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Clastic dikes in uppermost Tertiary sediments of the Kleszczów Graben and their significance to reconstruction of Quaternary diastrophism

Morphologic features, lithology, spatial arrangement and stratigraphical position of clastic dikes in sediments of the uppermost Tertiary in the Kleszczów Graben (Bełchatów brown coal open mine) are presented. Origin of dikes is related to development of broad anticlinal structures during the Quaternary, after deposition of the oldest glacial series of the South Polish Glaciation (Nidanian).

INTRODUCTION

The term "clastic dikes" can be differently understood as it is applied in two various meanings. In the narrow meaning, it is used to define sheet-like elongated, vertical or close-to-vertical injections of sediments, discordant against structure (e.g. bedding) of surrounding rocks (S. Dżułyński, A. Radomski, 1957; A. H. Bouma, 1962; F. J. Pettijohn, P. E. Potter, 1964).

However many a time (T. Hayashi, 1966; J. C. Dionne, W. W. Shilts, 1974), the same term has a more general meaning and deals with various sedimentary sheet-like or wedge-like bodies (sandy, silty, clayey and others) that fulfil the already mentioned criterion of discordance. In the present approach the term has no univocal genetic reference and is applied to various structures, both if mechanisms of open cracks or fissures, as well as their varying infillings are concerned.

Such a broad definition includes clastic dikes which have developed within tensile cracks, penetrating down to the depth to about 80 m in the vertical section of the uppermost Tertiary sediments in the Kleszczów Graben (Bełchatów brown coal open mine). Such

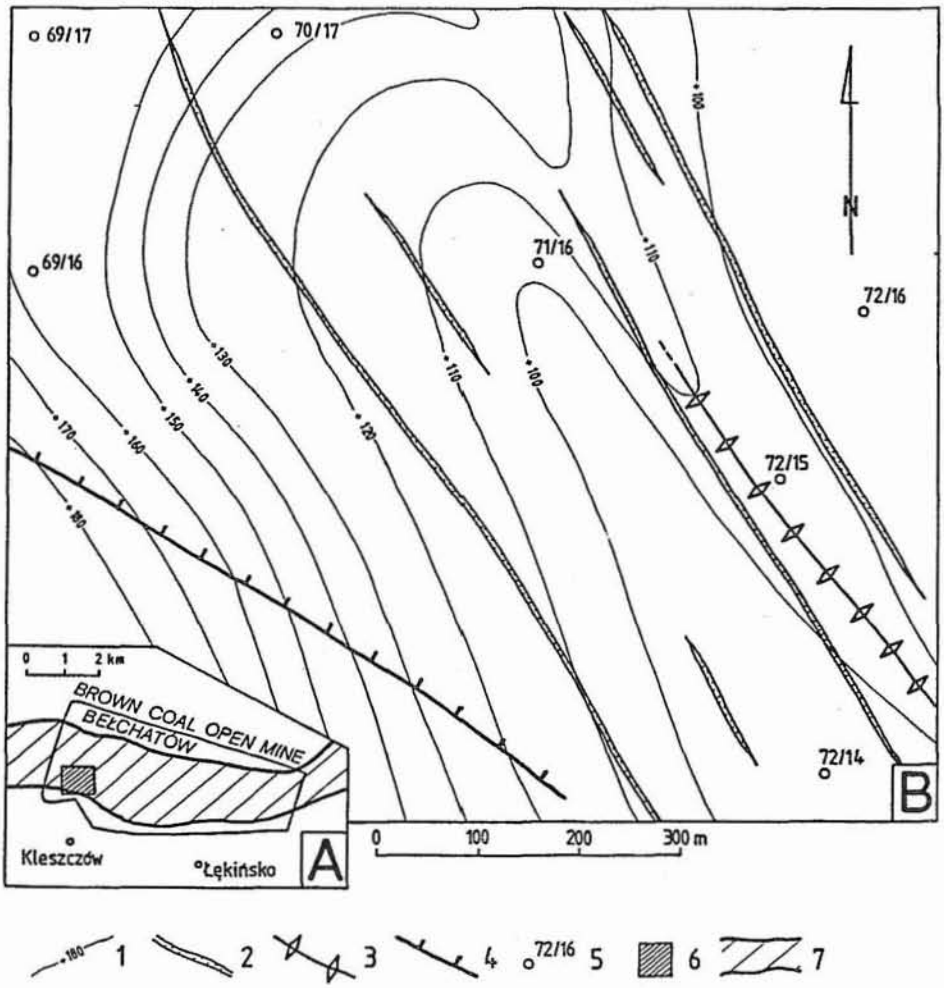

Fig. 1. Occurrence of clastic dikes in folded sediments of the Pliocene and the Middle Miocene: A — location of the studied area, B — occurrence of clastic dikes

