Application of joint analysis for paleostress recostructions in structurally complicated settings: Case study from Slesian nappe, Outer Carpathians (Poland) (extended abstract)

Leonard Mastella[1], Witold Zuchiewicz[2], Antoni K. Tokarski[3] Jacek Rubinkiewicz[1], Paulina Leonowicz[1], Ryszard Szczęsny[1]

Introduction

Joints are ubiquitous structures and therefore they present considerable potential for paleostress reconstructions. Moreover, it has been demonstrated that the identical stress axes can be inferred from populations of joints and faults. Joints have been extesively used in structural analyses of regions of mild deformation like platforms or some volcanic arcs. There, joints are considered to be related to far-field stresses. In contrast, joints in more structurally complicated settings are considered to be related to local stresses (cf. Dunne & Hancock, 1994). The main object of this paper is to demonstrate that the last assumption is not valid and, in contrast, joints in structurally complicated settings are related to far-field stresses, except locally and, therefore, they should be used in paleostress reconstructions of those settings. Moreover, we attempt to show that, contrary to current opinions (cf. Pollard & Aydin, 1988), in some structural settings shear joints are ubiquitous.

The Polish segment of the Outer Carpathians has been chosen as the study area because it is one of the very few structurally complicated settings in which joints have been studied extensively. The results of these studies show that joints in the Outer Carpathians present consistent pattern evidently related to the map-scale tectonic features. The present paper summarizes some of these results.

This paper is focused on the Silesian nappe for two reasons. (1) Regional mapping of joints, which has been going on since 1995, within the Paleogene and Neogene strata in the whole Polish segment of the Outer Carpathians, has been already completed for the Silesian nappe. This paper presents first results of this mapping. (2) Structural trend of the Silesian nappe changes along the Polish segment of the Outer Carpathians. Therefore, within this nappe it has been possible to study joints in relation to the map-scale folds of different axial orientations.

In this paper we follow the terminology summarized by Dunne & Hancock (1994). Moreover, following Dunne & Hancock (1994) we use here the word "joint" as a field term.

Regional setting

The Polish segment of the Outer Carpathians is a fold-and-thrust belt composed largely of Lower Cretaceous through Lower Miocene flysch. The belt is composed of several nappes. Two of these nappes, the Silesian nappe and the Magura nappe, extend along the whole belt. According to current opinions, folding and thrusting within the Silesian nappe occurred only once, during Late Oligocene through Early Miocene times. Within the nappe, the map-scale fold axes display shallow plunges, except locally (Fig. 1). East from Tarnów, these fold axes are oriented WNW, whereas west from Tarnów they are oriented W–E.

Joints

Joints have been studied in 116 stations located within the Paleocene through Lower Miocene strata along the 320 km long Polish segment of the Silesian nappe (Figs 2, 3). The spacing between the stations is biased by the degree of exposure which is considerably higher east of the Wisłoka River than west from this river. In each station, there occur 2–5 sets of joints. These are: one or two sets of fold-parallel joints and one to three sets of cross-fold joints. Fold-parallel joints strike parallel or under small angles to map-scale fold-axes and are perpendicular or subperpendicular to the bedding (70–90°). The origin of fold-parallel joints is not quite clear. At least some of these joints are related to map-scale folds. The fold-parallel joints will not be further discussed in the present paper.

Cross-fold joints — description

Cross-fold joints comprise: (1) a single set (T) striking perpendicular or subperpendicular to map-scale fold axes (80–90°) and (2) two sets (D_1 and D_2) striking under high angles (60–80°) to map-scale fold axes, whereas the acute bisector between these two sets is oriented perpendicular to map-scale fold axes. Joints of all three sets (T, D_1 and D_2) are oriented perpendicular to the bedding, whereas the set T joints are also vertical.

T joints were observed in 88 stations (Fig. 2). Surfaces of T joints are non-planar, and their traces on the bedding surfaces are curvilinear. T joints are not accompanied by feather fractures. They are commonly filled by mineral veins. Strike of T joints varies along the studied segment of the Silesian nappe (Fig. 3). East of the Dunajec River, T joints strike NE to NNE. Further westward, between the Dunajec and Raba rivers, these joints strike NNE to N–S. Still further westward, west of the Skawa River, T joints strike NNW. Along the whole studied segment of the Silesian nappe, T joints strike roughly perpendicular to the map-scale fold axes.

