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Glaciotectonic features in Lithuania

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Systematic investigations of glaciotectonic features in Lithuania started in 1994. The first glaciotectonic review map of Lithuania has been carried out as a constituent part of the glaciotectonic map of central Europe. Two groups of landforms linked with glaciotectonic structures (composite ridges and massifs, drumlins and flutings) have been distinguished. Distribution of the pre-Quaternary megablocks in the Quaternary deposits is presented also, and the number of megablocks composed of rocks of different age and lithology is directly proportional to their extension in the sub-Quaternary surface. The other more detailed investigations of glaciotectonic features in Lithuania are connected with regular geological mapping in scale of 1:50,000. Results of the first detailed studies of glaciotectonic features (folds, thrust faults, diapirs) investigated in two outcrops in southeastern Lithuania and in the Lithuanian maritime region are presented in the paper.

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INTRODUCTION

In the wide spectrum of Quaternary investigations in Lithuania, there are glaciotectonic features that have not yet attracted due attention of researchers. As various glaciodislocations are widely distributed in the Quaternary deposits, researchers have noticed them. Unfortunately almost all previous scientific publications dealt mainly with visual descriptions of glacial dislocations, which sometimes were only mentioned (or given in pictures or photos) as an evidence of the activity of ice sheets. There were only several more detailed scientific publications on glacial dislocations in Lithuania (Petakov and Griškevič, 1984; Gaigalas *et al.*, 1985). Moreover, manifestations of glaciotectonic features were analysed only in one aspect i.e. studying pre-Quaternary megablocks. However, even in the latter case the approach was purely pragmatic as to a source of raw material. So, the main attention was paid to the megablocks of the Cretaceous carbonate rocks and glauconitic sands, although one could find more information about them in popular literature than in scientific publications (Linčius,1972; Paškevičius and Baltrūnas, 1979; Baltrūnas and Šliaupa, 1980).

Traditionally most intensive research on glaciotectonics of the Baltic region was carried on in Belarus, Poland, Latvia and Denmark. S. A. S. Pedersen and P. R. Jakobsen, Danish experts in glaciotectonics, organized in September 1994 a field seminar on glaciotectonic studies based on a bilateral cooperation program between Danish and Lithuanian Geological Surveys (Pedersen, 1994). This was a strong incentive to pay more attention to investigations of glaciotectonic phenomena in Lithuania, especially during geological mapping. Stipulation to a new approach arose from the bachelor's thesis on glaciotectonics of one author (P. Aleksa) and participation of the other (A. Bitinas) in the international project to prepare the European glaciotectonic data base (later this project was transformed into the Central European Glaciotectonic Map Project). The first results of special glaciotectonic investigations in Lithuania are presented in this paper.

GLACIOTECTONIC MAP OF LITHUANIA

The first digital glaciotectonic review map of Lithuania has been compiled (Fig. 1) according to a slightly adjusted legend unified for the central European glaciotectonic map. The legend is rather simple; it is approved taking into account different levels of glaciotectonic awareness in different countries. In Lithuania, where detailed glaciotectonic data are lacking, only two groups of relief forms linked with glaciotectonic structures have been distinguished, i.e. the first including composite ridges and

