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Glaciotectonics of Belarus

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Different glaciotectonic structures and landforms occur in the territory of Belarus: folded dislocations, glacial depressions, rafts and injective features. The largest folded glaciodislocation is 30 km long and 8–11 km wide, and glacial rafts are up to 1.5 km long and 20–25 m thick. Many glaciotectonic structures are clearly expressed in landscape. Most large folded glaciodislocations were formed during the Sozh (Warthian) Stage of the Dnieper Glaciation.

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INTRODUCTION

Glaciotectonic investigations in the territory of Belarus have a long history. Starting from the beginning of the 19th century, numerous glaciotectonic features were noted (Fig. 1). For the first time Severgin (1803), Ullmann (1827), Push (1830) and Eichwald (1830) described dislocated rocks of the Cretaceous and Paleogene in the western part of the country near Grodno. Such structures were studied later in the same area by Berendt (1870), Grewingk (1872), Dymczewicz (1879), Giedroyć (1886, 1895), Siemiradzki (1889, 1909), Missuna (1904), and others. Among them, Giedroyć (1895) and Missuna (1904) presented the best recognition of glaciotectonic dislocations of the pre-Quaternary rocks. During the mid-war times, exposures of glaciodislocated rocks near Grodno were studied by the Polish geologists: Zaborski (1927), Limanowski (1929), Rydzewski (1929), Prószyński and Rühle (1933), Halicki and Sawicki (1935), Kongiel (1937) and Halicki (1951). Halicki and Sawicki (1935), and Halicki (1951) investigated numerous glaciotectonic features exposed in the Neman valley near Grodno. In the central part of Belarus Tyszkiewicz (1847), Karpiński (1892) and Missuna (1904) described exposures of glaciodislocated deposits of the Cretaceous. Armashevski (1895) noted large rafts of the Middle Devonian dolomites near Slavgorod and Krichev. Glacial rafts of the Devonian dolomites were investigated later by Terletski (1928), Maliarevich (1931), Kovalev (1931), and Saks (1934). Tyszkiewicz (1847), Karpiński (1892), Terletski (1928), Zhirmundski (1923) and Mirchink (1946) studied a large block of the Ordovician near Rovanichi, eastwards from Minsk. In northern Belarus, glacial rafts of the Devonian rocks were discovered in river valleys of the Sarianka and the Dnieper (Vozniachuk and Tikhonov, 1968).

Starting from the 1970s, considerable glaciotectonic investigations were carried out by Goretski (1972, 1973, 1981), Kriger (1971, 1983), Matveev (1976) and especially, by Levkov (Levkov, 1980; Gubin and Levkov, 1983; Levkov and Karabanov, 1983, 1988, 1992*a*, *b*, 1994; Levkov and Kharchenko, 1975; Levkov and Derugo, 1975; Karabanov and Levkov, 1990, 1992, 1993). Levkov systematized numerous glaciotectonic data, described main glaciodislocations in Belarus and presented a theoretical model of development of large folded dislocations and rafts (Fig. 2).

GLACIOTECTONIC FEATURES

Glaciotectonic features were determined by Aber (1985) as structures and landforms produced by deformation (folding and faulting) and dislocation of soft bedrock and drift masses as a direct result of glacier-ice movement. Glacial depressions and the ones formed by collapsing during melting of stagnant ice were not considered by Aber (1985) to be of glaciotectonic origin. On the contrary, Levkov (1980) stated that glaciotectonic features include all dislocations connected with stagnant and dead ice. Several glacial depressions were determined by Levkov

Fig. 1. Location of glaciodislocations in Belarus

(Levkov, 1980; Karabanov and Levkov, 1992) as paragenetic features, coupled with folded dislocations. In Belarus there are folded dislocations, glacial rafts, glacial depressions, diapiric hills and ridges. Glaciotectonic structures and landforms are frequently associated with glaciodislocations of the pre-Quaternary rocks.

FOLDED GLACIODISLOCATIONS

Moving ice formed folded glaciodislocations, represented both by single over thrust folds and by large glaciotectonic constructions, and involving hundreds of thrust folds and scales. Large folded glaciodislocations are distributed mainly within a marginal zone of the Sozh Stage of the Dnieper Glaciation. In Belarus fifteen large folded structures formed by the glaciodislocated pre-Quaternary rocks were noted, as well as dozens of smaller features. Large folded dislocations are arc-shaped, their extents varying from 2 to 30 km. In plan they almost resemble a parabolic arc (complete dislocation) or at least a segment of it (reduced dislocation). Some separate folds are from as little as a few tens metres to as much as 1–1.5 km long. Width of the dislocated rock belts varies from 1 to 11 km. The folded pre-Quaternary rocks are most often 80–100 m (occasionally up to 250 m) thick.

