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Glaciotectonic deformations of the Upper Cretaceous rocks: evidence from the chalk quarry in Chełm (Lublin region, Eastern Poland)

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Soft, horizontally bedded Upper Cretaceous (= Upper Maastrichtian) rocks occurring in the Lublin region are strongly deformed. Most structures (mesofaults, joints, and cleavage) are brittle tectonic deformations connected with the Late Laramian and Young Alpine phases of tectonic activity. However, some of the deformations are also indicative of the glaciodynamic influence of Pleistocene ice sheets on the carbonate bedrock, including translocation of primary tectonic structures. The pattern of glaciotectonic deformation structures indicates both termino- and subglacial deformation environments connected with the transfluence of ice masses over preglacial elevations of the chalk substratum.

Key words: glaciotectonic structures, chalk, Upper Cretaceous, Lublin region, Eastern Poland

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INTRODUCTION

Glaciotectonic deformations (termino- and subglacial) of solid bedrock are quite often found in areas glaciated in the Pleistocene and in our times (e. g., Ruszczyńska-Szenajch, 1985; Aber et al., 1989; Alexandrowicz, Radwan, 1992; Benn, Evans, 1996; Aleksa, Bitinas, 2000; Karabanov, 2000; Philips et al., 2002,2008; Rattas, Kalm, 2004; Van der Wateren, 2005; Benn, Prave, 2006; Aber, Ber, 2007). Most of these structures have an internally complicated architecture and involve both bedrock and unconsolidated glacigenic sediments. However, they are usually only partially accessible to examination in exposures. Most often they are identified by a dense net of borings or geophysical techniques. So, the interpretation of deformation mechanisms in the majority of such cases is based on indirect evidences. Glaciodynamic deformations of solid bedrocks observed on a macroscale – in large quarry exposures – give a rare opportunity to analyse in detail the genetic relations between individual deformation structures (Dobrowolski, Terpiłowski, 2006).

In this paper, we there is described a structural record of the glaciodynamic influence of ice masses on the Upper Cretaceous carbonate rocks exposed in a chalk quarry in Chełm (Lublin region, Eastern Poland). The morphologic position of the site (= central part of a preglacial chalk hill, in the zone of the northern edge of the Lublin Upland), as well as a considerable lateral and vertical extent of the exposure enable to reconstruct the conditions of the deformation environment. Indirectly, it is also possible to estimate the influence of the diversified morphology of the advancing ice-sheet foreland on the course of glaciotectonic processes.

LOCATION OF STUDY SITE AND ITS GEOLOGICAL CONTEXT

The research site is a large chalk quarry in Chełm (51°07’45”N, 23°34’05”E), about 2 km^2 in area, situated within a large, sub-latitudinal, island chalk hill (223 m a. s. l.). The Upper Maastrichtian chalk forming the hill core is bedded (subhorizontal sedimentation surfaces with a low-angle dip to E). Exploitation is carried out on five exploitation levels (each about 10 m high), and the top part of the rock complex is exposed to a depth of 50 m (Fig. 1 A–C).