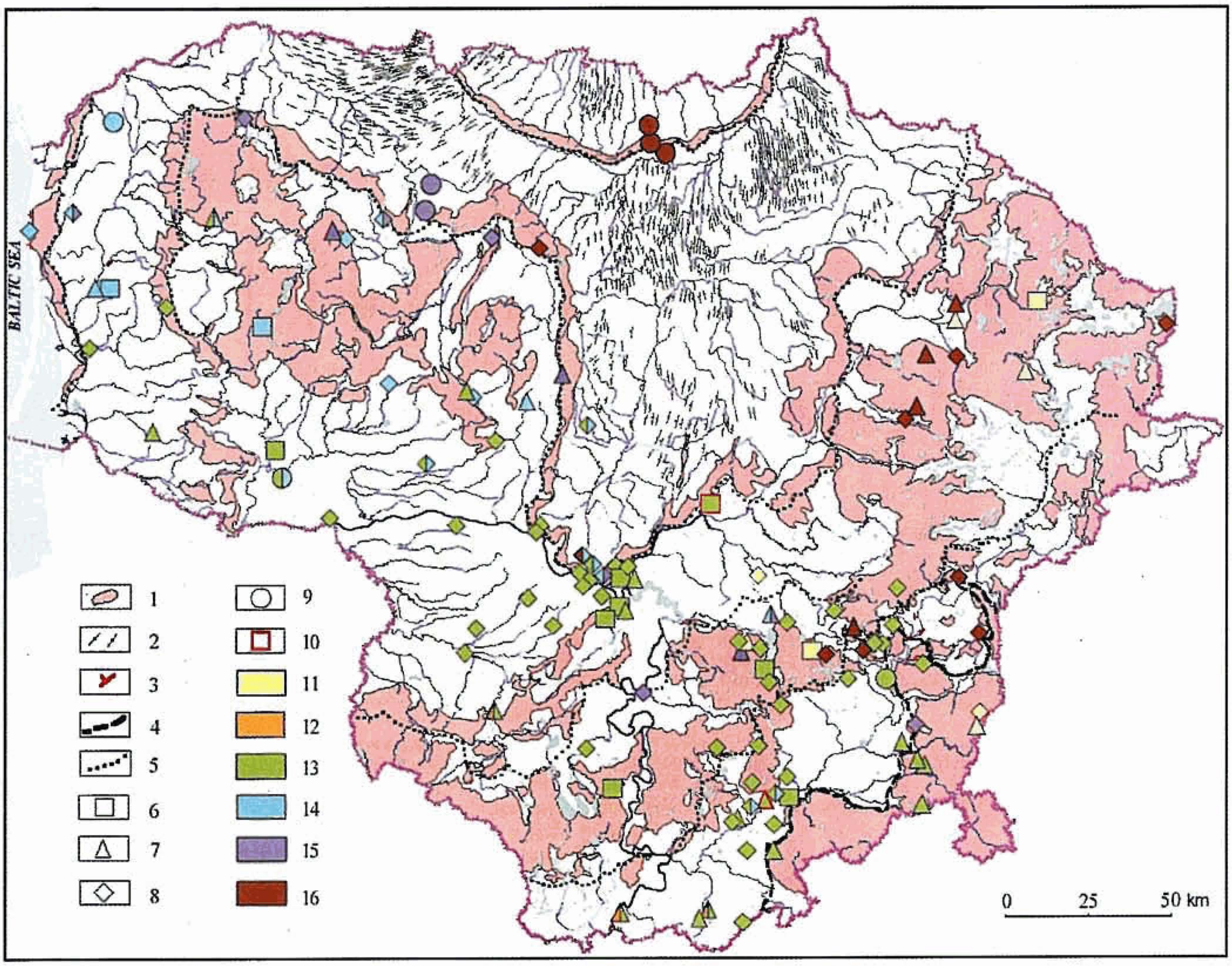

Fig. 1. Glaciotectonic review map of Lithuania, compiled on the basis of the *Quaternary Geological Map of Lithuania* (Guobytė, 1998) and the *Geomorphological Map of the Soviet Baltic Republics* (Straume, 1980)

1 — composite ridges and massifs (in scale) on deformed Quaternary substratum, 2 — drumlins and flutings, 3 — buried glaciotectonized Quaternary deposits in exposures, 4 — ice sheet limit of the last glaciation (Upper Nemunas, Late Weichselian), 5 — oscillation ice sheet limit; **megablocks of pre-Quaternary sediments within**: 6 — Upper Nemunas Formation (Late Weichselian), 7 — Žemaitija and Medininkai formations (Saalian and Warthian), 8 — Dzūkija and Dainava formations (Elsterian), 9 — poorly dislocated, directly on pre-Quaternary deposits, 10 — megablock in exposure; **age of megablocks**: 11 — Neogene, 12 — Paleogene, 13 — Cretaceous, 14 — Jurassic, 15 — Triassic, 16 — Devonian

massifs, and the second with drumlins and flutings. In addition, pre-Quaternary megablocks in the Quaternary deposits are most important mapping elements. As it is difficult to identify reliably the older Quaternary megablocks pulled into the younger Quaternary formations, their portrayal was abandoned. On the contrary, regularities in distribution of the pre-Quaternary megablocks, in our opinion, are worthy to be commented in more detail. The map presents the megablocks, at least 1.5–2 m thick, distinguished according to the borehole data. In order to select them, all the descriptions of drillings have been reviewed. These drillings were done for mapping, as well as hydrogeology, structural geology and other purposes; they are highly reliable (with exact drilling site, correct interpretation of lithology and stratigraphy of a section, *etc*.). For this purpose, manuscripts stored in the Geological Fund of the Lithuanian Geological Survey and data from the Borehole Cadastre Subsystem (within State Geological Information System) were used.