[1]Faculty of Geology, Warsaw University, Żwirki i Wigury 93, 02-089 Poland
[2]Institute of Geological Sciences, Jagiellonian University, Oleandry 2a, 30-063 Kraków, Poland
[3]Institute of Geological Sciences, Polish Academy of Sciences, Senacka 1-3, 31-002 Kraków, Poland

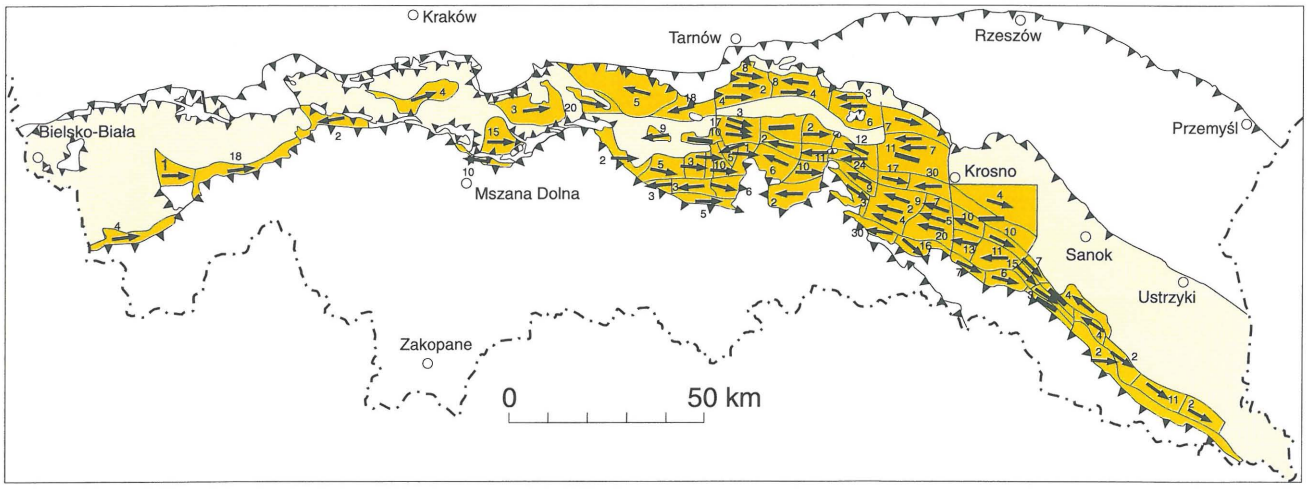

Fig. 1. Map of the map-scale fold axes for the Paleogene and Neogene strata of the Silesian nappe. Dark-yellow is mapped Tertiary, light-yellow is Cretaeceous or unmapped. Arrow shows direction of plunge, number shows value of plunge