1 — contour lines of the base of the Pliocene sediments in metres a.s.l.; 2 — tensile fissures with clastic dikes (generalized); 3 — anticline axis with coal-bearing sediments of the Middle Miocene; 4 — southern marginal fault of the graben in Mesozoic sediments; 5 — location of selected boreholes with borehole number; 6 — studied area; 7 — extent of the Bełchatów brown coal field

Rozprzestrzenienie dajek klastycznych na tle fałdów w utworach pliocenu i środkowego miocenu: A — lokalizacja obszaru badań, B — szkic rozprzestrzenienia dajek klastycznych

1 — izohipsy spągu utworów pliocenu w m n.p.m.; 2 — szczeliny tensyjne z rozwiniętymi wzdłuż nich dajkami klastycznymi (obraz zgeneralizowany); 3 — oś antykliny z węglonośnymi utworami środkowego miocenu; 4 — przebieg południowego uskoku rowu brzeżnego w utworach podłoża mezozoicznego; 5 — lokalizacja wybranych otworów wiertniczych złożowych z numerem otworu; 6 — obszar badań; 7 — zasięg złoża węgla brunatnego Bełchatów

structures have been many a time noted in various exploitation zones of the mine (R. Gotowała, 1982; K. Brodzikowski et al., 1987) but have been never of main interest for geologists who carried out studies in this area.

Systematic observations of escarpments of the gradually exploited and therefore displaced western slope have been undertaken by the author in recent years. The aim of this research is a description of the phenomenon, a discussion on genetic classification of the structures and on their relationships to the main tectonic elements of this area. At present, a preliminary presentation of these structures seems useful, completed with some suggestions as to their general geological implications.

LOCATION AND GENERAL GEOLOGICAL SETTING

Data presented in the paper were collected in 1990–1992 in a southwestern part of the Bełchatów brown coal open mine, near the village of Kleszczów (Fig. 1). This area constitutes a fragment of larger deformation zone that extends well outside the present borders of the pit and is being successively exposed westwards, following the exploitation. Against deep major dislocations in Mesozoic sediments that delimit general borders of the Kleszczów Graben, the described area is located inside — in a zone 500–700 m wide and continuing northwards from a southern marginal fault of the graben.

The occurrence of tensile fissures and accompanying clastic dikes is restricted to a certain interval of the lithostratigraphic profile. It comprises sediments of the uppermost Tertiary, recently dated at the Pliocene (D. Krzyszkowski, A. Szuchnik, *personal information, paper in preparation*), and of the lowermost Quaternary — corresponding to the South Polish Glaciation (Nidanian) and the Ferdynandów Interglacial. An exact determination the age of the Quaternary layers crosscut by fissures in their uppermost parts is still an open problem.

The location of fissures is schematically presented on a lithostratigraphical section (Fig. 2). More detailed data on lithofacial development and stratigraphy of Cainozoic sediments in the Kleszczów Graben are available, among others in papers of A. Hałuszczak (1987), L. Stuchlik et al. (1990) and D. Krzyszkowski (1990, 1992).

Most field data used in the paper were collected from the Pliocene sediments that outcrop at several successive escarpments between 100 and 175 m a.s.l., i.e. between 100 and 35 m below the ground surface.

The Pliocene complex is composed of fluvial and lacustrine sediments with mainly gravels, coarse- and medium-grained sands, sandy clays and clays, total thickness of which is about 60–70 m. A bottom of the sequence is defined by the occurrence of black, well-rounded, siliceous gravels resting with an angular unconformity on strongly eroded coal-bearing sediments of the Middle Miocene. This discordant surface forms an important correlative horizon in the widespread graben area. The described sediments have been also known as the so-called Clayey-sandy Unit. It forms the youngest lithostratigraphical unit of the Tertiary, according to the subdivisions used among others in geological documentations (*Kompleksowa dokumentacja geologiczna...*, 1983, 1989).

The Pliocene sediments are composed of interbedded extensive layers of sand (a few to several dozen metres thick) and of finer fractions (silty sands, sandy clays and clays,

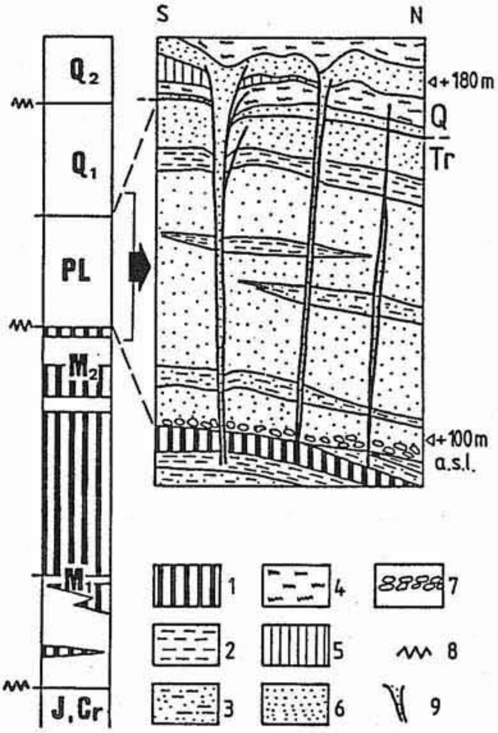

Fig. 2. Location of clastic dikes against schematic stratigraphical section of the Kleszczów Graben

