# Morphology and Geometry of Deformation Bands in Glaciodynamic Melange of the Odranian Age from the Kleczew Graben Zone (Polish Lowland)

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The morphology and geometry of deformation bands cutting the matrix of glaciodynamic mélange is the object of considerations here. The glaciodynamic mélange exposes within the Kleczew graben zone (northern part of the Konin elevation, Polish Lowland). This is mélange of sedimentary type. It developed as the effect of simple shearing of freshly melted subglacial till beneath active ice-sheet of the Odranian glaciation. The matrix composed of clayey--silty-sand is major component of this mélange. Glacially abraded erratics of crystalline and sedimentary rocks as well as subglacially deformed inclusions of poorly indurated sediments of the Miocene and the Pleistocene age constitute a small percentage of mélange volume. The glaciodynamic mélange is typical block-in-matrix mélange. The matrix is cutting by dense network of meso-scale shears represented by both the Riedel shears within the middle and upper part of the mélange and the scaly fabric within the lower part of it. The prevailing shear sense estimated on the basis of these kinematic indicators is to the SSW.

The microstructural studies were based on the analysis of thin sections under an optical microscope as well as images obtained from scanning electron microscope (SEM). From each of 21 oriented samples of matrix collected from 3 investigation sites, three thin sections and one specimen for SEM were prepared. Thin sections were cut along three perpendicular sample sections: the N-S-trending vertical and longitudinal section (VL), the W-E-trending vertical and transverse section (VT) as well as the horizontal and longitudinal section (HL). Such procedure allows to define the 3D microstructure model. The images obtained from SEM represent the VL sections of the samples. For quantitative description of microstructures, software: NIH Image and STIMAN (Structural Image Analysis) have been used.

Results obtained from the microstructural studies show that the deformation bands appear as linear zones of different morphology and geometry. The skeletal porosity, microporosity as well as the microfabric are here clearly changed in relation to the host matrix material. The microfebric is defined by preferentially-oriented long axes of skeletal grains as well as clay platelets or domains. Taking into account the character of changes and width of these zones, three generations of deformation bands were documented, based in part on classification after Antonellini et. al., (1994): deformation bands with no cataclasis and with compaction (DBC), deformation bands with no cataclasis and with dilatancy (DBD) and discrete deformation bands with no cataclasis and with dilatancy (DDBD).

The geometry of the deformation bands is more composite. They arrange into conjugate sets, particularly if images obtained from the VL and HL sections were analysed. The acute-angle bisectors between conjugate bands analysed along the VL sections show different orientation. The bisectors related to the DBC dip gently in the same direction as the shear sense, whereas those related to the DBD and DDBD in opposite direction. Moreover, a lot of these bisectors within DDBD are oriented nearly vertical. Often the composite pattern of the deformation bands is related to the Riedel shears geometry.

The volume changes of the mélange matrix recorded in morphology of deformation bands as well as the other microstructural characteristics of them have been allowed to indicate different micromechanics of discrete shearing of matrix and thus to reconstruct the hydraulic conditions within the glaciodynamic mélange. The critical state theory (Shoefield and Wroth 1968, Antonellini et. al. 1994) have been used as the basis for this considerations.

The DBC appear as linear zones where skeletal grains are densely packed than in the host matrix material, what is additionally expressed by reduction of the skeletal porosity up to 50 %. Diameters of the skeletal grains are frequently greater here. The morphology of DBC suggests that the enrichment of the skeletal larger grains, which initially must have been loose packed in matrix, might have produced during shear propagation and consolidation along these bands. The outflow of the pore-water excess induced during shearing and consolidation along evolving DBC might have been enough rapid to elutriate the finer particles here. The signs of consolidation along DBC point to normally consolidated or "virgin" state of the mélange matrix material. The pore pressure might have been equal to hydrostatic pressure or higher to some degree.

The DBD are characterised by preferred orientation of microfabric elements within matrix, that is: the long axes of the loose packed skeletal grains and the clay platelets or domains. The positive correlation between the microporosity and the number of fissure-like micropores as well as the degree of preferred orientation of micropores (results obtained from SEM analysis) may show dilatancy of sheared matrix material along DBD. The maximum width of these bands which range between 1-3 mm, shows that they are most penetrative structures of all types of deformation bands.

