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Problems Related to the Role of Shear-bands as Kinematic Indicators

Ondrej LEXA[1], John COSGROVE[2] and Karel SCHULMANN[1]

[1] *Institute of Petrology and Structural Geology, Charles University, Prague, Czech Republic*
[2] *T.H. Huxley School of Environment, Earth Sciences and Engineering, Imperial College, London, United Kingdom*

Small-scale shear zones inclined at intermediate angles to an earlier anisotropy are often observed in deformed rocks. They are traditionally described as shear bands, C-bands, extensional crenulation cleavage, asymmetric boudinage, asymmetric folds or normal kink bands formed as a result of extension along an older anisotropy (or shortening perpendicular to the anisotropy). Their sense of shear (or internal rotation) and geometry are widely used to describe the large-scale kinematics of deformation and/or the deformational history of a given area. These various structures result from different processes and unless this is fully understood, there is a great danger of drawing wrong conclusions if they are used as kinematic indicators. It can be shown that when these three-dimensional structures are looked at in two-dimensional outcrops or in thin sections, they may seem geometrically identical.

We have developed simple computer techniques allowing geometrical evaluation of all possible sections across folds of arbitrary geometry (degree of asymmetry, shape and interlimb angle). In order to determine shear-band geometry, we used criteria defined by Platt and Vissers (1980) such as the angle of limbs and enveloping surface and the interlimb angle. Planar sections, in which a fold exhibits geometry of a shear band, are quantified using the above criteria and displayed in stereographic projection as shaded areas. In addition, the quality of shear-band shape is visualized by different intensity of shading.

We demonstrate that for any fold geometry, there are two distinct groups of sections close to the axial plane showing shear band-like geometry and opposite sense of shear criteria. The size of areas in a stereogram representing these sections is increasing with the increasing fold interlimb angle. Symmetrical folds exhibit symmetrically distributed areas of the same size in the stereogram whilst asymmetrical folds show areas of different sizes and positions in stereographic projection. Since geologists are traditionally using sections parallel to lineation and perpendicular to foliation to determine kinematics of deformation (and lineations are often parallel to fold axes), there is a high probability of misinterpretation when secondary folds are present. We shall provide two field examples, from the Jeseníky Mountains and from the Vepor basement of Western Carpathians, where reconstructions of structural evolution related to extensional collapse are often based on apparent extensional shear bands, which are in fact oblique sections of compressional folds.

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Cretaceous Collision in the Western Carpathians: Role of Complex Basement Shape on Crustal-Scale Polyphase Deformation Partitioning

Ondrej LEXA and Karel SCHULMANN

Institute of Petrology and Structural Geology, Charles University, 128 43 Prague, Czech Republic

The present structure of the SE Western Carpathians consists of three main tectonometamorphic units. From the north to the south and from the bottom to the top they are: 1) Variscan crystalline basement with Late Paleozoic and Mesozoic cover (Vepor Unit). 2) Early Paleozoic basinal, mostly turbiditic metasedimentary unit (Gemer Unit) overlying pre-Cambrian? crystalline basement (sub-Gemer Unit). The Vepor crystalline complex irregularly surrounds the Gemer embayment from west and east. 3) Mesozoic accretionary wedge (melange) containing blueschist-facies relics (Meliata Unit) is overlain by flat unmetamorphosed Silica nappe.

The pre-Alpine crystalline Vepor Unit and the Gemer Unit in the S show NW-dipping Variscan fabric and inverted metamorphic zoning resulting from south-verging Variscan thrusting. The latter is manifested by overthrusting of high-grade gneisses over Barrovian micaschists in the Vepor unit, and by overthrusting of medium-grade Devonian? metabasites over the Cambro-Ordovician low-grade volcanosedimentary sequence of the Gemer Unit.

The Alpine Orogeny started by Late Jurassic overthrusting of subduction melange over the continental margin represented by the Gemer Unit. The continuous N–S convergence resulted in development of an internal thrust within the sub-Gemer basement in the Cretaceous. Propagation of this thrust into the overlying low-grade metasediments of the Gemer Unit produced an asymmetrical cleavage fan with narrow southern and wide northern flank with decreasing deformation intensity towards the north. The irregular shape of the Vepor basement started to play a significant role during further shortening of the weak Gemer sequence. Large NE–SW-trending margin of the western Vepor basement took the role of an oblique indenter at these times. Consequently, at the contact with this crystalline basement, the whole Gemer and Mesozoic successions were exceptionally shortened, which resulted in the development of transpressional deformation that overprinted early cleavage fan. Geometry of planar structures, subhorizontal stretching and numerous sense-of-shear criteria suggest sinistral transpression. This zone propagates farther NE, where it forms the major Central Gemer Shear Zone (CGSZ) and cross-cuts the central part of the Gemer domain. The major effect of this transpressional sinistral movement is overthrusting of southern part of the Gemer Unit on eastern Vepor basement, buckling of cleavage fan structure with a wavelength of ~60 km and formation of new N–S-striking clevage in the hinge zone of a large buckle fold.