Some regular distribution of the pre-Quaternary megablocks is seen in the map. Distribution of megablocks composed of rocks of different age and lithology (except for the Devonian) is directly proportional to the extension of these rocks in the sub-Quaternary surface, i.e. Cretaceous megablocks prevail. The blocks seem to be concentrated mainly in southern Lithuania where palaeoincisions are the most common in the sub-Quaternary relief (Šliaupa *et al*., 1995). In northern Lithuania, the Devonian rocks outcrop in a flat sub-Quaternary relief; these rocks are harder and more resistant to glacial erosion than the Cretaceous formations. Therefore the Devonian megablocks are significantly more rare. It seems that the sub-Quaternary relief and physico-mechanical properties of the pre-Quaternary rocks are the main factors that determine formation of megablocks. The combination of the uneven sub-Quaternary relief and the soft pre-Quaternary rocks provides best conditions for derivation of megablocks. Moreover,

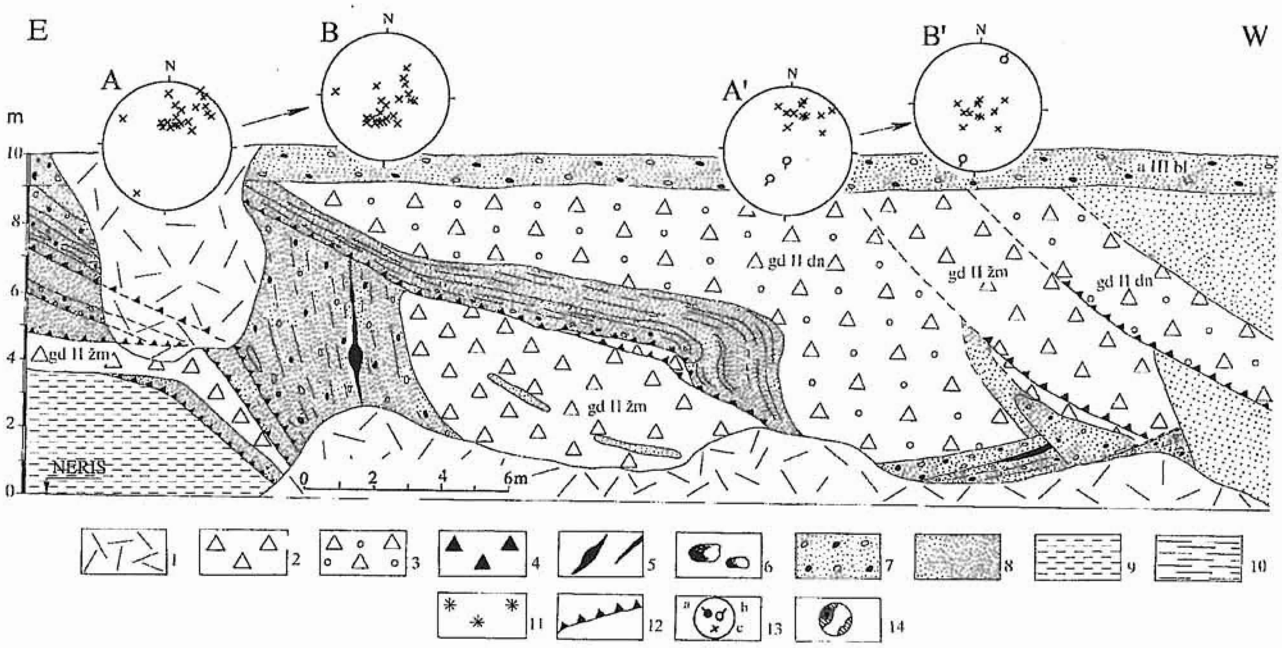

Fig. 2. Glaciodislocations in the outcrop on the left bank of the Neris River close to the mouth of the Veršupis Creek (northern part of Vilnius); diagrams A and B are for left flank, and A' and B' for right flank of the exposure

