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Quaternary of the Gulf of Gdańsk and Lower Vistula regions in northern Poland...

VERTICAL STRESS OF THE PLEISTOCENE CONTINENTAL GLACIERS AND ITS HYPOTHETICAL EVIDENCE IN PRESENT RELIEF OF NORTHERN EUROPE

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Abstract. The present morphology of northern Europe was undoubtedly shaped by neotectonics connected with a structural plan of the old basement and activated by particular Pleistocene ice sheets along parallel and meridional relaxed and fractured zones. These zones were mainly formed at the lithologic boundaries between structural units of different density. Parallel and meridional faults, activated during Pleistocene as a result of glacioisostasy (loading and unloading by advancing and retreating ice sheets) marked present surface as blocks or polygons in a whole glaciated territory, however, within the limit of the Last (Vistulian) Glaciation there are predominating elevations of the interlobate moraines named glaciotectonic insular heights (GIH).

Key words: vertical stress, glacioisostasy, morainic blocks, interlobate moraines, faults, glaciotectonic insular heights (GIH), present relief.

Abstrakt. Na ukształtowanie powierzchni północnej Europy miały wpływ neotektonika i plan strukturalny (systemy uskoków) głębokiego podłoża, aktywizowany przez pionowe naciski kolejnych transgredujących lądolodów. Nowe uskoki powstawały na granicach skał o różnej litologii. Naciski pionowe lądolodów doprowadziły do powstania dobrze widocznych we współczesnej rzeźbie obszarów zlodowaconych bloków morenowych lub poligonów. W obrębie zasięgu ostatniego zlodowacenia w topografii bloków morenowych uwarunkowanych tektonicznie dominują wysoko wyniesione moreny międzylobowe.

Slowa kluczowe: nacisk pionowy, glaciizostazja, bloki morenowe, uskoki, moreny międzylobowe, glacitektoniczne wyniesienia wyspowe (GWW), ukształtowanie powierzchni.

INTRODUCTION

Glaciotectonic insular heights (GIH) named also Cupola hills (Aber, Ber, 2007; Ber, 2007), in Poland as iPe – isolated Pleistocene elevations (Mojski, 1998), either the glacial accumulative insular heights (Raukas, Karukäpp, 1999) or insular accumulative heights (Zelčs, Markots, 2004), with dome-like morphology modified by the action of overriding ice, are common in glaciated part of northern Europe within the limit of the Last Glaciation i.e. Wolin Island, Chełmska Hill, Kaszuby Elevation, Wieżyca Hill, Elbląg Upland, Szeskie Hills, Dylewska Hill and so on, in Poland; Grodno Highland in Belarus, Żemaitia Upland in Lithuania, and Kursa, Vidzeme, Sakala, Otepää, Haanja, Latgale, Lembolovo and so on, in Latvia, Estonia and Russia territories (Fig. 1). Their internal structure is strongly glaciotectonicly deformed and the origin directly influenced either presence of the soft substratum or influence of the deeper basement. During the younger Pleistocene period the GIHs located within the limit of the last glaciation formed substantial obstacles for the ice sheets and favoured their disintegration into ice streams and lobes (Aber, Ber, 2007).