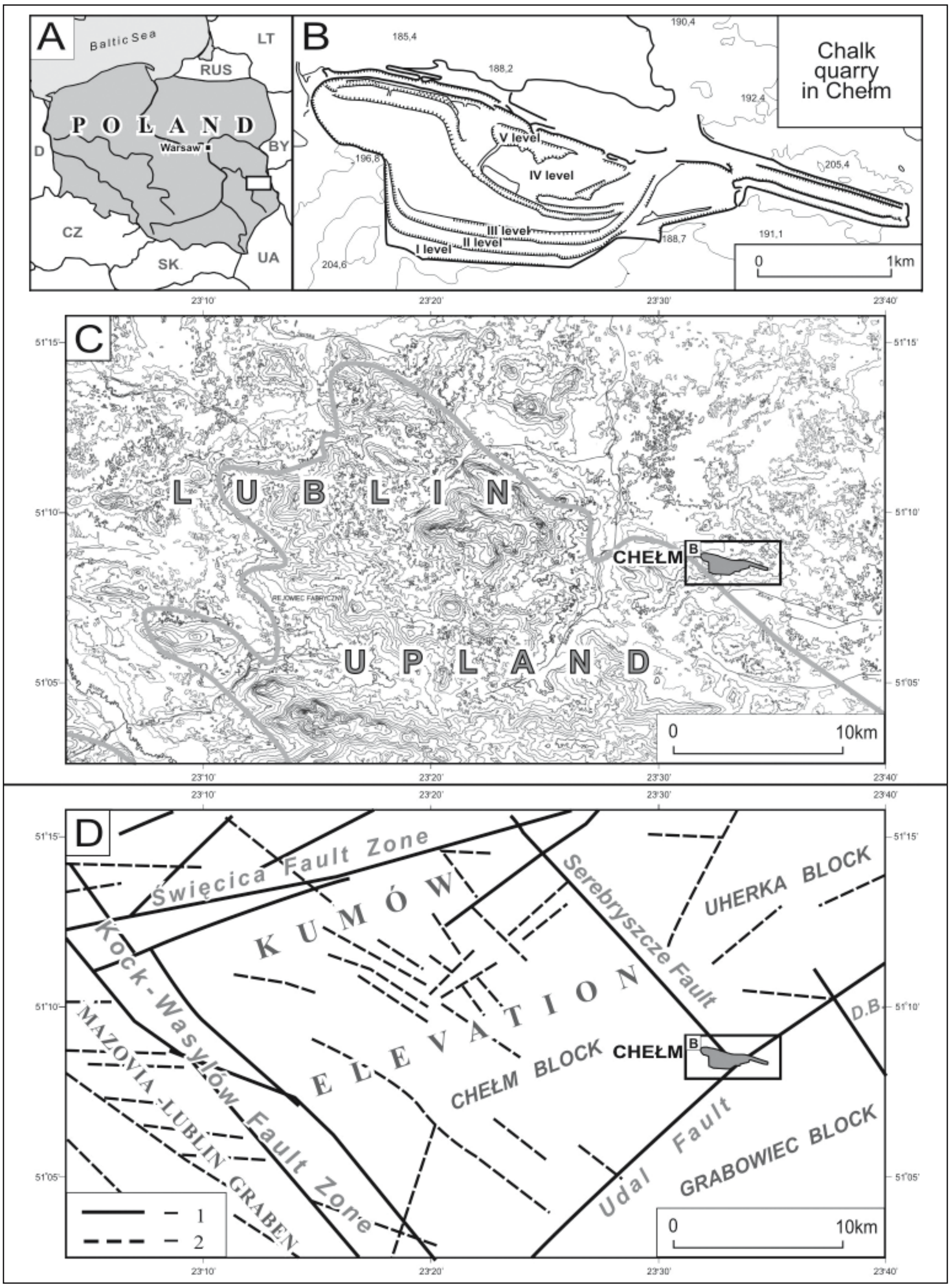

Fig. 1. General location of the Chełm chalk quarry (*A*). Situation of the quarry against the background of hypsometry with the maximum extent (marked by grey line) of the Saalian glaciation (*B–C*) and the tectonic sketch of Eastern Poland (*D*): *1* – main faults and fault zones of the Palaeozic complex (after Żelichowski, 1972); D. B. – Dubienka Block, *2* – main faults and fault zones of the Meso-Cainozoic complex (after Henkiel, 1984)

1 pav. Chelmo kreidos karjero vieta (*A*). Karjero situacija hipsometriniame fone su Saalio apledėjimo maksimalaus paplitimo riba (stora pilka linija) (*B–C*) ir Rytų Lenkijos tektonine struktūra (*D*): *1* – paleozojaus komplekso pagrindiniai lūžiai ir lūžių zonos (pagal Żelichowski, 1972); D. B. – Dubienkos blokas, *2* – mezokainozojaus komplekso pagrindiniai lūžiai ir lūžių zonos (pagal Henkiel, 1984)

In respect of tectonics, the site is situated in the central part of the Kumów elevation – a horst unit in the south-western margin of the East-European craton (Żelichowski, 1972) – in the direct cover of the Variscian crossing faults: Serebryszcze (NW–SE) and Udal (NE–SW). These faults divide the Kumów elevation into separate blocks of different uplift degree: in the NW part – the Chełm block, in the NE part – the Uherka block, in the SE part – the Dubienka block, and in the SW part – the Grabowiec block (Fig. 1 D).