1 — deluvium, 2 — brown till, 3 — brown-grey or grey-brown till, 4 — grey till, 5 — interbeds of reddish-brown till, 6 — boulders, 7 — gravel, 8 — sand, 9 — silt, 10 — clay, 11 — limonitization, 12 — thrust plane, 13 — the lower hemisphere stereographic projections of glaciotectonic structures (fold axis: a — measured, b — calculated, c — pole to bedding), 14 — fabric; **genesis and stratigraphy**: gd II dn — imbricated till of Dainava Formation (Elsterian), gd II žm — imbricated till of Žemaitija Formation (Saalian), g II md — basal till of Medininkai Formation (Warthian), gd III gr — imbricated till of Grūda Subformation (Late Weichselian), a III bl — alluvium of Baltija Subformation (Late Weichselian)

according to the stratigraphic position of pre-Quaternary megablocks in the Quaternary deposits, these megablocks were observed mainly in complexes of the Dzūkija–Dainava (Elsterian) and occasionally only in the Žemaitija–Medininkai (Saalian–Warthian) glaciations. Such blocks are very rare in deposits of the last glaciation (Upper Nemunas, Late Weichselian). Thickness and dynamics of the ice sheet may affect formation of megablocks too: the older ice sheets were thicker in Lithuania. Moreover, ice sheets of the former glaciations have eroded directly the pre-Quaternary rocks instead of the Quaternary deposits of different origin, as was the case during the last glaciation.

GLACIAL DISLOCATIONS IN OUTCROPS

During various geological investigations carried out in the last years (firstly performing geological large-scale mapping of the Quaternary deposits in western Lithuania), glaciotectonic structures have been studied in outcrops, cliffs, pits, trenches, *etc.* basing on the results, two examples are presented, including reconstruction of palaeogeographic setting and ice sheet dynamics.

NERIS RIVER SITE

In the outcrop in the northern part of Vilnius on the left bank of the Neris River, close to a mouth of the Veršupis Creek, there are intensively deformed Pleistocene glacigenic (till), fluvioglacial (gravel, vari-grained sands) and limnoglacial (silt) sediments (Fig. 2). Basing on petrographic analysis of gravels in tills, the deformed glacigenic deposits are attributed to the Dainava (Elsterian) and Žemaitija (Saalian) formations. The upper part of glaciodislocated deposits is eroded and covered with alluvium of the Neris River.

The basic type of deformation in the outcrop consists of thrust faults, which form the imbricated structure of beds. The outcrop contains six imbricated thrust fault planes of similar orientation. Moreover, sliding took place not only along these planes, but also along an interlayer of the reddish-brown till in the left flank of the outcrop. The till, with clear signs of boudinage, separates sands and gravels of uniform thickness. At the same left flank of the outcrop, where faults are formed between sand formations, fine sand microblocks in coarser deposits have been detected. They indicate that during deformation the pressure has exceeded a level of plasticity, and the brecciated fine-grained sand seems to have been frozen.