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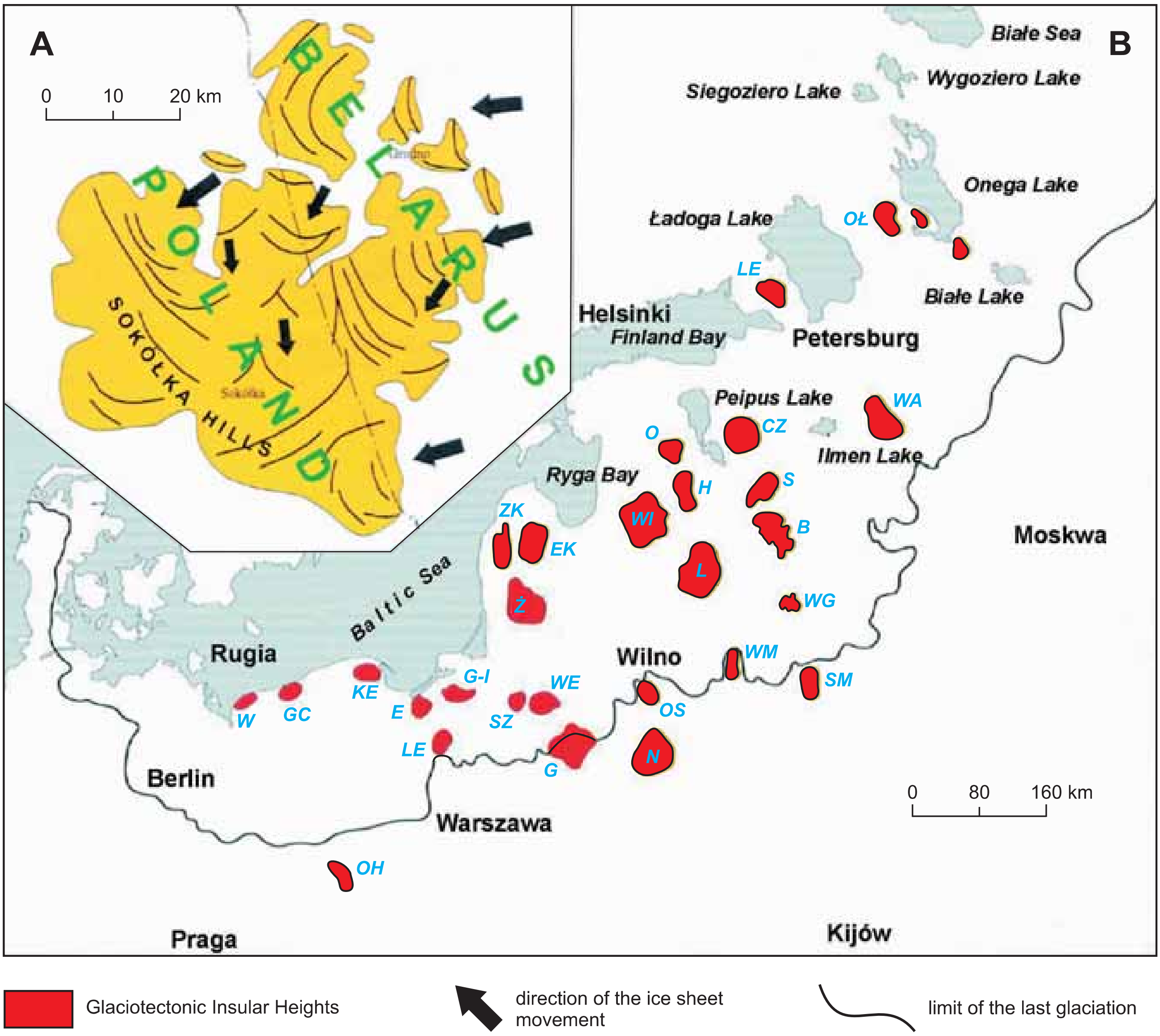

Fig. 1. Location map for Glaciotectonic Insular Heights (GIH) in northern Europe (after Karabanov, 1987, supplemented)

A – Grodno Highland; **B** – location of the GIH landforms: W – Wolin Island, GC – Chełmska Hill, KE – Kaszuby Elevation, E – Elbląg Upland, G-I – Górowo-Iławeckie Hills, LE – Lubawa Elevation, SZ – Szeskie Hills, WE – Wiżajny Elevation, G – Grodno Highland, Ż – Żemaitia Upland, ZK – Western Kursa Heights, EK – Eastern Kursa Heights, OS – Oszmiany Upland, N – Nowogród Upland, WI – Vidzema Heights, L – Latgala Heights, O – Otepää Heights, H – Haanja Heights, CZ – Czużska Upland, S – Sudowska Upland, B – Bieżanicy Heights, LE – Lembolowo Upland, WA – Waldaj Upland, OŁ – Ołomecka Upland, SM – Smolenska Upland, WG – Gorodokska Upland, OH – Ostrzeszów Hills, WM – Minsk Upland