J — Jurassic; Cr — Cretaceous; Tr — Tertiary: M_1 — Lower Miocene, M_2 — Middle Miocene, PL — Pliocene; Q — Quaternary: Q_1 — from the Nida to the Odra Glaciation (included), Q_2 — from the Pilica Interglacial to the Holocene; 1 — brown coal; 2 — clays; 3 — sandy clays; 4 — silts; 5 — tills; 6 — sands; 7 — black, siliceous gravels; 8 — main angular discordances; 9 — clastic dikes

Pozycja dajek klastycznych na tle schematycznego profilu stratygraficznego rowu Kleszczowa

J — jura; Cr — kreda; Tr — trzeciorzęd: M_1 — miocen dolny, M_2 — miocen środkowy, PL — pliocen; Q — czwartorzęd: Q_1 — od zlodowacenia nidy po zlodowacenie odry (włącznie), Q_2 — od interglacjału pilicy po holocen; 1 — węgiel brunatny; 2 — iły; 3 — iły piaszczyste; 4 — muły; 5 — gliny zwałowe; 6 — piaski; 7 — nagromadzenia otoczaków skał krzemionkowych; 8 — główne powierzchnie niezgodności kątowych; 9 — dajki klastyczne

to several metres thick). They are generally subhorizontal or form gentle large folds. Intensity of fold deformations is relatively high for the analysed fragment of the Cainozoic section, and increases westwards. Principal geometric features of the folds are presented with contour lines of deformations at the base of the Pliocene sediments (Fig. 1B). Main deformation elements are structures with northwest-southeast trending axes; from the east they are successively: anticline, syncline and monocline draped over the deep marginal fault of the graben.

In the eastern part of the area (more deeply cut by mining works), but also in the western part within hinge zone of folds, the older series are exposed, being represented by the Middle Miocene sediments (sands, silts, coaly clays, brown coal, lacustrine limestones). They are folded as well showing, however, many individual structural features.

GEOMETRIC DESCRIPTION OF OPEN FRACTURES

The observations indicate that clastic dikes form widespread vertical infillings of open cracks (tensile fissures). Thanks to observations at numerous successive positions of exploitation escarpments, a spatial pattern of these fissures was reconstructed with considerable accuracy (Fig. 1B). Fissures show parallel, northwest trending arrangement to one another, at distances ranging from several dozen to several hundred metres.

Differences between particular structures are mainly due to dimensions of fissure opening (joint width), their horizontal extent and type of infilling (inner structure and dike lithology). These differences are firstly of quantitative character and result from degree of fissure development.

The largest structure, from now on called the Main Fissure, is located in the southernmost part of the studied area (Fig. 1B; Pl. I, Figs. 5, 6). It is characterized by an average width of 4–6 m, and until now has been traced along strike at a distance of 1 km (but is still expected to continue well beyond the outcrop boundary). Others fissures, occurring the northeast from the Main Fissure, are smaller. They are commonly up to 1 m wide. Their horizontal extent seems not to exceed 400–600 m.

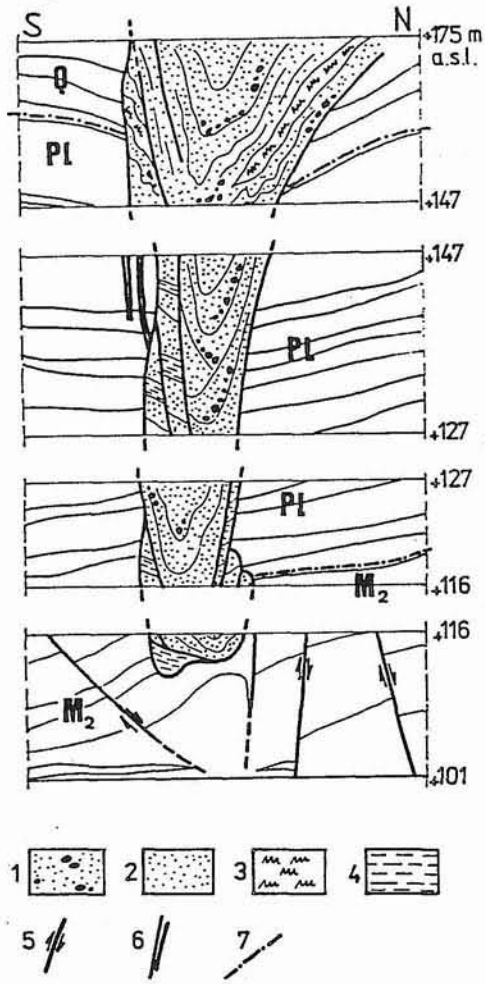

Fig. 3. Main fissure, reconstruction after selected fragments of pit escarpments

1 — coarse-grained sands and gravels; 2 — medium- and fine-grained sands; 3 — silts; 4 — clays; 5 — faults; 6 — clastic dikes; 7 — borders between main lithostratigraphical units; for other explanations see Fig. 2