Such dislocations are associated commonly with deep glacial depressions, excavated parallel to the main glaciotectonic arc and situated at short distance in a proximal direction. The smallest folded glaciodislocation, composed mainly of chalk (Okhovo dislocation, Pinsk district), is about 2–3 km long and 1 km wide (Fig. 3). The largest folded glaciodislocation is the Peski one, 30 km long and 8–11 km wide (Karabanov *et al.*, 1997). In plan the dislocations are curved, formed by thrust folds with participation of the dislocated Upper Cretaceous chalk and marl, Paleogene glauconite-quartz sand, Neogene clay and quartz sand, Quaternary till and glaciofluvial deposits. There are at least 20 folds in a cross-section of the Peski glaciodislocation. On top of some folds there are large quarries, from which chalk is exploited for production of cement (Fig. 3). Folds of the Peski dislocation are thrust over one another at angle 40–45° (Figs. 4, 5; Pl. I, Fig. 1). The glaciodislocated strata are from 40 to 200 m thick. Locally incised to the crystalline basement rocks, deep glacial depressions have developed as result of glaciotectonic pressure inside the Peski glaciotectonic arc.

The large chalky, mainly buried glaciodislocations play an important role in structures of Grodno, Volkovysk, and Novogrudok plateaux in western Belarus. Push moraines, composed mainly of glaciodislocated tills and glaciofluvial deposits are more typical for the large uplands in central and eastern regions (Oshmiana, Minsk, Orsha and Vitebsk plateaux). The structures formed of the folded Quaternary rocks are, however, smaller in comparison with large folds of chalk (Pl. I, Fig. 2).

GLACIAL DEPRESSIONS

Glacial depressions are typical both in the Quaternary bedrock surface and in the recent landscape. Among the buried features there are closed depressions and extended hollows. Two main types represent the latter. The first type has rather rectilinear or meandering outline, sometimes traced for 100–300 km, deep to 150–200 m and to several kilometres wide. The deepest forms are in western and northern districts, their bottom to 168 m b.s.l. near Grodno and 122 m near Chashniki. They have been glacial eroded partly, because they are mainly the subglacial tunnel valleys, at present occasionally occupied by rivers (Berezina, Pripiat, Dnieper, *etc.*). Glacial depressions of the second type are not so long; they extend inside large folds or are gathered around the injective forms. They have numerous local hollows and dams. Such depressions are usually in paragenes is

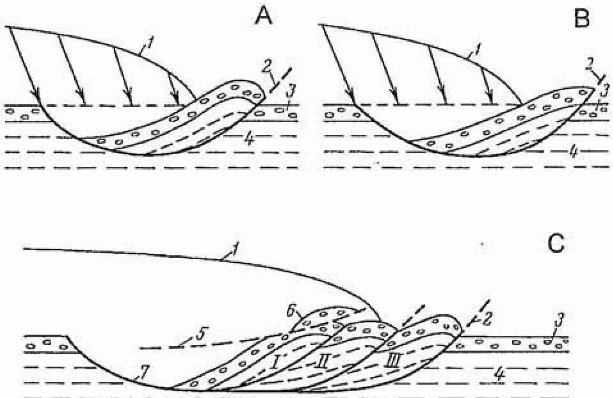

Fig. 2. Model of development of folded glaciodislocations and glacial rafts according to Levkov (1980)

A — anticlinal fold; **B** — monoclinal fold; **C** — folded glaciodislocation and glacial rafts; 1 — ice with indicators of ice loading, 2 — thrust surface, 3 — compliant layer, 4 — passively deformed layer, 5 — shift surface in ice, 6 — glacial raft, 7 — glacial depression, I–III — subsequent development of fold