GLACIOTECTONIC INSULAR HEIGHTS (GIH) WITHIN THE LIMIT OF THE LAST GLACIATION

The morainic uplands in shape of blocks or polygons creating present landscape with the glaciotectonic insular heights (GIH), are especially preserved within the limit of the last Pleistocene glaciation and constitute in places their highest elevations, mainly as interlobate moraines; they were connected with tectonic structures of the deeper basement (Fig. 2). Tectonic movements of the crystalline basement were superimposed by glaciostatic loading (vertical stress) and unloading, which took place during glacier advance and retreat (Liszkowski, 1993). It can be assumed that loading and relaxation within the crystalline basement occurred several times, during each glacial and interglacial period, causing rhythmic glaciostatic movements (Aber, Ber, 2007). Nearby the morainic uplands with interlobate moraine elevations, there are morainic blocks without any elevations. These landforms were created by vertical stress the ice masses only. Such characteristic landforms are presented in Poland, for example by the present landscape of the Poznań vicinity (Przybylski, 2008).

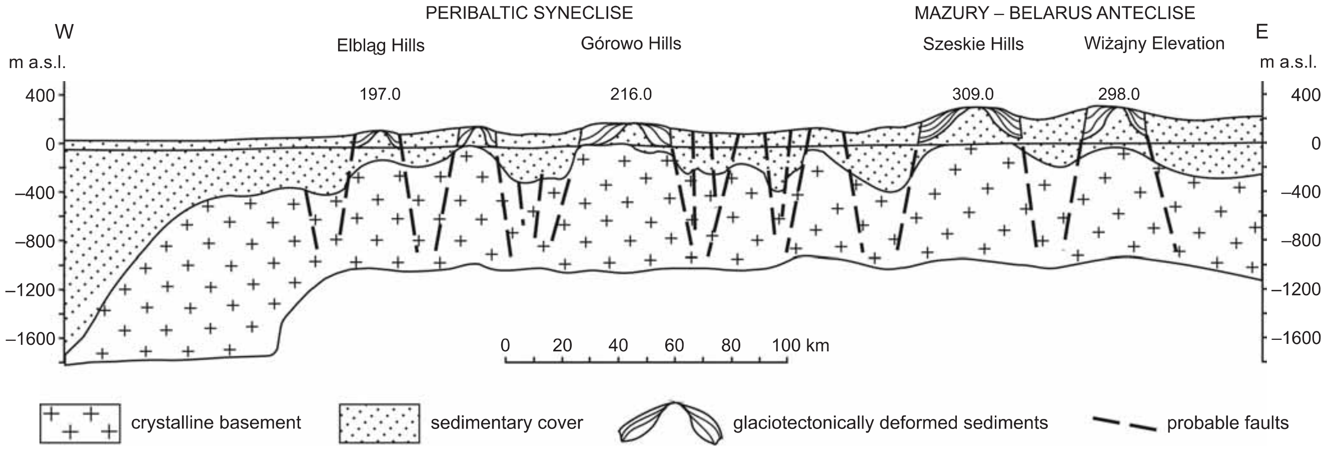

Fig. 2. Palaeotectonic sections from the Lower Vistula Valley to the Wiżajny Elevation (adapted from Aber and Ber, 2007)

The morainic uplands in shape of blocks or polygons in the present landscape in northern part of Poland, Lithuania and Belarus (Wolin Island, Chełmska Hill, Wieżyca Hill, Kaszuby Elevation, Elbląg Upland, Górowo Iławeckie Hills, Dylewska Hill, Szeskie Hills, Wiżajny Elevation, Żemaitia Upland and Grodno Highland) contain strongly disturbed glaciotectonic internal structure and in northern Poland correspond with buried positive pre-Arenigian palaeostructures composed of Cambrian and Valdai deposits (Ber, 2000; Aber, Ber, 2007).

As an example of the GIH located within the limit of the Last Glaciation in Poland there is the Elbląg Upland, described by Aber and Ruszczyńska-Szenajch (1997).

The **Elbląg Upland** is a large glaciotectonic insular height (GIH) located to the south of the Gulf of Gdańsk and rises to 200 m above the surrounding lowlands. Geology and stratigraphy of the Elbląg Upland were investigated by Makowska (1995, 1999, 2008). According to Aber and Ruszczyńska-Szenajch (1997) within the Elbląg Upland two morphologic patterns were defined: eastern arcuate belt, concave towards the northeast and western arcuate belt, concave to the west. The two morphologic sets that converge near the central, highest portion of the upland constitute the interlobate moraine. In addition, within this area drumlins are situated.

