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Pattern of the Mesoscopic Thrust Faults in the Central Part of the Silesian Nappe (Polish Western Outer Carpathians)

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Polish Western Outer Carpathians is a north-verging fold-and--thrust belt. The belt is mainly composed of Lower Cretaceous to Lower Miocene flysch sediments (Książkiewicz1977). The Outer Carpathians comprise several nappes. One of those nappes, the Silesian nappe, extends along the whole belt. The study area is located in the central part of this nappe, between the Dunajec and Wisłoka River.

In the traditional point of view the rocks of the Polish Outer Carpathians are folded during single regional episode (Książkiewicz 1977). In the two of the biggest nappes of the Carpathians, Magura and Silesian nappes the map-scale fold axes are oriented parallel to the frontal thrust of individual nappe. The fold axes vary their orientation along the orogen (from west to east): from WSW-ENE, through W-E to NW-SE (Książkiewicz 1977).

The tectonic evolution of the Polish Western Outer Carpathians is characterized by the superposition of two shortening events: a) NNW-(N), and b) NE-(NNE) directed ones (Aleksandrowski 1989, Decker et al. 1997, 1999). Folding and thrusting of the first event were of synsedimentary character. During the next, NE-(NNE) directed event, the NNW-directed thrust faults and related folds were overprinted and refolded.

The rocks of the studied area are cut by numerous map-scale faults mostly thrust and strike-slip faults. The thrust faults are oriented NW-SE and NE-SW but usually their orientation varying between ENE-WSW and WNW-ESE. The thrust faults are characterized by lateral termination, to westward mostly in the strike-slip faults. In the studied area occur mostly inclined folds. Axes of the map-scale folds are oriented NW-SE and roughly W-E, rarely SW-NE. The main map-scale anticlines are cut by thrust faults.

The studied mesoscopic thrust faults were divided into two groups formed in:

1. horizontal strata and
2. tilted strata.

Numerous thrust faults of (1) group were tilted, together with the host strata during folding. Such faults were backtilted at the beginning of the structural analysis.

There are two dominant strike orientations of the mesoscopic thrust faults WSW-ENE and ESE-WNW. The orientation of the fault strike of (1) group varies from ESE-WNW through W-E to WSW-ENE but the latter is the most common. However, the thrust faults of (2) group are characterized by more stable orientation of strike, which is ESE-WNW. According to crosscutting relationship older thrust faults are commonly these faults striking WSW-ENE and younger are these faults striking ESE-WNW. The reconstructed orientation of the horizontal compression is NNW-SSE for the older thrust faults and NNE-SSW for the younger ones. Locally, however, in the eastern part of the map-scale folds have been observed different relationship. The thrust faults caused by NE-SW–directed compression were cut by the thrust faults caused by NNE-SSE – directed compression.

The dominant age relationship of the thrust faults could be caused by clockwise rotation of the horizontal compression. Numerous thrust faults of (1) group vary in strike orientation with the host strata, this fact may suggest that the rotation of the horizontal compression took place locally before folding.

There is also second explanation of such thrust faulting: the NNE-oriented, stable horizontal compression and counterclockwise or locally (in the eastern part of map-scale folds) clockwise rotation of host strata. The orientation of the thrust fault strike of the (1) group is changing along the map-scale fold axis. On the contrary, the thrust fault strike of the (2) group is nearly stable and oriented about WNW-ESE. Therefore, the most probably during the tectonic shortening of the studied part of the Silesian nappe the horizontal compression was stable and oriented NNE-SSW. In such stress field the map-scale folds were formed and initially their fold axes were oriented WNW-ESE. During this time were formed also the in-sequence thrust faults striking WNW-ESE. Increasing of the tectonic shortening of this area caused increasing of the thrusting amplitude, which cut these folds. This thrusting caused the couterclockwise rotation of the western parts of the map-scale anticlines and clockwise rotation of the eastern parts of these folds. At the same time the existing mesoscopic thrust faults underwent also counterclockwise or clockwise rotation, together with the host strata. However, newly forming thrust faults were still characterized by WNW-ESE oriented strike.

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Calcite Twinning Stress Inversion Using OIM (EBSD) Data

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Deformation origin of calcite twin lamellae (e-twins) and their crystallographic laws have been recognized in the end of the 19th century (e.g., Mügge 1883). During the last 60 years it has been found that twinning is an important intracrystalline deformation mechanism with low critical resolved shear stress (e.g. Turner 1963, DeBresser and Spiers 1996) and therefore it is the main deformation feature for low temperatures, low confining pressures and low finite strains (up to 15 %). Since the fifties of the 20th century, when Turner (1953) developed a method for determination of stress axes from a set of e-twins (TDA), it became a useful tool for paleostress analysis in deformed calcitic rocks (or rocks containing calcite veins). Several methods of differential stresses estimations (Jamison and Spang 1976, Rowe and Rutter 1990) and stress tensor calculations (e.g. Lacombe and Laurent 1996) have been developed during last 60 years based on experimental and field data.

Orientation of calcite twin lamellae as well as the c-axis orientation can be measured directly on an universal stage. This cheap method does not require any special samples but it is subjective and inaccurate, especially if c-axis orientation is measured and very thin lamellae may cause problems as well (difficulty of differentiation between cleavage planes and e-twins). However, Orientation Imaging Microscopy (OIM) using Electron Backscatter Diffraction (EBSD) provides precise data without subjective factors. A chosen area within a thin section is investigated using a hexagonal grid of lattice orientation measurements. Such data set can be presented as a bitmap, where each pixel represents one measurement coded by color. One can then directly observe misorientation of grains, subgrains and e-twins. The greatest disadvantage of OIM is that it is a time-consuming method. One orientation map covers a tiny area (0.03 mm^2, 82,000 measurements), so investigating a sample of 1×2 cm would take weeks. We propose a grid of linescans to compensate this disadvantage. These linescans with measurement step 0.6 microns arranged in an orthogonal grid with 1 mm interval would cover a much larger area (1.3×0.7 cm) using the same number of measurements. This method is able to provide appropriate data from a relative large area in an acceptable time.

A new computer program has been developed for stress analysis of calcite twin lamellae, including most of the methods mentioned above, and processing EBSD data files as well. In our view, the optimal method of paleostress orientation and magnitude determination in calcitic carbonate complexes is the total search method of Lacombe and Laurent (1996). A modification of this method has been used in the Moravian Karst (Bohemian Massif) model area. Instead of using a set of random reduced stress tensors and then penalisation function to choose the most probable stress tensor, a systematical searching in all possible stress tensors generated from input limits was preferred.

Combination of precise calcite lattice orientation measurements (EBSD) and numerical methods of paleostress analysis makes calcite a very useful tool for evaluating deformation pathways in sedimentary complexes.

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