Szczelina główna, rekonstrukcja na podstawie wybranych fragmentów skarp odkrywki

1 — piaski gruboziarniste i żwiry; 2 — piaski średnio- i drobnoziarniste; 3 — muły; 4 — iły; 5 — uskoki; 6 — dajki klastyczne; 7 — granice między głównymi jednostkami litostratygraficznymi; pozostałe objaśnienia jak na fig. 2

The vertical extent of fissures is relatively uniform, and can be estimated at 70–80 m. Their lower termination is usually clearly defined. Most of the structures reach the bottom of the Pliocene sequence and show a tendency to die out just above the basal erosional surface, or few metres below it, in the uppermost part of coaly deposits of the Middle Miocene. Some structures end gradually, some abruptly (for instance against clayey layers). The latter terminate with 1–2 m wide pocket-like floor, that shows cross-cutting relations with sets of small faults and fractures reaching somewhat deeper.

The upper termination is transitional, because a progressive opening of fractures is accomodated by complex trough features at the top, within the Quaternary deposits. For such reason it cannot be defined in detail.

Individual structures are very distinctly visible within subhorizontal or gently folded layers of the host Pliocene sediments. Border walls of fissures form sharp-cutting, flat or slightly undulated vertical or subvertical planes. Some spatial variations has been expressed by irregular depressions and niches at sites of block detachment from the walls. Both border surfaces show roughly parallel arrangement, but they have been found as convergent downwards if traced at a longer vertical distance. It results in decreasing width of the Main Fissure from 7–8 m at the top of the Tertiary complex to 3–4 m at the base of the Pliocene sequence.

LITHOLOGY AND FABRIC OF DIKES

Lithology of presented structures is considerably varied. Fissure infillings contain both Tertiary (sands, various kinds of clays) and Quaternary material (gravels, sands, silts, tills), coming from fissure walls and overlying layers. Similar differentiation is also characteristic of the inner structure of dikes which is due to several different infilling mechanisms, coexisting at the same time. Genetic varieties of such structures was determined by T. Hayashi (1966) who distinguished intrusive, injection, infilling, squeezed-in and diagenetic dikes.

According to the author's observations, the fissures are generally filled with:

1. Material with well-preserved (or slightly deformed) sedimentary stratification, occurring as narrow (20–50 cm), vertical elongated blocks detached from fissure walls and than moved gravitationally downward.

2. Material with destroyed stratification, composed of various intermixed lithological types, formed by collapsing of the overlying layers and transported within a fissure at long distances.

3. Clayey veins, on the average up to 0.5 m thick, with varying vertical extent and shape (from wedge-like to sheet-like). They are connected with the Tertiary layers, which enclose or underlie a fissure.

4. Sandy veins, from several centimetres to almost a metre thick, with fluidal or homogenic structures, formed due to intrusion (*sensu* S. Dżułyński, A. Radomski, 1957) of liquefied sands (of quicksand type).

The collected observations indicate that the infilling within a individual fissure can change along the strike, and more commonly, with depth. Apart from typical simple dikes; due to single, opening events, there are also more complex ones. Particularly significant is the occurrence of composite dikes originated as a result of multistage opening and infilling of fissures (W. Jaroszewski et al., 1985). These dikes contain a sequence of infillings bounded by fissure-parallel discontinuities. Thus opening of fractures, particularly of the more advanced ones, seems to have been a relatively, prolonged process with distinct successive stages.