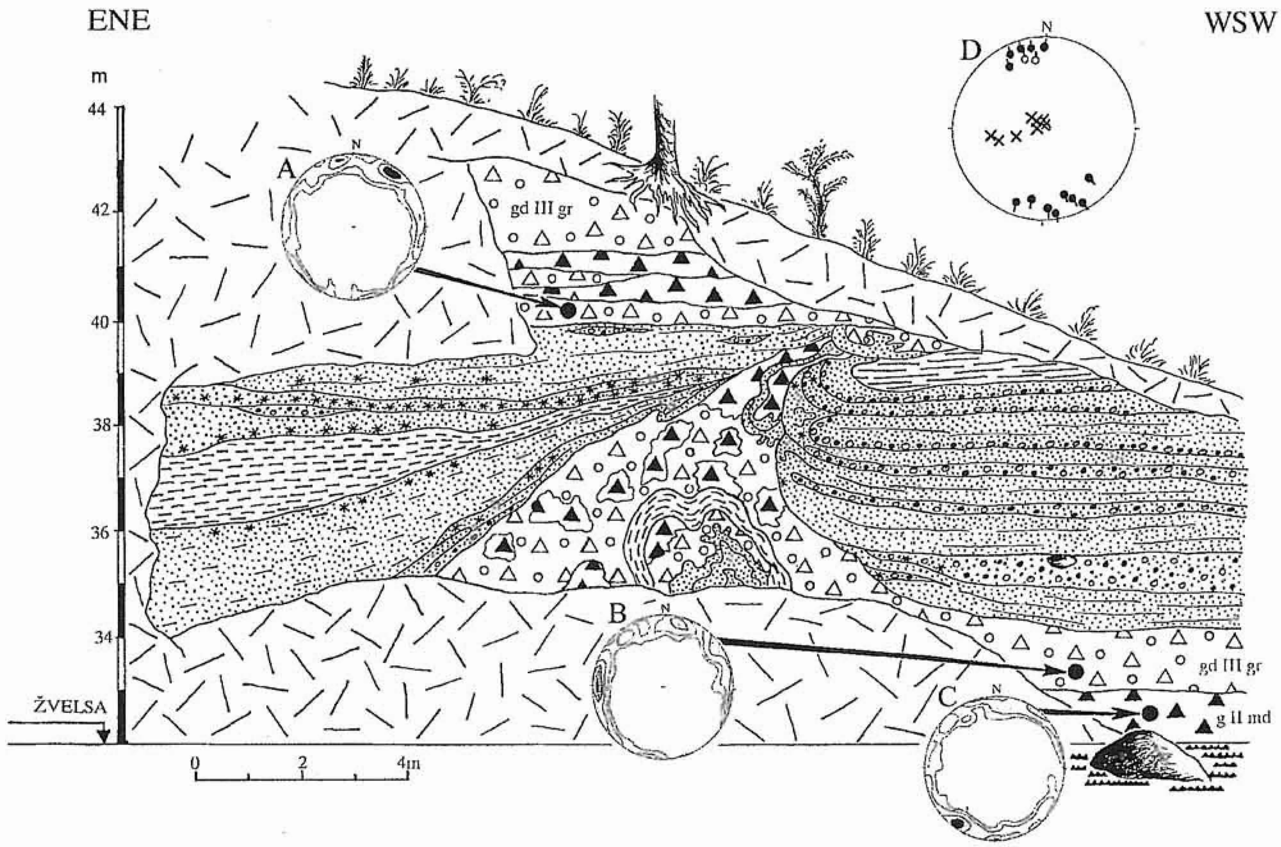

Fig. 3. Glaciodislocations in the outcrop on the left side of the Žvelsa Creek close to Lapiai in the Klaipėda District, western Lithuania

Black circles and arrows indicate fabric measurements (diagrams A–C) and orientation of glaciotectonic structures is presented in the diagram D; other explanations as in Fig. 2

In order to reveal the types of deformations and to determine direction of deforming forces, orientations of thrust faults and of two folds were measured. The imbricated structure of beds suggests a stress from SSW (Fig. 2, diagrams A and A') but this seems doubtful, since no ice sheet could move from this direction in the studied area. Moreover, axes of folds in the central part of the outcrop are of NNE–SSW orientation, thus indicating a perpendicular deforming pressure. Such discrepancy leads to a supposition that two or even more factors created the non-simultaneous deformations. Taking into account the thrust faults and folds, an assumption has been made that these two glaciotectonic forms are syngenetic. During their formation, axes of folds are usually more or less subhorizontal. Therefore, thrust fault and fold occurrence elements were rotated in stereographic projections in such a manner that position of the fold axes was as close as possible to a horizontal one (Fig. 2, diagrams B and B'). The rotation 60° (i.e. average plunge of fold axis) was done around the axis perpendicular to azimuth of the fold axes (the average azimuth of the latter equal to 195°). After rotation, strikes of the thrust fault planes changed almost by 90° and their orientation became NE–SW or even E–W. Dips of thrust planes decreased from 30–90 to 0–45°, hence, they correspond better to a theoretical model of such deformations (Park, 1989).