The Upper Cretaceous sedimentary complex of the total thickness of about 700 m is strongly tectonically fissured. The main types of deformation structures identified in the site include: (1) two systems of orthogonal joints: (a) N–S / W–E (older), (b) NE–SW / NW–SE (younger) with accompanying mesoscopic fractures: concentric, feather, tectonic ribs, (2) drape folds (with eastern vergence), (3) domino-type structures, (4) mesofaults: (a) normal-dip-slip N–S and NE–SW, (b) sinistral NE–SW (Dobrowolski, 1995).

The top surface of the Upper Cretaceous deposits is strongly reduced and uneven mostly as a result of the Neogene and Quaternary morphogenetic processes. Glacigenic and karst processes were especially important (average thickness of the denuded chalk layer in the Lublin region is estimated at 22 mm · ka^{-1} – after Maruszczak, 2001). In the Pleistocene, the study area was glaciated at least two times – during the Elsterian and the Saalian glaciations (Mojski, 2005), and during the Saalian glaciation it was in the ice-sheet marginal zone (Fig. 1 C). Glaciotectonic structures of the northern edge of the Lublin Upland were connected with frontal activity of the Saalian ice masses and involved mostly unconsolidated glacial and preglacial deposits. They were described earlier, among others by Jahn (1956), Mojski (1968), Wyrwicka & Wyrwicki (1986), Gardziel & Harasimiuk (2005), and Dobrowolski & Terpiłowski (2006).

GLACIOTECTONIC STRUCTURES

Description

Upper exploitation levels. Some joints and mesofaults (mostly of NE–SW orientation), documented in two upper exploitation levels (= original top part of the chalk hill) show signs of small- and medium-scale deformation structures, i. e. horizontal translocations along interstratal surfaces (Fig. 2). Horizontal fissures, with the primary fine-grained infilling of karst (= karst clay cortice) or / and glacigenic origin, show also deposit shearing and slickensiding (Dobrowolski, 2006). Tectoglyphs (striae and obsequent steps), commonly occurring on slikensided surfaces, indicate the translocation of the packages of Upper Cretaceous rocks to the SE. The size of translocation is from several to several dozen centimetres.

Lower exploitation levels. Horizontal interstratal translocations are also documented in three lower exploitation levels. However, the nature and scale of deformation structures