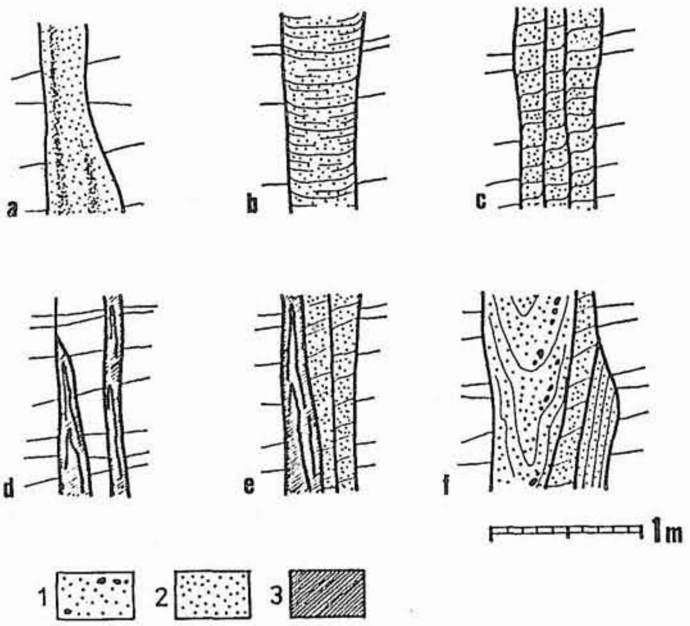

Fig. 4. Examples of clastic dikes from exposures in the western part of the mine pit Bełchatów

Simple dikes (of single-stage development): a — injection infilling, b — infilling in form of gravitationally displaced block; composite dikes (of multi-stage development): c — infilling in form of gravitationally displaced extremely elongated blocks, d — set of clayey veins (squeezed-out), e — changing infilling mechanism (gravitation, squeezed-out), f — gravitation infilling of varying deformation degree of laterally accompanying blocks; 1 — coarse-grained sands and gravels; 2 — medium- and fine-grained sands; 3 — clays

Przykłady dajek klastycznych z odsłonięć w zachodniej części odkrywki Bełchatów

Dajki proste (o jednoetapowym rozwoju): a — wypełnienie iniekcyjne, b — wypełnienie w formie przemieszczonego grawitacyjnie bloku; dajki pakietowe (o kilkuetapowym rozwoju): c — wypełnienie w postaci zespołu listwowatych bloków przemieszczonych grawitacyjnie, d — zespół żył ilastych (z wyciśnięcia), e — zmienny mechanizm wypełniania (grawitacyjny, z wyciśnięcia), f — wypełnienie grawitacyjne o różnym stopniu deformacji sąsiadujących obocznie bloków; 1 — piaski gruboziarniste i żwiry; 2 — piaski średnio- i drobnoziarniste; 3 — iły

Selected examples of simple and composite dikes are presented (Fig. 4; Pl. II, Figs. 7–10).

AGE OF CLASTIC DIKES

In case of unconsolidated deposits both processes: opening of cracks and their filling must have developed contemporaneously. Hence, the clastic dikes can be dated by determining the age of infilling material as well as by determining the age of the youngest layers cut by the dikes. The analysis of sediments within open cracks indicates that they developed during Quaternary. Such a conclusion is supported by the presence of more or less deformed blocks or veins of the Quaternary material. The Quaternary infilling material occurs in the fissures exclusively or together with the Tertiary sediment, reaching down along the fissures to a depth of 60–80 m below the base of the Quaternary sequence. It is also worthwhile to note that this statement can explain (except for technical reasons) the cases known from industrial, geological reports where the Quaternary material occurs in the drilling cores within the Tertiary sequence.

General age identifications were done on the basis of macroscopic features of the sediment, mainly the presence of the Scandinavian material and composition of heavy minerals in case of fine-grained and silty sediments. The second method enables closer determination of sediment origin by comparison of results with key assemblages of heavy minerals, listed for the Quaternary by D. Krzyszkowski (1990, 1992) and for the uppermost Tertiary by A. Hałuszczak (*paper in preparation*).

The most important premises to date development of the tensile cracks are provided by observations on their relations to the surrounding sediments, mainly on the involvment the Quaternary layers that overlie or cover the described structures. These observations indicate that the structures are younger than the oldest glacial series in this area. The latter series are correlated with the Folwark Formation, distinguished by D. Krzyszkowski (*op. cit.*), and corresponding to the South Polish Glaciation (Nidanian). The development of the described structures can be connected with deposition (at least partly) of the overlying Czyżów Formation corresponding, according to D. Krzyszkowski, to a polycyclic interglacial with well documented series of the Ferdynandów Interglacial at the base. A more detailed determination the age of the structures is still to be made.

REMARKS ON ORIGIN

The development of clastic dikes can be achieved trough active, pressure-induced intrusion forcing the cracks to open (S. Dżułyński, A. Radomski, 1957; F. J. Pettijohn, P. E. Potter, 1964). More frequently, however, the infilling medium behave passively and resulting cracks form spatially systematic arrangement. In these cases both mechanisms of infilling and opening should be examined separately.

Fissures and open cracks can originate in various ways. According to J. C. Dionne and W. W. Shilts (1974), the most important mechanisms are the following: 1 — sediment contraction under influence of frost or drying, 2 — mass movements (landslides, solifluction, etc.), 3 — sediment draining due to intensive compaction in the substrate or loading at reverse density gradient, 4 — subsidence due to substrate leaching, 5 — seismic activity, 6 — tensile stress at base of advancing glacier, 7 — disjunctive tectonic deformation that accompany folding.