Summing up, glacial deformations seem to have been initiated by the Medininkai (Warthian) ice sheet which was moving mainly from NW and dislocated the older glacial sediments. Strikes of thrust faults are more or less perpendicular to direction of ice sheet movement. Later, maybe during the last Upper Nemunas Glaciation (Late Weichselian), this entire thrust fault complex was once more folded into a large anticline; however, the deforming force came from NNE or NE. The outcrop at the Neris River is located at southern flank of an anticline, therefore the present dip of thrust planes is orientated toward the SSW. Unfortunately more detailed palaeogeographic reconstructions are difficult, because the upper part of the glaciodislocated beds was removed during development of the present Neris River valley.

ŽVELSA CREEK SITE

A typical injection diapir can be seen in the outcrop at the Žvelsa Creek, left tributary of the Minija River, close to Lapiai in the Klaipėda District, western Lithuania (Fig. 3). This glacial deformation is formed of mixed variegated till blocks (lithologically diamicton), with a core of silt and sand. The diapir is inserted in beds of waterlain sediments. Both the diapir and the surrounding deposits are attributed to the Upper Nemunas (Late Weichselian) Grūda Subformation. It is interesting to note that in the outcrop the diapir separates two lithologically different complexes: sand and gravel covered with a thin clay layer in the right flank of the outcrop, and fine-grained sand and silt in the left flank. The left-flank beds are dipping toward the ENE (see diagram), whereas the right-flank waterlain deposits are pushed into a recumbent fold. The axes of two largest folds and of the microfolds are perpendicular in NNW–SSE direction, with a slight inclination towards both sides.

Such geological structure could be interpreted as a kind of fault (most probably overthrust) formed prior to the diapir. By the way, according to references on glaciotectonics (Pedersen, 1987), the latter form is more typical for glacial dislocations. Since there are no disjunctive dislocations in the Žvelsa outcrop and vari-sized folds occur practically in all types of deposits, an alternate conclusion can be made that the Žvelsa glaciodiapir was formed during plastic deformation. Such deformations are possible at low internal friction only, lowered in this case due to high-pressure pore water. Such conditions seem to occur during a rise of a strong gravitation force, i.e. caused by the ice body. With decreasing load (melting of ice sheet), the pore pressure fell firstly in deposits with a higher filtration capacity, i.e. in sands. So, a pressure gradient between sandy and clayey deposits appeared. In the fault zone, the difference in internal pore pressure exceeded the sand elasticity limits, and in result of balance reconstruction an injective diapir was formed.

Measurements of structural glaciodislocation elements allowed reconstruction of palaeogeographical conditions during formation of the glaciodiapir. Judging from fabric in the brown till unaffected by diapirism in the right flank of the outcrop, the till was deposited by the ice sheet that advanced from the west. It seems to have been an early ice sheet advance during the last glaciation (Upper Nemunas, Late Weichselian). Waterlain sediments during ice sheet melting covered a till. The next ice sheet advance from the north-west formed firstly the above-mentioned overthrusts, and then the upper part of this feature was glacial-eroded. As the glacier started melting, environmental conditions favoured formation of a glaciodiapir. Ice sheet melting deposited a brown till with imbrication above the glaciodiapir; this till contains a lot of interlayers (blocks) of older grey till, probably of the Medininkai Glaciation (Warthian).

CONCLUSIONS

The first glaciotectonic review map of Lithuania reflects distribution of glaciotectonic features: composite ridges, drumlins, flutings and megablocks. A variety of glaciotectonic phenomena cannot be presented due to the preliminary stage of investigations. So, it is necessary in the future to continue research of glaciotectonic features, especially during large-scale geological mapping of the Quaternary deposits. New data on glaciotectonic phenomena help reconstruction of former directions of ice sheet movement, reveal peculiarities of development of the present or ancient landscape and palaeogeographic conditions, and in some cases enable also stratigraphic correlations.

A potential trend in glaciotectonic studies in Lithuania could arise from detailed lithological and palaeofaunistic studies of the pre-Quaternary megablocks, in order to reveal their occurrence *in situ*. They would provide very important information on directions and distance of megablock transport, processes of glaciodislocation formation, ice sheet thickness and palaeogeographic conditions.

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