The internal structure of the Elbląg Upland recognized by Makowska (1999, 2008) is, according to the present author, only a partly strongly deformed feature, displaced by ice pushing. The structural observations suggest multiple phases of deformation from different directions. In contrast, Aber and Ruszczyńska-Szenajch (1997) and Aber and Ber (2007) concluded that the entire mass of the Elbląg Upland has a glaciotectonic genesis and resulted from advances by two ice lobes, which pressed locally from the northeast and west, corresponding to the two main morphologic trends within the upland surface (Fig. 3).

In Belarus, Lithuania, Latvia and Estonia there are noteworthy the Grodno Highland, Żemaitia Upland, Eastern Kursa Upland and GIH located in southern Estonia (Otepää, Haanja).

The **Grodno Highland** located within the last glaciation limit in shape of a big block or polygon is the partly glacial interlobate massif at altitude about 298 m a.s.l., which was influenced by the main ice streams during Middle and Late Pleistocene glaciations (Karabanov, 1987) (Fig. 1A). According to Pavlovskaya and Karabanov (2002) the whole Quaternary sequence deposits within the Grodno Highland is glaciotectonicly deformed in the shape of hill-hole pairs stretching generally in W to E direction, with impressive dislocations of Cretaceous rocks, for example at Pyshki and Peski near Krasnoselsky.

In the chalk quarry at Pyshki there are folded scales of the Upper Cretaceous chalk and chalky marl deposits as well as the Upper Miocene and Lower Oligocene strata, and injective forms and magablocks overlain by Pleistocene a till and glaciofluvial sands (Karabanov, 2002a).

According to Karabanov (2002b) the Peski glaciodislocation represents a system of parallel ridges, up to 15–20 m high and composed of the Upper Cretaceous chalk and marls, Palaeogene glauconite-quartz sands and Neogene clay and quartz sands. Ridges (scales) are composed of megablocks or anticlinal folds, overthrusted at an angle of 40–45°. The thickness of glaciotectonicly disturbed sediments varies from 40 to 200 m. These glaciotectonicly disturbed sediments appear in the area where the crystalline basement is located at depth of 1000 m and dissected, similar to the Wiżajny Elevation in Poland, by the system of fractures. Karabanov (2002b) suggests that the fault system was activated by ice loading during the Middle Pleistocene glaciations.

The **Żemaitia (Samogitian) Upland** (NW Lithuania) is a sizable glacial highland to 300 m a.s.l. with glaciotectonicly disturbed internal structure. The upland occupies an area of about 9000 sq. km and is surrounded by 5 lowlands. The central part of this form is composed of the distinct hilly massifs (interlobate moraines?), with the highest point of the Medvegalis Hill at 234.6 m a.s.l. The Żemaitia Upland, similar to the Elbląg Upland in Poland, has two central glacioelevations and the central glaciodepression. According to Guobyte