The collected observations on fissures enable us to exclude most of the above mentioned mechanisms, particularly the hypergenetic ones. The morphological features of the analysed structures and their location within wide, open zones of anticlinal or flexural crests permit an assumption of tensile stresses as a direct cause of their formation. When the folding occurred, the tension along fold crests was relieved by development of open fractures parallel to the fold axes. Progressive opening of fractures during the folding is expressed by a sequence of structures starting from simple dikes, through composite ones to complex infillings within narrow, deep throughs, which show features typical of roof grabens (the Main Fissure described above). The commonly observed termination of fissures downwards at the border zone between the Pliocene and Miocene sediments can be explained by tensile stress drop towards the neutral surface in folds (cf. stress state in buckle folds — W. Jaroszewski, 1980; J. G. Ramsay, M. I. Huber, 1987). This interpretation is supported by field data from the eastern part of the mine pit (beyond the described area).

As particularly significant example may be taken on extensive open fracture (6–8 m width, horizontal extent 1.5 km, vertical extent up to 100 m) developed close to an anticline axis which has been observed along the borehole line 87/14 — 86/14 — 95/14.

Dating of the clastic dikes is an important aspect of their occurrence, resulting consequently in more detailed than in the past, age determination of one of the main deformation phases of the Cainozoic sediments in this area. Regardless of possible future progress in stratigraphy recognition, the described structures univocally confirm the presence of Quaternary tectonism in the evolution of the Kleszczów Graben, which has been already suggested by M. D. Baraniecka and Z. Sarnacka (1971), M. D. Baraniecka (1981), R. Gotowała (1982, 1987) and D. Krzyszkowski (1992).

A more detailed explanation for origin of the tensile structures and the related clastic dikes, in particular the determination of their dependence on higher-order tectonic processes, demands a wider analysis of all phenomena of extensional brittle deformation that are typical of the Pliocene–Lower Quaternary sediments in the Kleszczów Graben. It is, however, a separate problem, beyond the scope of the present paper.

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Andrzej HAŁUSZCZAK

DAJKI KLASTYCZNE W NAJWYŻSZYM TRZECIORZĘDZIE ROWU KLESZCZOWA I ICH ZNACZENIE DLA REKONSTRUKCJI CZWARTORZĘDOWEGO DIASTROFIZMU

Streszczenie

Jednym z charakterystycznych elementów budowy strukturalnej utworów pliocenu–niższego czwartorzędu w rowie Kleszczowa (Polska centralna) są dajki klastyczne. Szczegółowe badania prowadzono w SW części odkrywki kopalni węgla brunatnego Bełchatów, w rejonie południowego uskoku rowu brzeżnego, występującego w podłożu mezozoicznym.

Dajki klastyczne o zasięgu poziomym do ponad 1 km rozwinięte są wzdłuż systemu spękań tensyjnych o orientacji NW–SE. Ich zasięg pionowy wynosi średnio 60–80 m, przy czym zanikają one ku dołowi na kontakcie z niżejległymi, zawęglonymi osadami środkowego miocenu. Poszczególne struktury różnią się wzajemnie rodzajem wypełnienia (grawitacyjne, iniekcyjne, z wyciśnięcia), a także szerokością szczelin (od kilkudziesięciu centymetrów do 6–8 m). Oprócz typowych dajek prostych, powstałych w wyniku ciągłego, jednoetapowego rozwoju, występują dajki pakietowe, będące wynikiem wielokrotnego rozwierania i zapełniania szczelin. W obrębie większych struktur stwierdzono do 7–8 przylegających do siebie obocznie generacji wypełnienia.

Występowanie materiału czwartorzędowego (odcinkowo lub na całej wysokości szczelin) rozstrzyga w sposób oczywisty o czwartorzędowym wieku dajek. Deformacje warstw czwartorzędowych leżących powyżej szczelin wskazują, że proces ich rozwierania jest młodszy od najstarszej na tym obszarze serii glacjalnej (zlodowacenię południowopolskie — nidian).

Cechy morfologiczne analizowanego zespołu struktur, a szczególnie jego pozycja w obrębie stref antyklinalnych i fleksuralnych osadów kenozoicznych, pozwalają przyjąć, że bezpośrednią przyczyną ich powstawania były naprężenia rozciągające, rozwijające się w zewnętrznych częściach pakietów fałdowanych warstw.