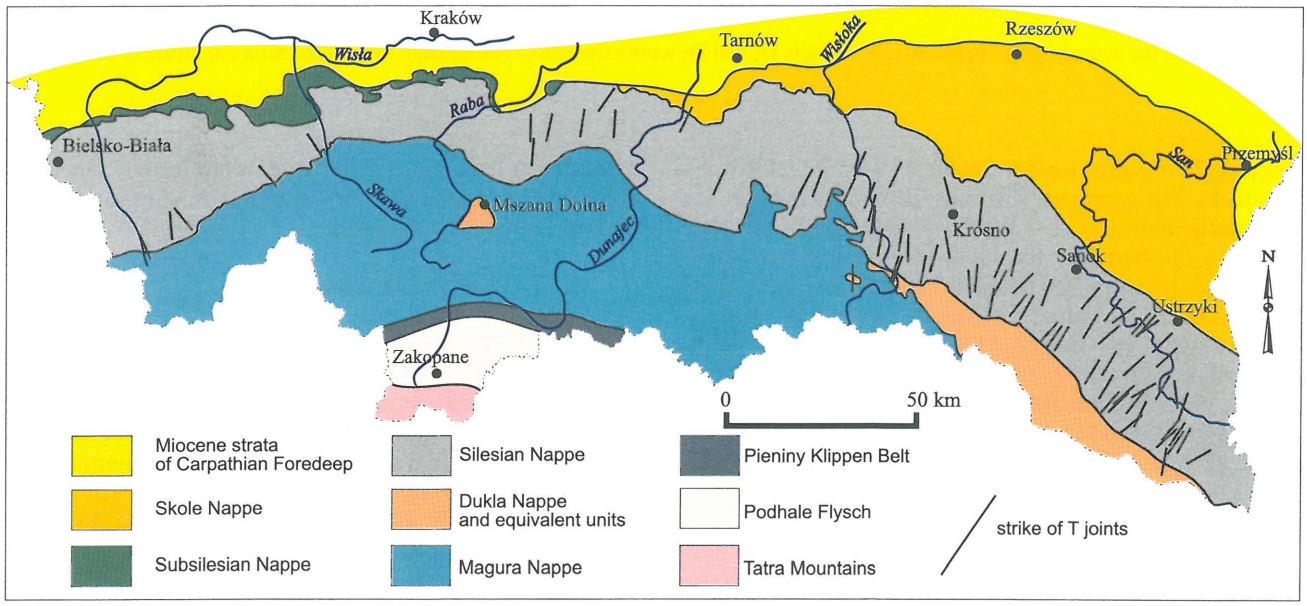

Fig. 2. Map of T joints within the Paleocene through lower most Miocene strata of the Silesian nappe

D_1 and D_2 joints are more numerous than T joints. They were observed in 109 stations (Fig. 3). The surfaces of D_1 and D_2 joints are planar and their traces on bedding surfaces are rectilinear. Some of the D_1 joints terminate on the D_2 joints and vice versa. Numerous joints of these two sets are accompanied by feather fractures whereas some of these joints pass laterally into en echelon oriented cracks. Some of the latter are filled by material derived from country strata or by mineral veins contamined by this material. Orientation of feather fractures and en echelon cracks is the same for each set of joints but differs between the sets. Within the studied segment of the Silesian nappe, the acute angle between D_1 and D_2 joints is 50–75^0 (mean value 60^0). The orientation of bisector of this angle varies along the studied segment of the Silesian nappe (Fig. 2). East of the Dunajec River, the bisector is oriented NE to NNE. Further westward, between the Dunajec and Skawa rivers, the bisector is oriented NNE to N–S. Still further westward, west of the Skawa River, the bisector is oriented NNW. Along the whole studied segment of the Silesian nappe the bisector is oriented roughly perpendicular to the map-scale fold axes and roughly parallel to T joints.

Cross-fold joints — interpretation

Within the studied segment of the Silesian nappe, the cross-fold joints display consistent pattern. Both the T joints and the acute bisector beetween D_1 and D_2 joints maintain there orientation perpendicular to the map-scale fold axes, notwithstanding variable orientation of these axes. This indicates interrelation between the joints and the map-scale folds and relationship of cross-fold joints to far-field stresses.

Abutting relationship indicates that the D_1 and D_2 joints are roughly coeval. D_1 and D_2 joints are associated with