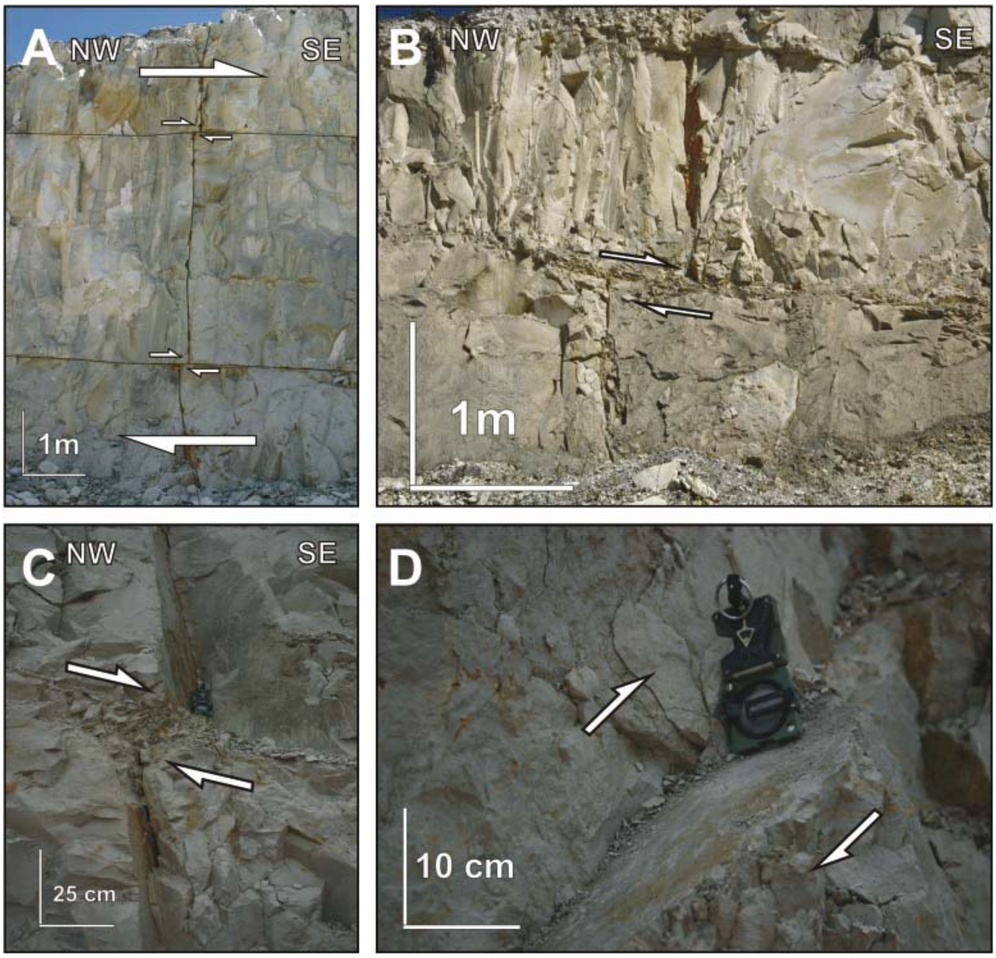

Fig. 2. Glaciotectonic deformations of Upper Cretaceous rocks in the upper exploitation levels of the Chełm quarry – sub-horizontal small-scale translocations of transverse joints along interstratal surfaces

2 pav. Viršutinės kreidos nuogulų glaciotektoninės deformacijos Chelmo karjero viršutiniuose eksploatacijos lygiuose – subhorizontalus nedidelis perstūmimas sluoksnių paviršiuje

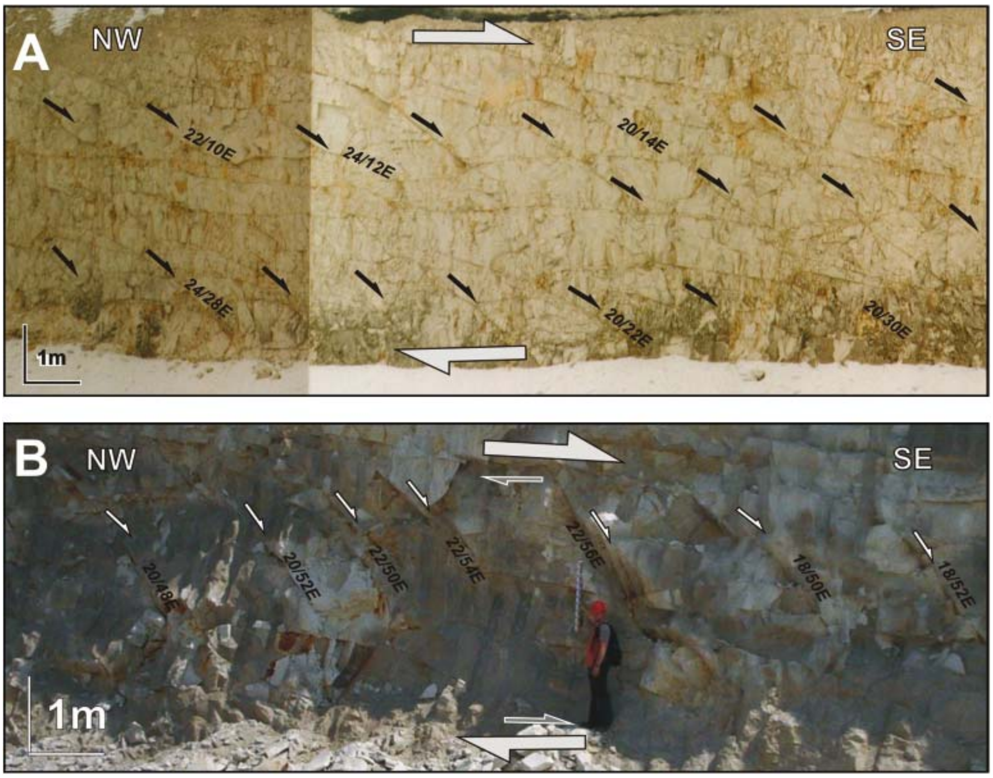

Fig. 3. Glaciotectonic deformations of Upper Cretaceous rocks in the lower exploitation levels of the Chełm quarry – normal-dip-slip faults in the domino-type structure
3 pav. Viršutinės kreidos nuogulų glaciotektoninės deformacijos Chelmo karjero žemesniuose eksploatacijos lygiuose – normalūs palinkę sprūdžiai „domino" tipo struktūroje

change considerably with the depth. The simple, small-scale translocations of layers without significant internal deformations, typical of two upper levels, in the lower levels are replaced by complicated deformation structures of domino-type, which consist of complexes of normal bedding-parallel faults with a convex profile and a strongly slickensided surface. They are usually limited to 2–3 layers (Fig. 3) and laterally disapper to SE (= on the distal slope of the hill). No domino-type structures were found in the lowest exploitation level (No V) at a depth of about 50 m.