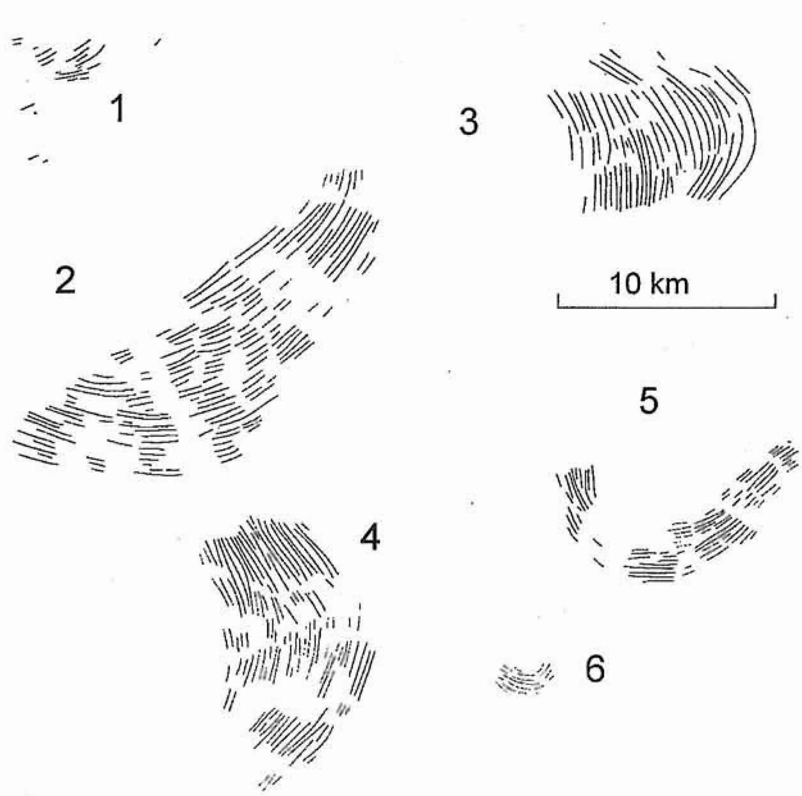

Fig. 3. Main folded glaciodislocations according to Levkov (1980), with some supplements

Each line corresponds to a single fold: 1 — Sopotskin, 2 — Peski, 3 — Nedvedz, 4 — Porozovo, 5 — Kremno, 6 — Okhovo

with large folded dislocations. In some cases, the excavated material from glacial depressions has been transported for a longer distance and deposited as glacial rafts outside the folded glaciodislocation belts. Such glacial depressions are often reflected in the present landscape.

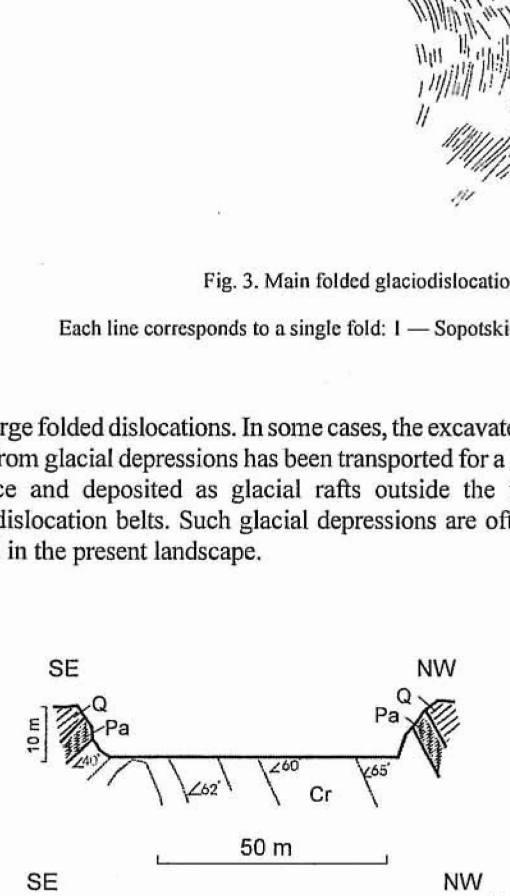

Fig. 5. Geological cross-section of the inclined anticlinal fold in the Upper Cretaceous chalk (Cr), Paleogene glauconite-quartz sand (Pa) and Quaternary deposits (Q) at Koliadichi, Peski glaciodislocation

Lens 4 (*cf.* Fig. 4): block 10 (top section) and 11 (bottom section)

GLACIAL RAFTS

The rafts (erratic megablocks) occur fairly often in Belarus. Their size varies considerably, but most often they are quite small. There are more than several hundred glacial rafts that are composed mainly of the Ordovician, Middle Devonian, Upper Cretaceous, Paleogene and Neogene rocks. The largest forms are up to 1–1.5 km long, but their thickness does not exceed