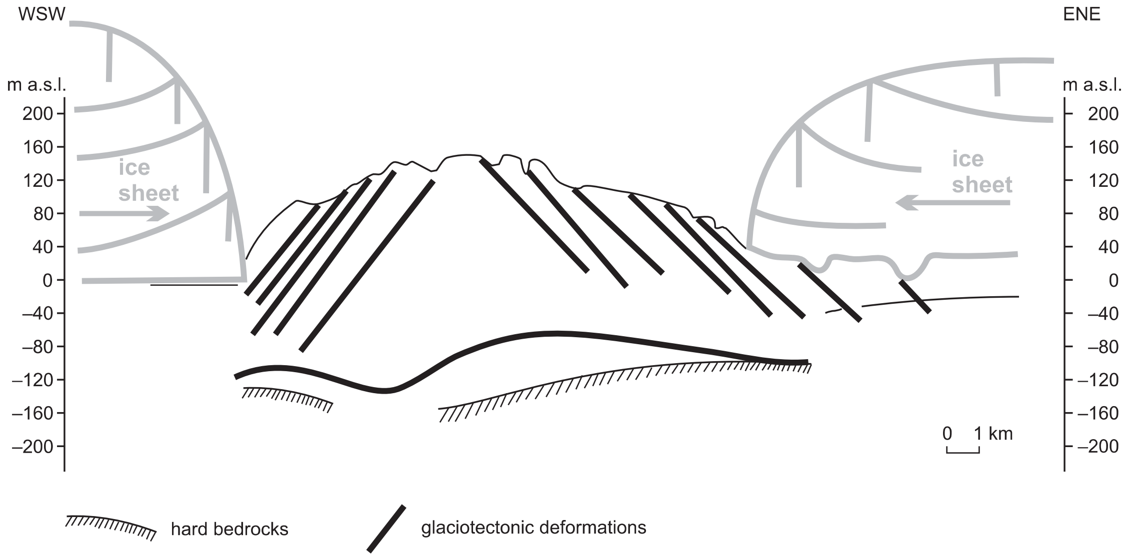

Fig. 3. Elbląg Upland – probable directions of the ice lobes stresses and glaciotectonic structures (after Aber and Ruszczyńska-Szenajch, 1997, modified)

(2007) the sub-Quaternary surface is composed of the Upper Jurassic, Lower Triassic and Lower Cretaceous rocks. The thickness of the Quaternary cover, on the Satrija hilly massif on example, probably strongly glaciotectonicly disturbed, varies from 50 to 250 m.

The **Eastern Kursa Upland** (north-western Latvia) covers an area of 3860 km^2 and is the largest radial GIH in Latvia. According to Seglinš (1999) and Strautnieks (1999) is located on a large plateau-like of the pre-Quaternary bedrock surface (Fig. 4). The bedrock core is composed predominantly of the Devonian rocks, but the Carboniferous sandstones and Permian limestones are also found and covered by glacial and glaciofluvial sediments. The thickness of the glacial and glaciofluvial sediments, which are often glaciotectonicly deformed, varies from 2–10 m in till plains to 30–80 m in hilly areas. The present glacial landscape of the Eastern Kursa Upland represents a variety of landforms with hills and ridges commonly occurring on the local bedrock elevations. According to Aboltins and Dreimanis (1995) the highest inner areas of this form were formed mainly subglacially during the early deglaciation phase during the last Pleistocene glaciation.

But it is also possible that GIH landforms, similarly as in Poland, were partly formed earlier, during advances and retreats of the older Scandinavian ice sheet.

The **Otepää and Haanja-Aluksne Hights** (eastern Estonia) described by Raukas and Karukäpp (1999) were created between active glacial lobes and composed of glacial and glaciofluvial deposits with bedrock cores, partly strongly glaciotectonicly deformed. On the Haanja Hights there is the highest point of the Suur Munamägi Hill, at altitude of 318 m a.s.l. Both landforms are slightly elongated in the direction of the ice sheet movement. According to Raukas and Karukäpp (1999), a high topography in the centre