Interpretation

The origin of the described deformation structures, both in the upper and lower exploitation levels, should be related to differentiated translocations of layers connected with the action of a couple of forces in the vertical plane. The pattern of tectoglyphs on slickensided fault surfaces indicates the translocation from NW to E and SE, which can be interpreted as a result of compression caused by advancing ice masses of the Saalian glaciation that covered the study area. The different translocations resulted in the replacement of friction forces by shearing stress. There were formed strongly rotated normal faults, with slickensided slip surfaces and inclination conformable to translocation direction.

MODEL OF DEVELOPMENT OF GLACIOTECTONIC STRUCTURES IN CHALK

The pattern of glacigenic deformation structures indicates a rather simple mechanism of their development during the progressive advance of the Saalian ice-sheet front (in the phase of its maximum extent) on the proximally inclined surface of the chalk hill. Two main stages can be distinguished in relation to different rheologic conditions of ice masses and, as a consequence, to different deformation environments: terminoglacial and subglacial (Fig. 4).

The first stage – *terminoglacial deformation environment.* The advance of the ice-sheet front towards the proximal slope of the chalk hill forces a slower movement of ice masses with a simultaneous increase of horizontal compression oriented to the SE. The exceeded critical stress values result in a simple shearing along the interstratal surfaces. At first, especially in higher hypsometric positions of the hill (= upper exploitation levels), there occur simple, low-scale translocations of joint and fault fissures (genetically connected with the Late Laramian and Young Alpine phases of tectonic activity), and slickensiding of residual clay (karst origin) filling horizontal fissures.

The second stage – *subglacial deformation environment.* The progressive advance of the ice sheet and the associated

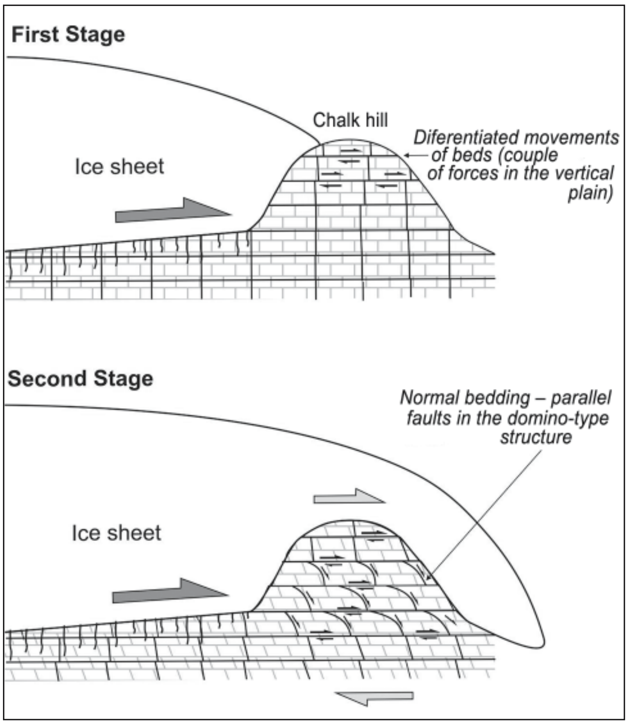

Fig. 4. Model of the development of glaciotectonic structures in the Upper Cretaceous rocks in Chełm. See a detailed description in the text
4 pav. Glaciotektoninės struktūros formavimosi modelis Chelmo karjero viršutinės kreidos uolienose. Išsamų apibūdinimą žr. tekste

relative growth of ice masses in ice marginal zone result in an increase of horizontal compression and then in the transfluence of ice masses over the chalk hill. With the progress of movement, the simple compression turns into a couple of forces in vertical plane, resulting in differentiated translocations of layers with a tendency to internal rotation of chalk packages. Differentiated translocations cause an obsequent inclination of transverse joints and the development of en-echelon row of normal bedding-parallel faults (often with a listric profile) forming structures of domino-type in deeper parts of the chalk hill (= lower exploitation levels).