The Alpine reworking of the western Vepor basement margin is also very intense. Here, the Vepor gneisses show strong greenschist-facies sinistral transpressive reworking with northward decreasing intensity of deformation. Internal part of the Vepor basement has been also affected by two major NE–SW-striking steep transpressive shear zones several kilometres wide, often associated with complete transposition of the early Variscan fabric. Major result of transpressional tectonics is a vertical extrusion of micaschists, which have been emplaced into supracrustal levels while the surrounding high-grade gneisses were affected by intense greenschist transtensional shearing with flat planar fabrics and E–W-trending stretching. This transtension is associated with dragging of overthrust Gemer and Mesozoic sequences by sinsitral movements of the CGSZ.

Deformation in the Henryków Gneiss (East Fore-Sudetic Block) – Further Evidence for the SW-directed Extensional Collapse in the East/West Sudetes Boundary Zone

Stanisław MADEJ

Institute of Geological Sciences, University of Wrocław, Pl. M. Boma 9, 50–204 Wrocław, Poland

The structural evolution of the East/West Sudetes contact zone involved several deformation events, the sequence and character of which remains a matter of controversy. In the Fore-Sudetic Block, an additional difficulty arises from poor exposure of the Variscan basement which is mostly concealed beneath the Cenozoic sediments. Therefore, each outcrop of basement rocks in that area is worth of being studied. This paper presents results of structural study on the gneisses from the vicinity of Henryków in the southernmost part of the Lipowe Hills. The obtained data indicate an important role played by late extensional deformation which has modified the earlier fabric in the East/West Sudetes boundary zone.

The Lipowe Hills massif is exposed in the eastern part of the Fore-Sudetic Block between the Niemcza–Kamieniec Ząbkowicki metamorphic unit in the west and the Strzelin crystalline massif in the east. It is composed of four main types of gneisses (Wójcik 1973; Wroński 1975; Oberc-Dziedzic 1995): (1) chlorite Henryków gneiss; (2) fine- to medium-grained light gneiss with sillimanite nodules; (3) light, coarse-grained or augen gneiss and (4) dark, thinly layered to migmatitic gneiss. Gneisses are accompanied by minor amphibolites, calc-silicate rocks, marbles, biotite-muscovite schists and quartzites. The metamorphic rocks are intruded by Variscan granitoids.

The Henryków gneiss is grey-green, fine-grained. It is usually layered and shows locally augen structure. The rock is composed of quartz, K-feldspar, plagioclase, muscovite and chlorite. Apatite, zircon and opaque minerals are main accessories. Individual layers, which define the main foliation, are up to 1.5 mm thick and consist of quartz, quartz + feldspars and muscovite + chlorite. Augens, elongated parallel to the layering, are composed of quartz or feldspar. Both K-feldspar and plagioclase are often strongly sericitized or saussuritized. Two generations of chlorite were distinguished. The first one comprises plates replacing biotite and orientated parallel to the main foliation, whereas the second generation fills brittle joints.

Effects of four deformational events were documented within the Henryków gneiss. The oldest D_1 deformation structures are represented by crenulated relics of the S_1 foliation, locally preserved between planes of the main S_2 foliation. The S_1 foliation is marked by elongation of quartz aggregates and white mica plates. In places, quartz veins, oblique or perpendicular to the main S_2 foliation, parallel the orientation of the S_1 planes. These quartz veins are sometimes deformed by isoclinal rootless F_2 folds, up to 2–3 cm in size. The main S_2 foliation is developed parallel to axial planes of the F_2 folds and dips to the W at angles of 30–40°. It is defined by layering and alignment of muscovite and chlorite (replacing primary biotite).

The S_2 foliation was subsequently reactivated during the D_3 event. In consequence, the L_3 mineral stretching lineation was developed on the S_2 foliation. The L_3 lineation is defined by parallel alignment of elongated quartz–feldspar aggregates and muscovite flakes. It plunges toward the SW at angles of 25–35°. Kinematic indicators originated during the D_3 event – S-C structures, mica fish, extensional shear bands and asymmetric pressure shadows – indicate a top-to-SW sense of shear during the D_3 deformation.

The youngest deformation structures D_4 are kink folds, brittle joints and zones of brecciation. The joints are filled with sec-