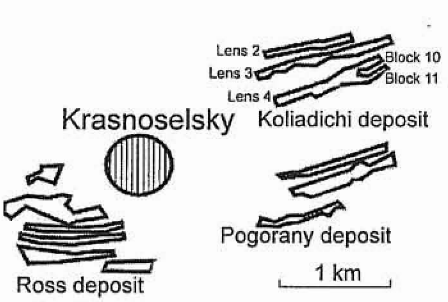

Fig. 4. Chalk quarries near Krasnoselsky, Volkowysk district (Peski glaciodislocation)

Each quarry usually corresponds with a single fold; the cement-plant geologists designate these folds as lens, but if two folds are exploited in the same quarry they are designated as blocks

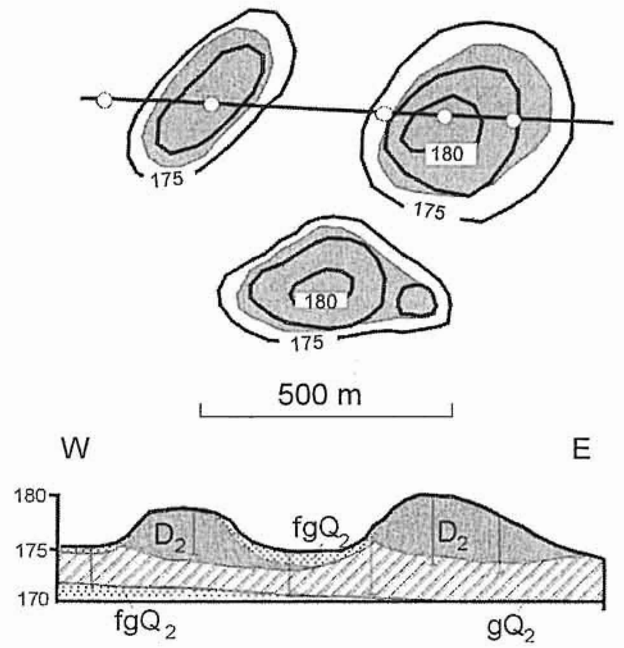

Fig. 6. Large glacial rafts of the Middle Devonian dolomites expressed in recent landscape near Gorna, Khotimsk district

D_2 — Devonian dolomites; Sozh Stage of the Dnieper Glaciation: gQ_2 — till, fgQ_2 — glaciofluvial sands, gravels and pebbles

20–25 m. Near Slavgorod and Khotimsk there are aggregations of large-scale erratic blocks (6–12 m thick) of the deformed Middle Devonian limestones, dolomites and occasionally clays. They are clearly expressed in landscape, forming hills about 60–500 m long and 7–11 m high (Fig. 6). Occurrence of large erratic blocks is predominantly connected with tills. Hard rocks are broken commonly and plastic deposits are folded. The rafts are located more often in the area with quite thick and soft covering deposits (chalk, clay, and clayey sand), especially adjacent to the large folded glaciodislocations. In general, in Belarus there are several hundreds of glacial rafts, more than 1 m thick.

INJECTIVE FEATURES

Injective features are represented by buried diapirs, diapiric hills and squeezed ridges. Plastic deposits (most often chalk, clay, and occasionally clayey sands) form the buried glaciodiapirs. The largest glaciodiapirs are composed of chalk and are up to 100–150 m high (Grodno, Novogrudok district). Many of them have steep slopes and distinct asymmetry. The diapirs and other injective forms are associated usually with compensating depressions, from which plastic deposits have been squeezed (Levkov, 1980 and Karabanov, 1987). In some cases, mainly in the marginal zone of the last glaciation, glaciodiapirs are expressed in the landscape by hills, 20–30 m high. Ridges with injective cores were formed mainly by squeezing up clayey deposits in long cracks between large dead-ice blocks. The main area of injective ridges in the Naroch-Vilija and Chashniki plains separated and dammed the lakes Ushachi and Sorochanka (Karabanov and Levkov, 1992). Dislocated tills, glaciofluvial and glaciolacustrine deposits form symmetric or slightly inclined anticlinal folds in a cross-section. The injective ridges have symmetric cross-sections and steep slopes (35–40°); they are 8–37 m high and up to 150–200 m wide. The lower ridges usually have convex tops, and the higher landforms are more flat. Ridge systems are from several hundred metres to 2–3 km wide and up to 18 km long. In plan the ridges form a grate with cells, 2–4 km large. Based on height of ridges, size and depth of lake basins, a thickness of dead-ice blocks could be estimated as 80–150 m.