The DDBD are represented by narrow zones (3–30 μm), where the clay platelets and domains are very strong preferentially-oriented and form the interweaving bunches. Very often these bunches are accompanied by the microfractures extended parallel to them. The DDBD cut the mélange matrix irrespective of the orientation of microfabric elements observed here. Moreover, they cut the loose packed skeletal grains, too. The presence of the microfractures may result from dilatancy of the sheared matrix material along DDBD.

The dilatancy recorded in morphology of the DBD and the DDBD shows the overconsolidation state of the mélange matrix material. During development of these bands, the pore pressures were much higher than during DBC formation. They might have reached values close to the lithostatic pressure related to the ice-sheet loading. According to the experimental studies of Arch et. al. (1988) confirmed the positive correlation between the width of deformation bands with dilatancy and the pore-water content within sheared sediment, the DDBD might have developed after significant dewatering of the mélange matrix. The pore-water content during development of the DBD was much higher than during formation of the DDBD. The comparison of the pore-water content during formation of the DBD and the DBC is not possible without information about primary porosity of the mélange matrix material when this later band developed.

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# The Structure of the Gypsum-Anhydrite Dome at Alsótelekes

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The Rudabánya Mountains is a SW-NE striking elongated chain of hills in the NE part of Hungary. It lies in the Darnó Zone, a major sinistral strike-slip fault zone of Lower Miocene age (Zelenka et al. 1983), which is about 4–5 km wide here. The Mezozoic rocks of the Rudabánya Mts. belong to the Silica nappe system. These nappes were detached from their original basement in the gypsum-anhydrite containing, incompetent material of the Upper Permian Perkupa Anhydrite Formation acting as décollement horizon (Less 2000). These strata are on several sites in a near-surface position. The Alsótelekes occurrence was explored in 1968 when the At-478 borehole penetrated a gypsum-anhydrite body with more than 400 m thickness. In the ’80s 230 exploration boreholes and ground geoelectric surveys prepared the start of the mining. The open pit works since 1987 and it offers unique opportunity for studying the structural features of the evaporite body. Our surveys aimed to get a picture about the structural details of the gypsum-anhydrite body based on the geological documentation of the drill cores and the pit walls with structural measurements, and to build up a model for the formation of them with respect to the regional tectonics.

The Darnó Zone consists of several individual fault blocks. The open pit lies some 100 metres away NW from the Telekes Valley indicating a fault parallel with the main strike of the zone. On the SE side of this fault Gutenstein Dolomite crops out, on the NW side the Perkupa Anhydrite Formation (Fülöp 1994) is covered by Neogene sediments. This evaporitic formation is a typical lagoon facies sediment with sabkha-like conditions on the higher and reductive conditions on the deeper parts. In the tidal zone there are three textural types of gypsum layers: brecciated, selenitic (coarse-grained) and laminitic. The strata formed beneath the tidal zone are dark, sometimes bituminous shales, sulphates and carbonates with fine scattered pyrite grains. Anhydrite occurs either with shale and sandstone inclusions or with dolomite interlayering. The microlayering of the dolomitic anhydrite and the lamination of the gypsum indicates (probably seasonal) changes in temperature. The direct cover of the evaporite is a red clayish continental sediment with debris and lenticular bodies of limestone breccia and resedimented black or purple clay of the evaporite. This sediment can be classified by its facies and material in the Lower Miocene Zagyvapálfalva Clay Formation. There are 10m-scale blocks of dark and bright limestone enclosed in or thrusted upon on the continental sediments or the evaporites. The bright limestone with rich fossil content comes from the Steinalm Limestone F. of the Silica Nappes. The uppermost beds are Pannonian fine-grained lacustric and limnic sediments with several lignite beds.

The present open pit explores the western side of a NE-SW elongated dome structure. The formation of the dome started in the Lower Miocene with the opening of a pull-apart basin, elongated parallel to the NNE-SSW striking Telekes Valley fault. The incompetent evaporite material was moving toward this zone by ductile flow under the load of the overlying Mezozoic rocks and produced an anticline by its thickening. The lamination of sedimentary origin became wholly transposed containing isoclinal or nearly isoclinal, dm-scale conical sheath folds and 10m-scale diapir structures. The remnants of the Mezozoic cover were uplifted and partly embedded in the evaporite while other blocks slipped aside. As the anhydrite became the outcropping layer on the surface, it was partly transformed into gypsum with karst features on the top. Meanwhile in the basin thick continental debris was accumulated, burying step by step the dome.

In the next phase, maybe still in the Lower Miocene (during the continuing sinistral strike-slip movement along the Telekes Valley fault) the basin was inverted and closed by a NNW-SSE trans-