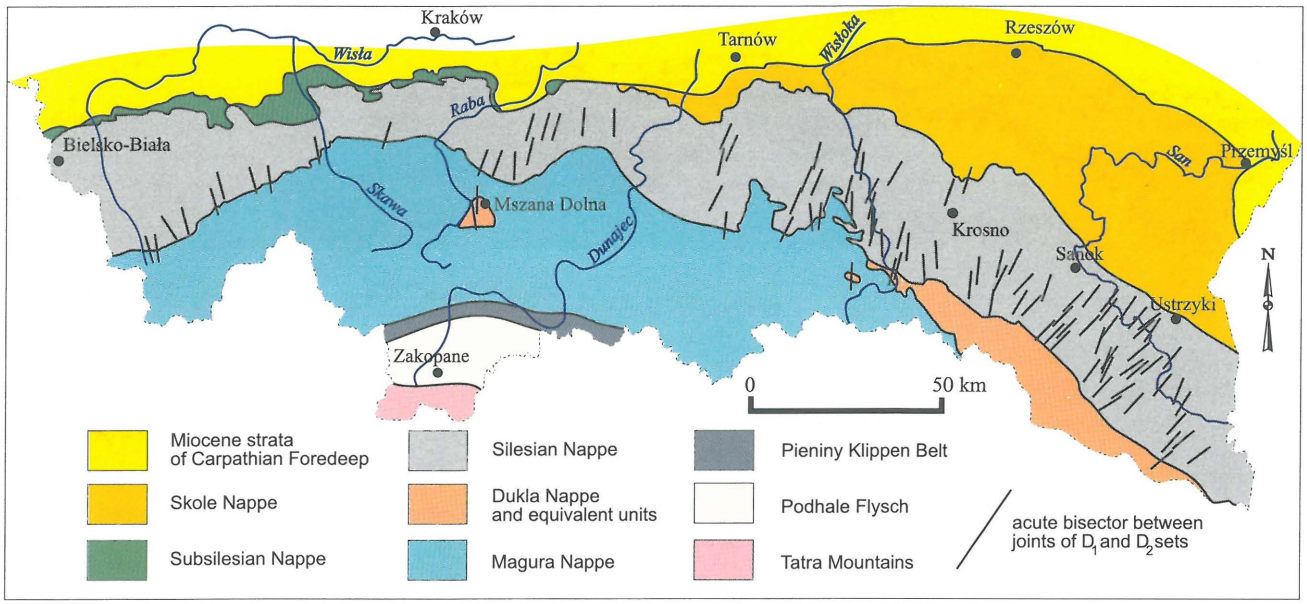

Fig. 3. Map of the acute bisector between joints of sets D_1 and D_2 within the Paleocene through lowermost Miocene strata of the Silesian nappe

small-scale features: feather fractures and en echelon oriented cracks. The geometrical arrangement of these small-scale features indicates that the D_1 and D_2 joints are shear fractures. Furthermore, the small-scale features associated with the D_1 joints show a tendency to left-lateral movement, whereas those associated with the D_2 joints show tendency to right-lateral movement. Moreover, the bisector of the acute angle between D_1 and D_2 joints is oriented perpendicular to the map-scale fold axes. All these features indicate that : (1) the D_1 and D_2 joints form a conjugate system and, (2) the orientation of the main stress axis (σ_1) was the same during the regional folding and during formation of the conjugate joint system.

Morphology of T joints indicates that they are extension fractures and, therefore, orientation of σ_1 can not be reconstructed basing solely on the orientation of T joints. However, T joints strike perpendicular to the map-scale fold axes. Therefore, we believe that the orientation of σ_1 was the same during the regional folding and during formation of T joints. Summing up, it appears that the orientation of σ_1 was the same during: (1) the regional folding, (2) formation of the D_1 and D_2 conjugate system and possibly, (3) formation of T joints.

D_1 and D_2 joints are perperdicular to the bedding, notwithstanding orientation of the bedding. This attests that these joints are of pre-folding age, they were formed when the strata were still in horizontal position. Moreover, some of the en echelon oriented cracks associated with the D_1 and D_2 joints are filled by material derived from country strata or by mineral veins contamined by this material. This indicates that at least some of the joints were formed when the country strata were still poorly lithified. In contrast, the age of T joints remains unknown.

Conclusions

1. In the Silesian nappe, cross-fold joints are related to far-field stresses and, therefore, they should be used in paleostress reconstructions.

2. Within the Paleogene and Neogene strata of the Silesian nappe cross-fold shear joints are more numerous than cross-fold extension joints.

3. In the study area, orientation of σ_1 was the same during: (i) the regional folding, (ii) formation of D_1 and D_2 joints and possibly, (iii) formation of T joints.

4. The discussed D_1 and D_2 joints are of pre-folding age. They were formed when the country strata were still in horizontal position and (at least some of the joints) when the strata were poorly lithified.

Acknowledgements. This study has been supported by grant 9T12B02009 of the Polish Committee for Scientific Research to Antoni Tokarski.

References

DUNNE W.M. & HANCOCK P.L. 1994 — [In:] Continental deformation, P.L. Hancock (ed.): 101–120. Pergamon Press.
POLLARD D.D. & AYDIN A. 1988 — Geol. Soc. Amer. Bull., 100: 1181–1204.