CONCLUDING REMARKS

Interpretation of glaciotectonic deformation structures formed in a solid bedrock as a consequence of the dynamic effect of ice masses is difficult, mostly because the record of glaciotectonic influence is superimposed on older deformation structures from the phases of strictly tectonic activity. Therefore, glaciotectonic structures are often interpreted as a result of neotectonic activity in a particular area. The structures of domino-type in the chalk quarry in Chełm were similarly described. Formerly they had been treated as a result of reorientation of local stress fields, caused by the transformation of a simple horizontal NE–SW compression into a couple of forces in vertical NW–SE plane during the Late Laramian tectonic movements (Dobrowolski, 1995). New facts, both mesostructural (complete record of deformation structures in the whole profile accessible to examination, their geometric features and spatial relation to other tectonic structures) and palaeomorphological (translocations of relatively young mesofaults and joints), force to revise this opinion and to relate the origin of these structures to the compression caused by ice masses advancing from NW to SE. The translocation of carbonate bedrock packages (= shearing along interstratal surface) was favoured by fissuring of the rock massif. The lubrication layer consisted of residual clay (= karst cortice) or / and fine-grained glacigenic deposit subglacially "injected" in interstratal horizontal fissures (*vide* Ford, 1987; Ford, Williams, 1989; Boulton et al., 1996; Piotrowski et al., 1999; Dobrowolski 2006). Taking into account these structure-forming factors and the low compression strength (only 4–6 MPa) of chalk (Rybicki, Rybicki, 1973; Łozińska-Stępień, 1988; Liszkowski, 1993), it can be assumed that the deformation of such a type could develop even under a relatively low pressure exerted by the ice-sheet front.

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VIRŠUTINĖS KREIDOS UOLIENŲ GLACIOTEKTONINĖS DEFORMACIJOS: CHEŁMO KREIDOS KARJERO (LIUBLINO REGIONAS, RYTŲ LENKIJA) PAVYZDŽIAI

Santrauka

Liublino srityje (Rytų Lenkija) horizontaliai slūgsančios viršutinės kreidos viršutinio Mastrichčio uolienos yra palyginti minkštos ir smarkiai deformuotos. Dauguma struktūrų (vidutinio dydžio sprūdžiai, raukšlės, klivažas) yra tektoninio deformavimo rezultatas ir siejamos su vėlyvąja laramininės ir ankstyvąja alpinės tektoninės veiklos fazėmis. Dalis struktūrų buvo siejamos su neotektoniniais judėjimais, tačiau nuodugnus deformacijų tyrimas atskleidžia reikšmingą pleistoceno apledėjimo glaciodinaminį poveikį karbonatiniam pagrindui ir pirminių tektoninių struktūrų pokyčiams. Glaciotektoninių deformacijų struktūra rodo ledyno pakraščio ir poledyninę pagrindo uolienų deformavimo aplinką, susidarančią ledo masėms slenkant per karbonatinių uolienų pakilumas. Glaciodinaminių struktūrų kilmė Chelmo kreidos karjere yra siejama su ledo masių spaudimu slenkant Saalio amžiaus ledynui iš šiaurės vakarų į pietryčius.

Радослав Добровольски

ГЛЯЦИОТЕКТОНИЧЕСКИЕ ДЕФОРМАЦИИ СКАЛ ВЕРХНЕГО МЕЛА: ПРИМЕРЫ ИЗ КАРЬЕРА В ХЕЛМЕ (ЛЮБЛИНСКИЙ РЕГИОН, ВОСТОЧНАЯ ПОЛЬША)

Резюме

Мягкие горизонтально напластованные скалы верхнего мела (верхнего маастрихтского периода) Люблинского региона сильно деформированы. Большинство структур (мезоразломы, закономерные трещины и кливаж) – это тектонические деформации, связанные с позднохларамийским, а также младоальпийским периодами тектонической активности. Однако часть деформаций документирует также гляциодинамическое влияние плейстоценовых ледников на карбонатовую скальную базу, в том числе транслокацию первоначальных тектонических структур. Гляциотектоническая запись деформационных структур указывает как на термино-, так и на субгляциальную деформационные среды, связанные с трансфлюэнцией ледяных масс выше догляциальных горбов меловой базы.