the beginning of the Early Pleistocene.
5. The Pleistocene cycle of relief development concluded with the maximum deepening of the valleys during the Celestynów Interglacial and their subsequent filling by sediments of the Krasnystaw series.
6. The proposed morphogenesis of Giełczew Heights is representative of the entire Lublin-Volhynian Uplands. However, further research using detailed field and laboratory methods is required.

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