PLATE I

Fig. 5. Main fissure in the Pliocene brown coarse-grained sands. Width 7 m at the top. Infilling composed of several generations of strongly deformed blocks of the Quaternary lightgrey sand. Curvilinear border planes of the fissure distinct on the photo (underlined) are due to intersection of vertical walls of the structure and step-like profile of the escarpment. Fragment of the western escarpment between the levels 125 and 147 m a.s.l. For explanations see Fig. 2

Szczelina główna w brunatnych piaskach gruboziarnistych pliocenu. Szerokość w górnej części 7 m. Wypełnienie w postaci kilku generacji silnie zdeformowanych bloków jasnoszarych piasków czwartorzędowych. Widoczny na zdjęciu (podkreślony) krzywoliniowy przebieg powierzchni granicznych szczeliny jest wynikiem intersekcji pionowych ścian struktury oraz schodowo ukształtowanego profilu skarpy. Fragment skarpy zachodniej między poziomami 125 i 147 m n.p.m. Objaśnienia jak na fig. 2

Fig. 6. Further fragment of the fissure noted on the previous photo (Fig. 5), about 400 m to the northeast. Fragment of the western escarpment between the levels 125 and 147 m a.s.l. For explanations see Fig. 2

Kontynuacja szczeliny widocznej na poprzednim zdjęciu (fig. 5) ok. 400 m w kierunku północno-wschodnim. Fragment skarpy zachodniej między poziomami 125 i 147 m n.p.m. Objaśnienia jak na fig. 2

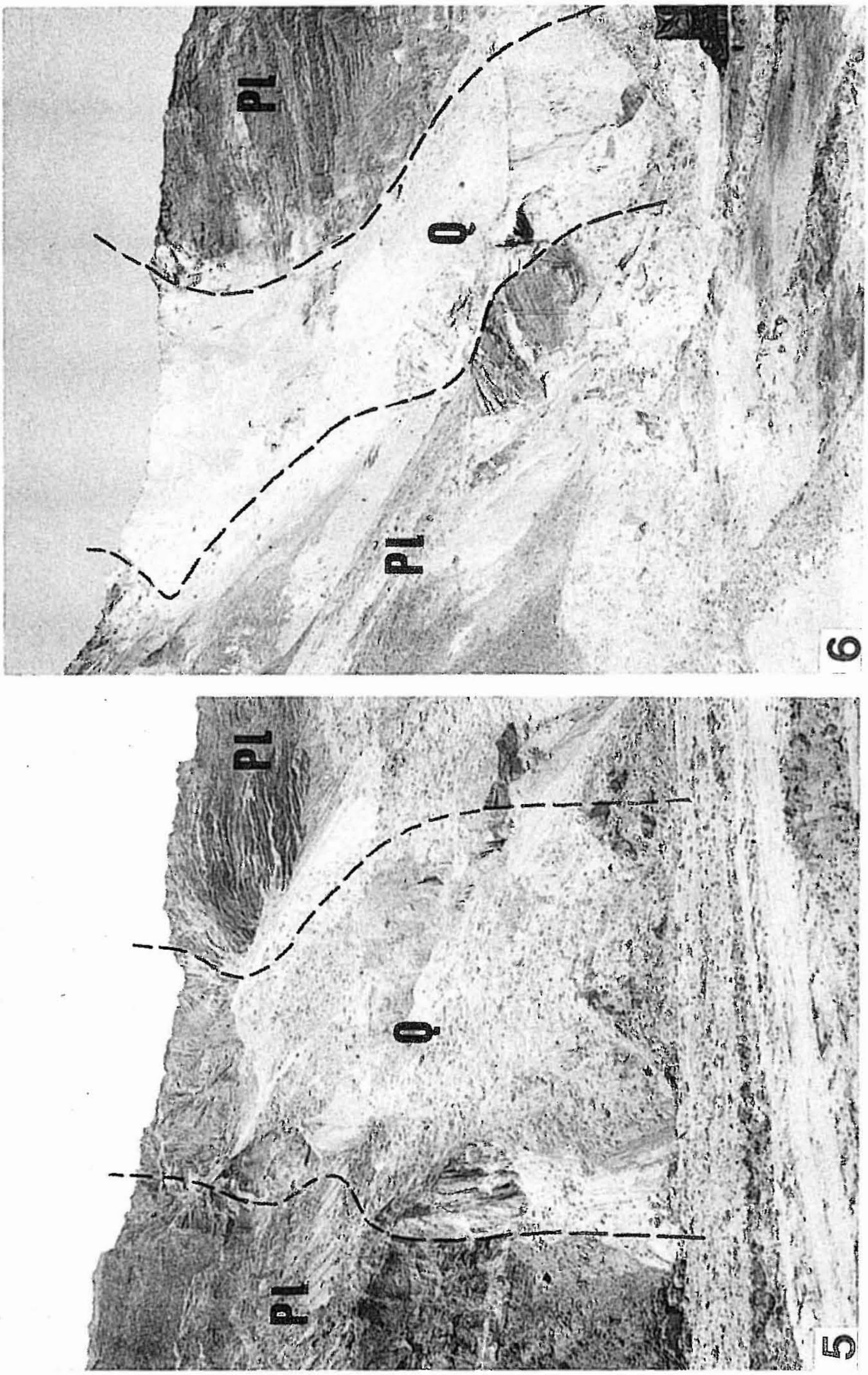

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PLATE II

Fig. 7. Simple dike in the Pliocene sandy and clayey sediments. Fissure width about 70 cm. Infilling of gravitationally displaced block of the Quaternary sand showing well-preserved primary bedding. Fragment of the western escarpment between the levels 115 and 125 m a.s.l.