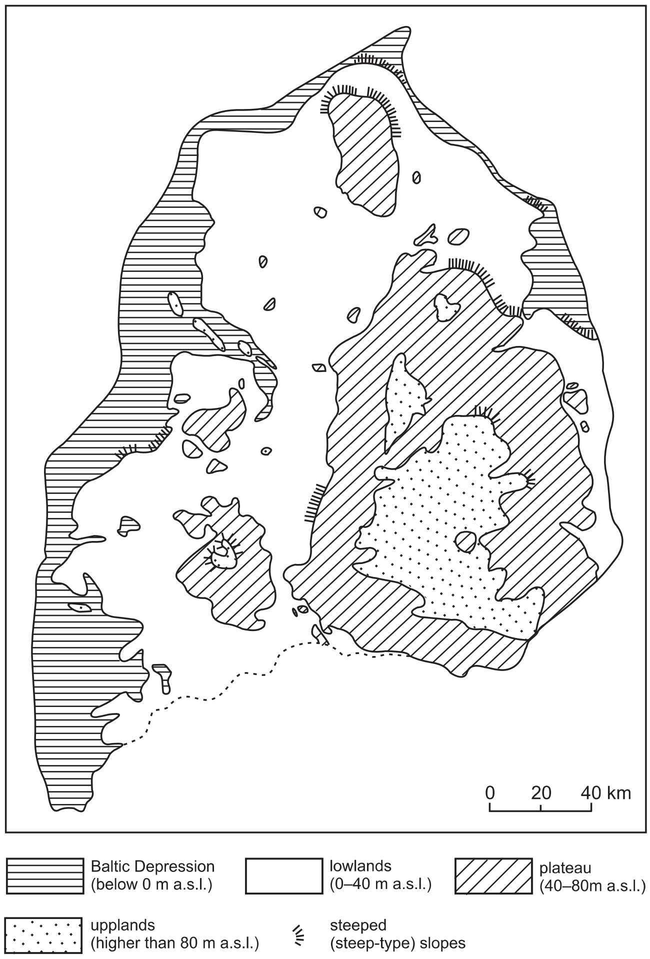

Fig. 4. The bedrock of the Western and Eastern Kursa Heights; structures of the pre-Quaternary deposits surface (after Seglinš 1999, modified)

of both heights is due to glaciotectonics from extremely great horizontal and vertical stresses which created from medium to large-sized imbricate overthrusts. The structural base of the hills was primarily formed as a result of subglacial ice push deformation and then, during stagnant ice phase, when clays in ice-dammed lake were deposited on the landforms.

The eastern Estonian GIHs have, similar to the Elbląg Upland and the Żemaitia Upland, two central glacioelevations with a glaciodepression between them.

GLACIOTECTONIC INSULAR HEIGHTS (GIH) BEYOND THE LIMIT OF THE LAST GLACIATION

As a GIH located beyond the limit of the last glaciation the Ostrzeszów Hills are noteworthy.

Ostrzeszów Hills are situated at the south-eastern end of the Wielkopolska Lowland. They form the easternmost and highest part of the Silesian Rampart, with altitude that exceeds 280 m a.s.l., but without the highest part that is represented by an interlobate moraine. The Ostrzeszów Hills display an arcuate curvature concave towards the west. The Odolanów Basin which is located in the northwest and marked surficially, represents a buried glaciodepression within the Neogene substratum.

The Ostrzeszów Hills are a thrust end moraine, pushed from the west by the Wartanian Glaciation (Rotnicki, 1967). Their internal structure consists of steeply dipping imbricated blocks, pushed from the west, that include Pleistocene, Pliocene and Miocene sediments. The Odolanów Basin marks the source region for material thrust into the hills.

According to Markiewicz and Winnicki (1997) the deep glaciotectonic deformations were favored by a diversified geological structure of the Neogene upland with horst structures of the Triassic hard substratum. Glaciotectonic movements of the mentioned Triassic substratum were probably connected with processes resulting from irregular ice loads exerted repeatedly during multiple glaciations (Aber, Ber, 2007).

Similarly as within the younger glaciation limit, these structures (tectonic blocks) were activated by loading (vertical stress) of the advancing older ice sheets. At present, they are also represented by a surficial image by glaciotectonicly disturbed morainic blocks or polygons.

It is quite possible that morainic uplands in shape of blocks or polygons are creating the present landscape within the limits of the older glaciations. In contrast to GIHs located within limit of the last glaciation, their surficial image is not so clearly visible at the highest elevations created by the interlobate moraines. It seems therefore that the present relief of these older areas depends from sustained erosion processes.

CONCLUSIONS

According to the above presented hypothesis the present relief of the glaciated Europe issue is to be subdivided into two parts:

– morainic uplands (GIHs) tectonically influenced with elevations of the interlobate moraines, mainly located within limit of the last glaciation;

– morainic uplands tectonically influenced in shape of blocks or polygons that created the present landscape in limits of the oldest (Saale, Elstere) glaciations.

These landforms in present land surfaces have been most probably created and activated (without the interlobate moraines) by loading (vertical stress) by the advancing ice sheets.

The GIH forms, either within the limit of the last glaciation or limits of the older glaciations were connected with tectonic structures of the deeper basement. These structures (tectonic blocks), activated by loading (vertical stress) of the advancing ice sheets, are represented by morainic blocks or polygons in a surficial landscape.

On the base of the analysis of the present landscape we can hypotheticly subdivide the territory of Poland into individual morainic blocks of different size. It is also possible to connect the limits of the marked blocks with a tectonic system of the deeper basement.

However, the ice sheets dynamic (horizontal) stress is indicated in the present landscape, among others by linear glacial landforms as marginal (with interlobate moraines) and glaciotectonic zones, different types of subglacial positive and negative landforms.

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