REGIONAL REGULARITIES IN DISTRIBUTION OF GLACIOTECTONIC FEATURES

Glaciotectonic features are very widespread in Belarus. They have exerted remarkable influence on structure of the upper part of the sedimentary cover down to depths of 100–250 m. The largest glaciotectonic deformations occur in areas with thick chalk, clay or other compliant layers. Apart from thickness of plastic deposits, an important role is played by depth at which there are crystalline basement rocks or a hard sedimentary layer. The glaciotectonic stress became significantly stronger in the area of the hard rock highs at depth less than 500 m (Levkov, 1980). The best conditions for development of large folded glaciodislocations and glacial rafts are represented at the Belarussian Anteclise and Polesie Saddle in western Belarus, in the area of northeastern and eastern Belarus with the Devonian limestones and dolomites. Thickness of plastic deposits commonly rules a form of glaciotectonic features; in areas with very thick (more than 100 m) compliant layers there are mostly large diapirs. Mean thickness (50–100 m) is more favourable for folded glaciodislocations, and small thickness (less than 30–50 m) favours development of large rafts. There is connection between location of some folded glaciodislocations (Sopotskin, Kremno), injective ridge systems (Ushachi lake group) and faults in the crystalline basement that cut also the sedimentary cover.

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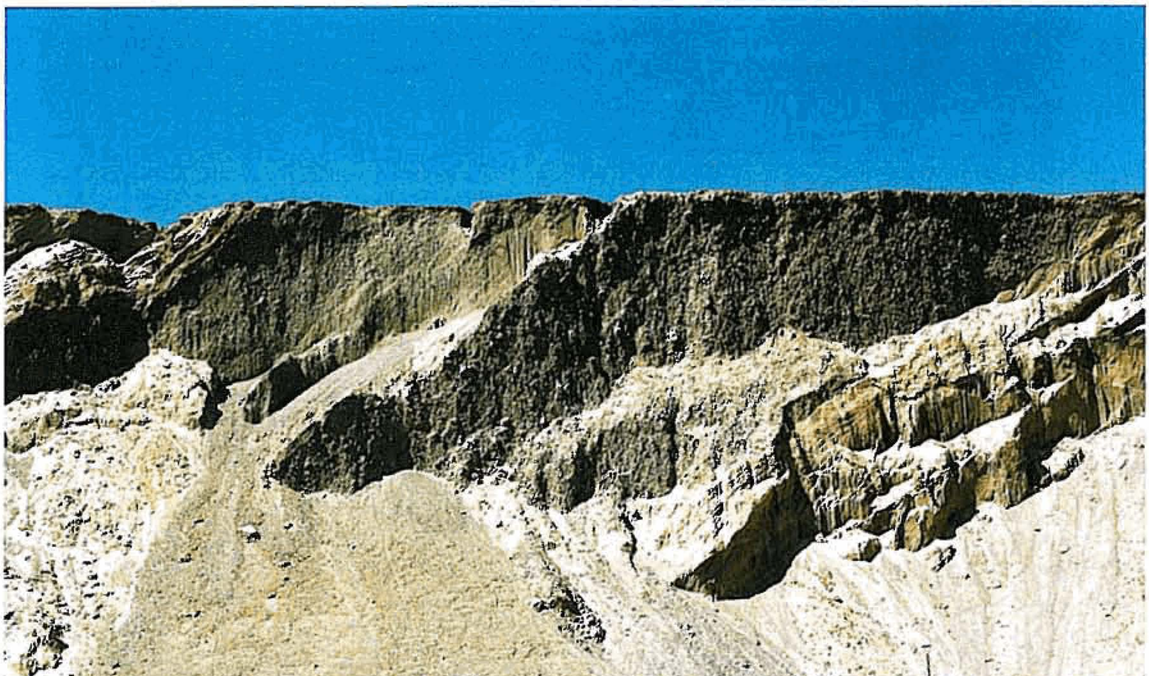
1. Thrust of the Upper Cretaceous chalk over the Paleogene glauconite-quartz sand. Koliadichi, lens 2 (*cf.* Fig. 4)



2. Folded sands and gravels in the end moraine at Yanushkovichi, northwards of Minsk