Dajka o charakterze prostym w piaszczystych i ilastych utworach pliocenu. Szerokość szczeliny ok. 70 cm. Wypełnienie w postaci grawitacyjnie przemieszczonego bloku piasków czwartorzędowych o zachowanym pierwotnym warstwowaniu. Fragment skarpy zachodniej między poziomami 115 i 125 m n.p.m.

Fig. 8. Simple dike in the Lower Quaternary sandy sediments. Fissure width about 50 cm. Injection infilling — sandy vein with poorly preserved fluidal structures. Fragment of the western escarpment between the levels 115 and 125 m a.s.l.

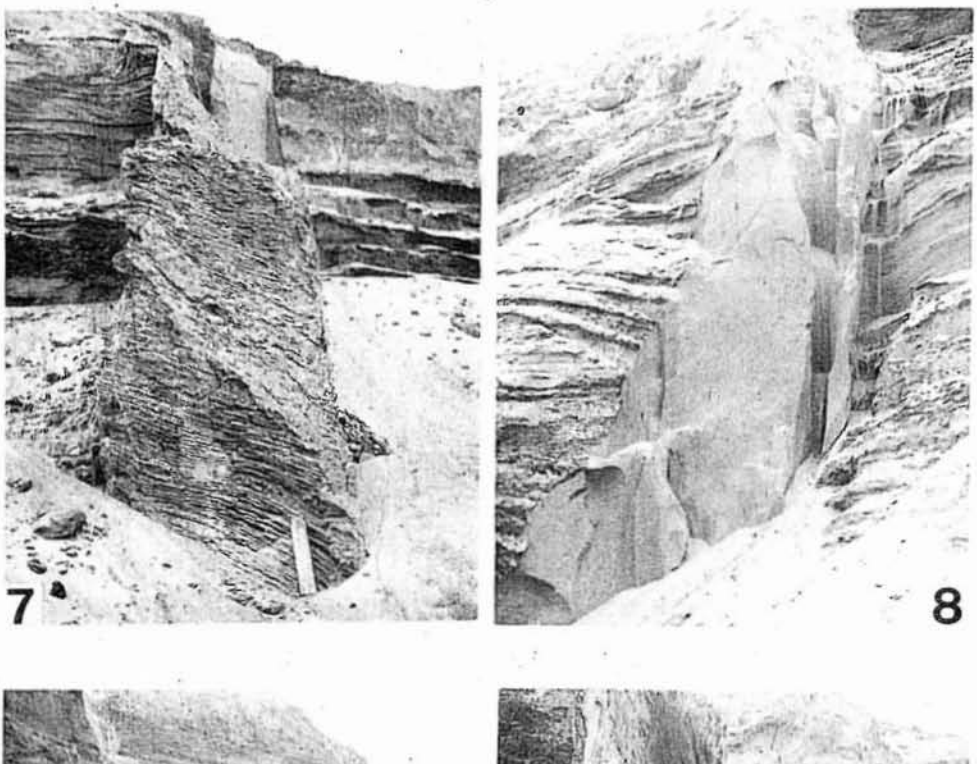
Dajka prosta w utworach piaszczystych niższego czwartorzędu. Szerokość szczeliny ok. 50 cm. Wypełnienie iniekcyjne — żyła piaszczysta o słabo zarysowanych strukturach fluidalnych. Fragment skarpy zachodniej między poziomami 115 i 125 m n.p.m.

Fig. 9. Set of simple dikes in the Pliocene sandy and clayey sediments. Infilling of the Quaternary material: injection type (to the right), gravitation type (to the left). Fragment of the western escarpment between the levels 125 and 147 m a.s.l.

Zespół dajek prostych w piaszczystych i ilastych utworach pliocenu. Wypełnienie materiałem czwartorzędowym: iniekcyjne (po prawej), grawitacyjne (po lewej). Fragment skarpy zachodniej między poziomami 125 i 147 m n.p.m.

Fig. 10. Example of composite dike in the Pliocene clayey sediments. Width about 50 cm. Infilling as extremely elongated blocks of the Quaternary silty sand. Fragment of the western escarpment between the levels 115 and 125 m a.s.l.

Przykład dajki pakietowej z ilastych utworów pliocenu. Szerokość ok. 50 cm. Wypełnienie w formie wąskich, listwowatych bloków czwartorzędowych piasków pylastych. Fragment skarpy zachodniej między poziomami 115 i 125 m n.p.m.



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